DEVELOPMENT OF SUSTAINABLE POWER SYSTEM FOR DEVELOPING ECONOMIES

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By

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ABSTRACT

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Koh Siong Lee

It is a consensus among the research community that global warming caused by excessive greenhouse gas (GHG) emission is having catastrophic effects to our living environment. If not contained, it will endanger our well beings and the continual anthropological survival. Despite this grim consequence, the world has not been able to achieve a climate deal. One of the reasons is the argument between the developed countries and developing countries on the respective share of responsibility to address the issue. Historically, the United Nations Framework Convention for Climate Change (UNFCCC) and Kyoto Protocol placed much of the responsibilities on the developed countries because they were accounted for most of the GHG emissions. The situation is different now because, based on projection by the International Energy Agency (IEA), GHG emissions from the developing countries accounted for 49% of the world emissions in 2009. It will increase to 61% by 2030. Therefore, the importance of GHG emission reduction in developing economies cannot be neglected. Although the developing countries have also embarked on various measures to reduce GHG emissions in recent years, these measures have not been very effective, as proven in the above data from IEA. As most of the GHG reduction measures and technologies are developed in the

Europe and USA, the effectiveness may be reduced when applied in the developing economies. Developing economies have unique characteristics which are not present in the developed countries. Therefore, this research was designed to address the needs of the developing countries in GHG emissions reduction under the constraints of these unique characteristics. Based on the unique characteristics, a methodology was developed and applied to the power system in Sabah based on actual data collected in this research. The methodology was refined and verified in the process. Consequently, a solution was found by applying the methodology for Sabah for long term sustainable power system development to meet its GHG emissions reduction target.

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APPROVAL SHEET

This dissertation/thesis entitled "**Development of Sustainable Power System for Developing Economies**" was prepared by KOH SIONG LEE and submitted as partial fulfillment of the requirements for the degree of Doctor of Philosophy in Engineering at Universiti Tunku Abdul Rahman.

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It is hereby certified that **KOH SIONG LEE** (ID No: **10UED02130**) has completed this thesis entitled "**Development of Sustainable Power System for Developing Economies**" under the supervision of Dr Lim Yun Seng (Supervisor) from the Department of Physical Science, Electrical and Electronic Engineering, Faculty of Engineering and Science, and Dr Stella Morris (Co-Supervisor) from the Department of Physical Science, Electrical and Electronic Engineering, Faculty of Engineering and Science.

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Koh Siong Lee

DECLARATION

I hereby declare that the dissertation/thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UTAR or other institutions.

Name: Koh Siong Lee

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LIST OF ABBREVIATIONS

ACC	Annualised Capital Cost
AHU	Air Handling Unit
APEC	Asia Pacific Economic Corporation
BEI	Building Energy Index
BEPAC	Building Environmental Performance Assessment Criteria
BioGen	Biomass Power Generation and Demonstration
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CCS	Carbon capture and storage
CDM	Clean Development Mechanism
CER	Certified Emission Restrictions
CFD	Computer Fluid Dynamic
CO_2-eq	CO_2 equivalent
CPO	Crude Palm Oil
CRF	Capital Recovery Factor
EEWH	Green Building Evaluation System
EFB	Empty Fruit Bunches
FBC	Fluidised Bed Combustion
FFB	Fresh Fruit Bunches
FiT	Feed In Tariff
GBI	Green Building Index
GBIAP	GBI Accreditation Panel
GBISB	Greenbuildingindex Sdn Bhd

GBTool	Green Building Tool
GDP	Gross Domestic Product
GEO	Green Energy Office Building
GHG	Greenhouse gas
$GtCO_2$-eq	Gigaton of CO_2 equivalent
HRSG	Heat Recovery Steam Generator
IEA	International Energy Agency
IEQ	Indoor Environment Quality
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
LCA/LCC	Life Cycle Assessment/Life Cycle Cost
LEAP	Long-range Energy Alternatives Planning
LEED	Leadership in Energy and Environmental Design
MBIPV	Main Building Integrated Photovoltaic
MGTC	Malaysia Green Technology Corporation
MIEEIP	Malaysian Industrial Energy Efficiency Improvement Project
MMBTU	Million BTU
NEP	National Energy Policy (Malaysia)
NPV	Net Present Value
O&M	Operation and Maintenance
OECD	Organisation for Economic Co-operation and Development
OER	Oil Extraction Rate
OTTV	Overall Thermal Transfer Value
PCC	Pulverised Coal Combustion
POME	Palm Oil Mill Effluent

PPM	Part Per Million
PV	Photovoltaic
R&D	Research and Development
RDF	Refuse Derived Fuel
RE	Renewable Energy
RTTV	Roof Thermal Transfer Value
SDC	Sabah Development Corridor
SESB	Sabah Electricity Sdn Bhd
SREP	Small Renewable Energy Programme
SRI	Solar Reflective Index
UBBL	Uniform Building By-Laws (Malaysia)
UFAD	Underfloor Air Distribution
UNFCCC	United Nations Framework Convention for Climate Change

CHAPTER 1

INTRODUCTION

1.1 Greenhouse Gas and Global Warming

The Earth Summit in Rio de Jenairo in 1992 brought the attention of the world leaders to the global warming issues. It had successfully led to the subsequent Kyoto Protocol whereby the developed nations had agreed to reduce the greenhouse gas (GHG) emission. Today, after 20 years, global warming and GHG emission reduction are still at the top of agenda in all international forums. It is featured prominently at all national and international policies, with the effects impacting all aspects of our lives. A significant amount of resources have been allocated globally to address global warming because of its projected disastrous consequences. At the extreme, it may affect our own anthropological survival.

Global warming is a problem started by human beings more than 200 years ago. As shown in Figure 1-1, the CO_2 concentration of the atmosphere was at a consistent level prior to 1800. It was maintained in a narrow band between 260 to 280 part per million (ppm). In the early 1800s, when industrial revolution started, the CO_2 concentration in the atmosphere started to increase at the same time. There has been a consistent rise until today. The rise was accelerated in the second half of the 20^{th} century and the CO_2 level has significantly increased to around 375 ppm (Lenny et al., 2007).

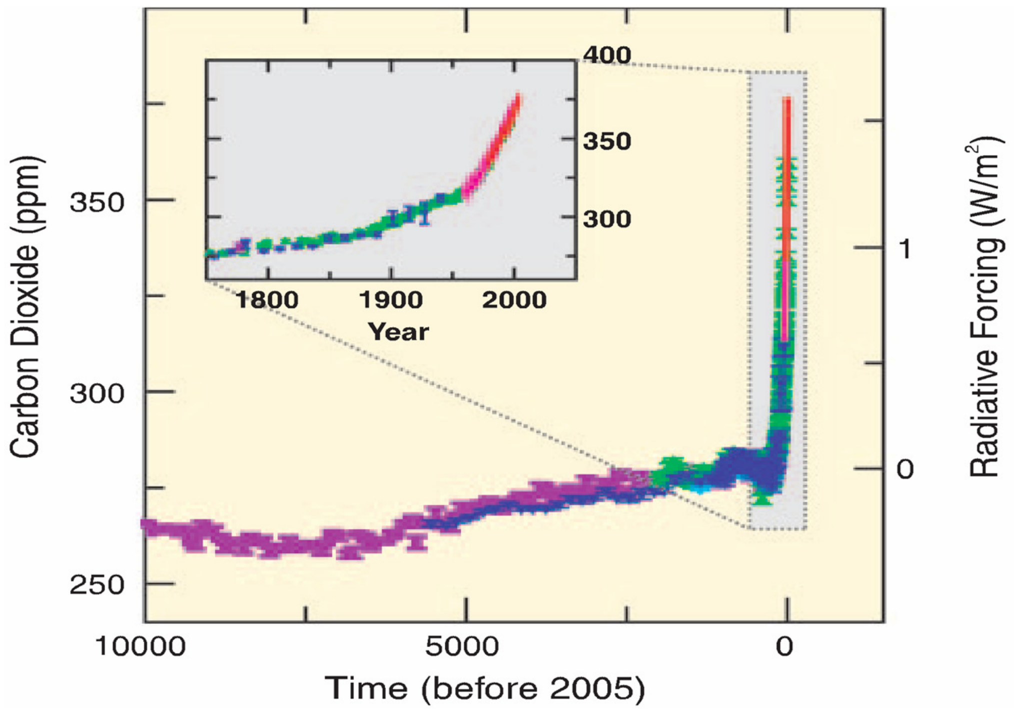


Figure 1-1: Historical Carbon Dioxide Concentration of the Atmosphere (Source: IPCC Climate Change 2007 Synthesis Report)

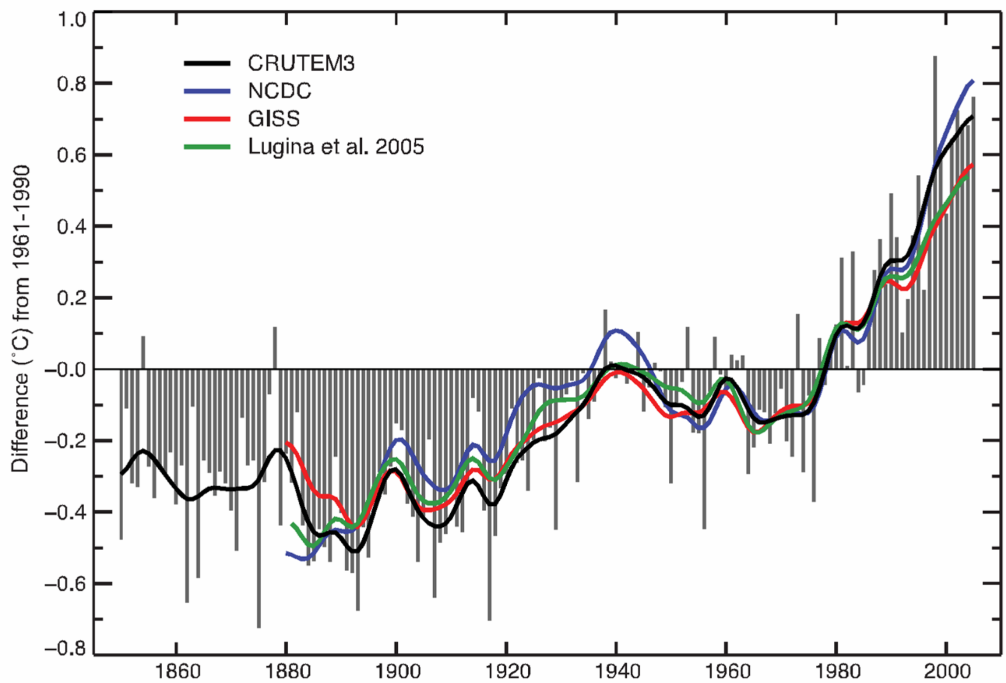


Figure 1-2: Global Average Temperature Trend (Source: IPCC WG1 Fourth Assessment Report)

When the data on CO_2 level was compared to the global average temperature, it was found that there is a strong correlation between the two sets of data. As shown in Figure 1-2, the global temperature has been rising consistently since the 19^{th} century. As shown by the four different curves in Figure 1-2, there is a slight variation on the estimated average temperature using different methodologies. However, the results from all the methodologies are consistent in concluding that there has been a consistent rise in the average global temperature (Treut et al., 2007). With the temperature of 1940 as a reference point, the global temperature has increased by around 0.8^{o} C.

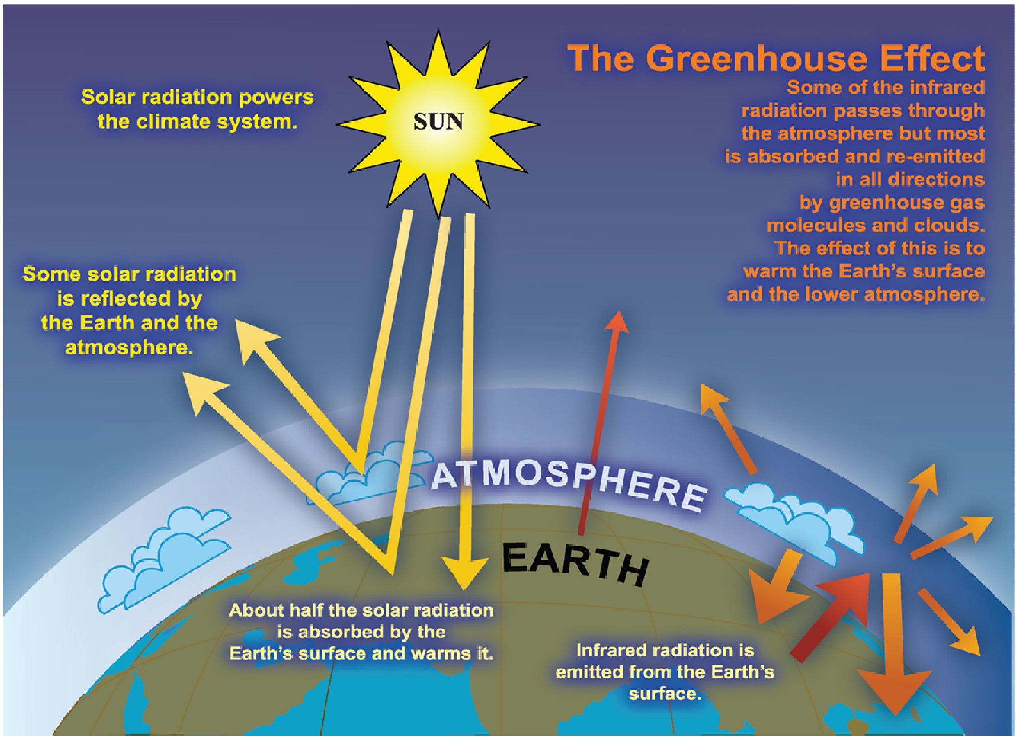


Figure 1-3: Greenhouse Effect as the Cause of Global Warming (Source: IPCC WG1 Fourth Assessment Report)

Many prior researches have been carried out to study the cause of the temperature rise. As reported by the Intergovernmental Panel on Climate Change (IPCC) (Treut et al., 2007), it is concluded that the temperature rise is mainly caused by the increased concentration of GHG in the atmosphere. CO_2 is one of the GHG. Other GHG includes methane and nitrous oxide.

It is found that at the equilibrium state, the earth is receiving energy from the sun via solar radiation as illustrated in Figure 1-3. On reaching the earth, part of the solar radiation is reflected by the atmosphere and lost in the outer space. About half of the energy from the solar radiation is absorbed by the earth surface. With the absorbed energy, the earth surface warms up and emits infrared radiation. Part of the infrared radiation is absorbed by GHG in the atmosphere and re-emitted in all direction within the atmosphere. This effect is known as the radioactive forcing by GHG. The rest of the energy from the infrared radiation passes through the atmosphere and lost in the outer space. The total energy from the solar radiation and the re-emitted infrared radiation from GHG maintains the equilibrium temperature of the earth surface and the lower atmosphere.

With the increasing concentration of GHG, particularly the CO_2, within the atmosphere, the amount of energy absorbed by GHG also increases. This results in increased energy from the re-emitted infrared radiation from GHG. Hence, the total energy contained within the earth surface and the atmosphere increases. Consequently, the equilibrium temperature increases. This was found to be the main cause of the global warming. As shown in Figure 1-2, the increase of CO_2 concentration from 275 ppm to 375 ppm has resulted in the increase of radioactive forcing from GHG by 1.5 W/m^2.

Various in-depth studies has been carried out by IPCC to examine the effect of GHG on global warming and the consequences of the temperature increase. Different scenarios have been constructed to forecast the potential GHG emission level and CO_2 concentration in the future. As shown in Figure 1-4, based on these scenarios, the temperature rise can be as much as 6^o C by 2100, compared to the average temperature in 2000 (Lenny et al., 2007).

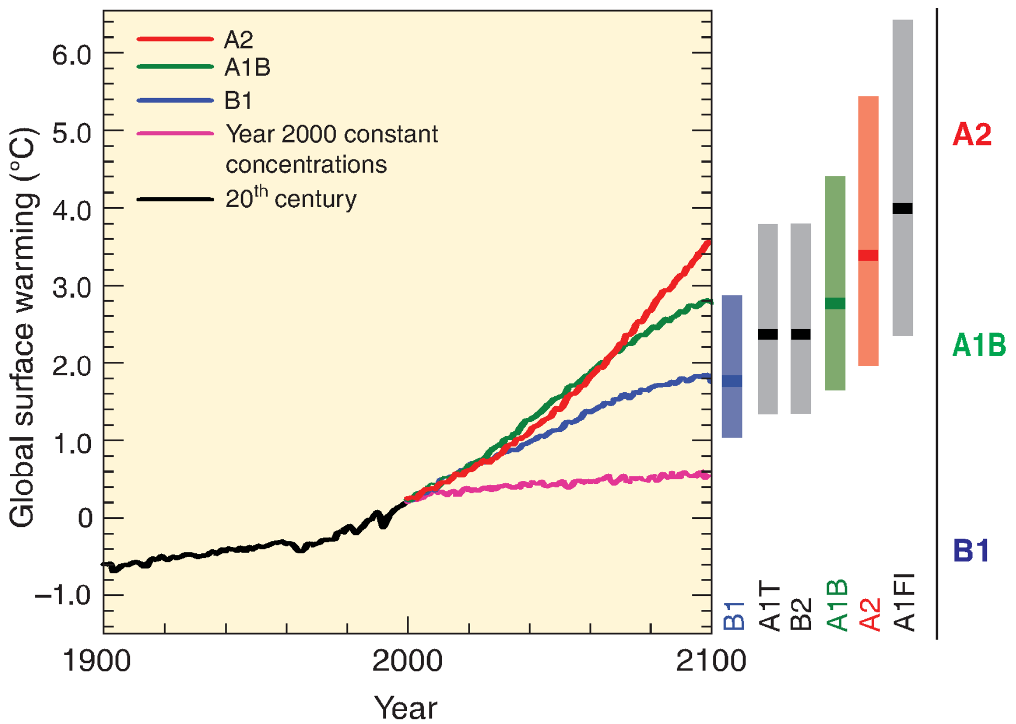


Figure 1-4: Projected Global Temperature Increase based on IPCC Scenarios (Source: IPCC Climate Change Synthesis Report 2007)

The high temperature rise will result in disastrous effect to the earth. From the IPCC studies, a 3^{o} C temperature rise will have adversely changed all aspects of lives on the earth and these changes will be irrevocable. Among the adverse effects are:

- **Climate**: Extreme conditions with associated disturbances including flooding, drought, wildfire, ocean acidification;
- **Ecosystems**: Increased risks of extinction of plant and animal species by 20% to 30%, resulting in major negative changes in ecosystem structure, function, geographical ranges, and biodiversity;
- **Food**: Decrease in crop productivity;
- **Water**: Reduced availability of water resources as a result of changes in precipitation, temperature and mass losses from glaciers;
- **Human Habitat**: Adversely affecting and reducing human habitat as a result of rising sea level, eroding coast lines and frequent floods;
- **Society**: Adverse effects on all aspects of the society with economies closely linked with climate-sensitive resources or with locations subject to extreme weather conditions; and
- **Health**: Increased disease, injury and death from extreme climate conditions.

Therefore, it is the aim of IPCC and other global organisations to keep the temperature rise below 3^{o} C to avoid these undesirable effects. In order to achieve this, the GHG concentration has to be kept below 450 ppm CO_2 equivalent (CO_2-eq.). As different type of GHG has different level of radioactive forcing capability, the greenhouse effect of each type of GHG is standardised, using CO_2 as the reference. Following the standard, 1 unit of CO_2-eq represents the amount of GHG with the equivalent greenhouse effect of 1 unit of CO_2. Based on the findings by IPCC, the global GHG emission has to be kept within the green belt as shown in Figure 1-5 to maintain the 450 ppm level. The global emission level has to be kept below 30 $GtCO_2$-eq/year (Gigaton of CO_2 equivalent per year). This is similar to the emission level in 2000. In addition, the emission level has to be reduced continuously over the next century. By 2070, the world net GHG emission has to be reduced to near zero emission. To maintain the emission level within the green belt, major GHG emission reduction measures need to be implemented as the projected emission level in the business-as-usual scenario will be much higher. As shown in Figure 1-5, without any measures to reduce GHG emission, the world emission level will have reached 140 $GtCO_2$-eq/year by 2060 and continue to increase after that. This will have resulted in a GHG concentration of more than 1130 ppm CO_2-eq in the atmosphere.

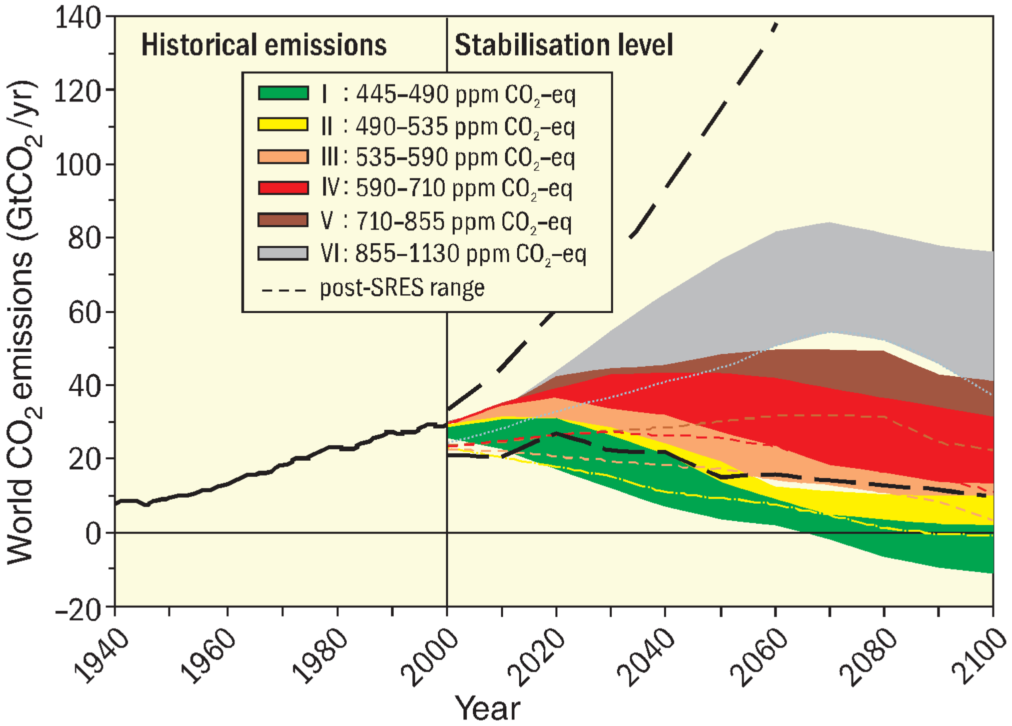


Figure 1-5: Projected GHG Emission to Achieve Different GHG Concentration (Source: IPCC Climate Change Synthesis Report 2007)

1.2 The Challenges

From the above findings by IPCC, the world will need to work together to cut down its GHG emission dramatically in order to avoid the disastrous consequences of global warming. At least 20 years have been spent to look for a solution since the first discussion on global warming at an international forum at The Earth Summit in Rio de Jenairo in 1992. However, there is still no concrete solution implemented to achieve the required GHG emission reduction until today. The world has yet to arrive at a resolution that can be agreed and implemented by all nations to achieve the targeted 450 ppm CO_2-eq level. There are still many challenges to be overcome. Some of the main challenges are investigated in details in the following parts of this section.

1.2.1 Divided World – Developed versus Developing Countries

Historically, the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol categorised the world into developed countries and developing countries. While fighting global warming was identified to be the common goal for all, different responsibilities were assigned to each group. The developed countries, commonly known as the Annex I countries, were mandated to implement control actions to reduce the GHG emission to a specific level in the Kyoto Protocol. The developing countries, or the non-Annex I countries were exempt from these control actions. The split of responsibilities were derived based on the following considerations (Parker and Blodgett, 2008):

- Environmentally, the Annex I nations account for about 72% of total carbon dioxide emissions accumulated in the atmosphere between 1950 and 2000. Therefore, the Annex I nations bear the most responsibility to the cumulative CO_2 that has contributed to global warming.
- Economically, UNFCCC has explicitly acknowledged that the the non-Annex I nations depended heavily on increasing use of energy, including fossil fuels for the development of their nations. Increasing use of energy from fossil fuels are the main sources of carbon dioxide which is the dominant GHG. From this perspective, a logic for the differing treatment of the two

groups is that the Annex I countries can afford to control emissions because they had achieved a relatively advanced level of development, while the non-Annex I countries have the right and should be given the opportunity to expand energy use as necessary for their economic growth.

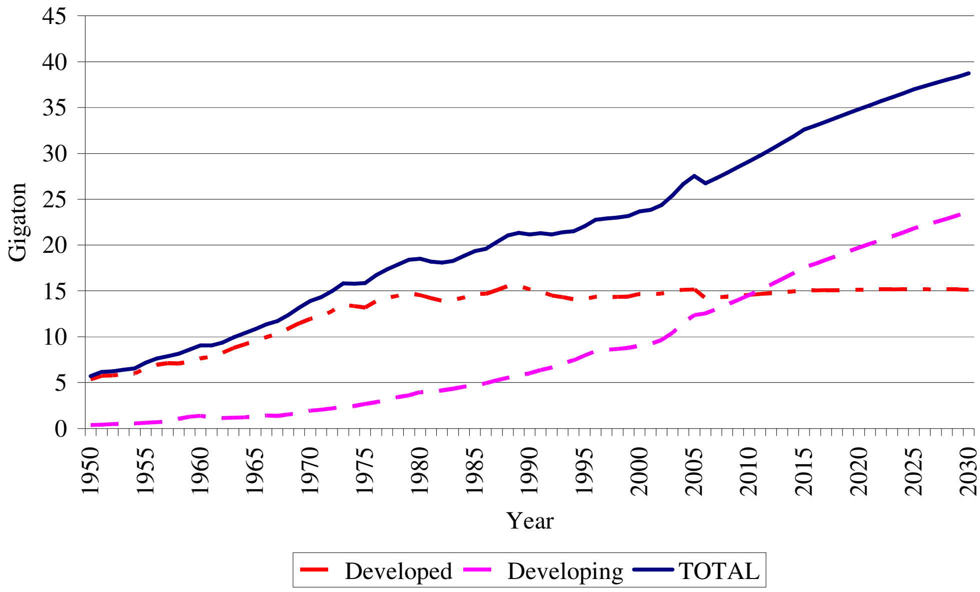


Figure 1-6: Trend of CO_2 Emission by Developed and Developing Countries)(IEA, 2008)

The above arrangement was an effective short-term measure in 1997 when the Kyoto Protocol was first adopted. However, this split of responsibilities becomes a key issue of contention now. With rapid industrialisation, the emission level of the developing countries, especially China, India and Brazil, has since increased tremendously. In 1997, the total annual CO_2 emission from the developed countries constituted 63% of the global CO_2 emission (WRI, 2010). However, based on the projection by the International Energy Agency (IEA) (IEA, 2008) as shown in Figure 1-6, the total CO_2 emission from the developing countries will overtake that of the developed countries in 2011. By 2030, it will have constituted 61% of the global emission. Therefore, at the world climate summit such as the much anticipated UN Climate Summit at Copenhagen in December 2009, the developed countries expect the developing countries to take a bigger responsibility in the emission reduction. The developing countries, on the other hand, argue that the developed countries have had the opportunity to enjoy unrestricted emission level to achieve the developed status prior to this. Also, the developed countries are responsible for most of the GHG emitted into the atmosphere prior to this. Hence, it will not be fair to impose the emission control on the developing countries now. It will be a big financial burden and will impede the development of their countries. The developing countries, therefore, demand the developed countries to take a bigger role in terms of financial and technical assistance to the developing countries in emission reduction. In additional, developed countries are also expected to take a bigger cut in emission at their home land.

The above disagreement is a consequence of difference in expectation and the needs to protect the interest of their respective country. This has prevented the world from agreeing on a climate deal. Without a climate deal endorsed by all the countries, the world has not been able to move in tandem to achieve the required emission reduction and the agenda to address the global warming has been impeded.

Co-incidentally, most of the developed countries are members of the Organisation for Economic Co-operation and Development (OECD). They are countries with high-income economies and high human development index. In the following sections of this thesis, the OECD countries are regarded as the developed countries. The developing countries are represented as the non-OECD countries.

1.2.2 Quantum Leap

Based on a research by BP (BP, 2011), the world energy demand will continue on a rising trend to meet the global energy demand as shown in Figure 1-7. The total energy consumption will reach 16.4 Gigaton oil equivalent in 2030. At the same time, the world GHG emission is projected to rise in tandem. As shown in Figure 1-6, the global GHG emission will reach 38.7 Gigaton in 2030 (IEA, 2008). Compared to the green belt in Figure 1-5, the emission level has to be kept at 20 Gigaton in 2030. This is equivalent to a 48% reduction in GHG emission. This can only be achieved by: (a) reducing the world energy demand by adopting energy efficient life style and technologies; and (b) reducing the emission factor of energy production via low carbon power production technologies.

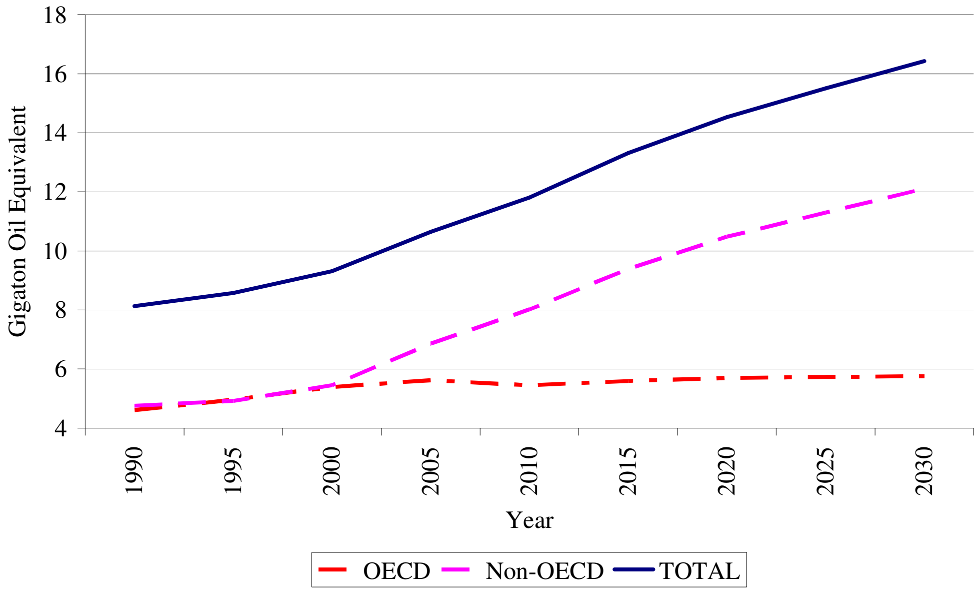


Figure 1-7: World Energy Consumption

Based on the above figures and the IPCC reports (Lenny et al., 2007, Metz et al., 2007, Treut et al., 2007), the world need to reduce GHG emission at the magnitude of tens of $GtCO_2$-eq. per year in order to contain the adverse effects of global warming. The amount of emission reduction has to be achieved while meeting the growing energy demand of the world. This means that tens of terawatts of low carbon power generation technologies have to be commissioned to replace the current high emission energy sources over the next century. In additional, on the demand side, technologies with higher energy efficiency have to be developed and adopted. The magnitude of this task imposes a formidable, if not impossible challenge, especially from the technological and financial perspective.

1.2.3 Technological Challenges

From the technological perspective, the deployment of new low carbon technologies of the required scale is unprecedented. To achieve this level of GHG emission, gradual or incremental improvement based on current technology will not be sufficient. More innovations and breakthroughs in new technologies through intensive research and development (R&D) are required. Moreover, existing low carbon technology options are expensive, limited in availability, or not sufficiently reliable for deployment at very large scale.

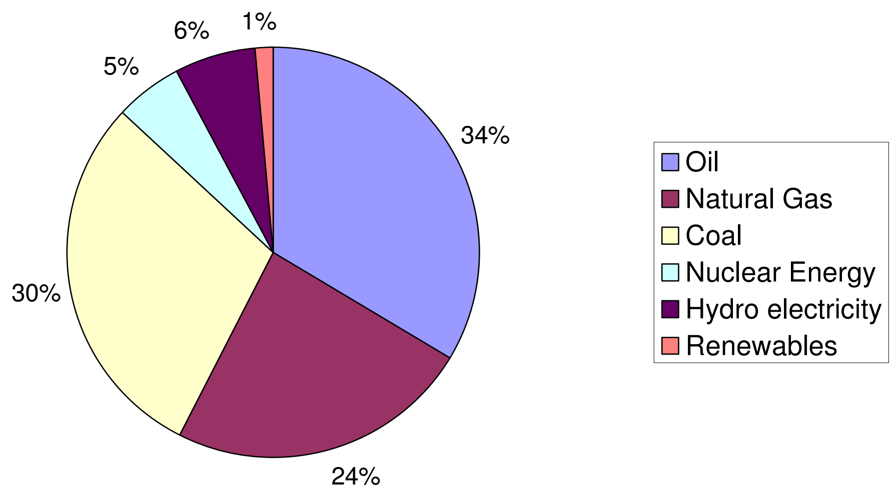


Figure 1-8: World Energy Consumption by Fuel Types in 2010

Figure 1-8 summarises the world energy consumption in 2010 based on fuel types (BP, 2011). It is found that 87% of the world energy is still derived from the fossil fuels, namely oil, natural gas and coal, which are known to have a high emission factor. Coal alone contributed to 30% of the world energy consumption. Renewable energy (RE) represents only 1% of the total energy consumption. Hydro-electric and nuclear energy contributes to 6% and 5% respectively. For comparison, in the IPCC special report on emission scenarios (Davidson and Metz, 2007), one of the low emission scenarios – scenario A1T requires that the share of coal to be reduced to 10% by 2050 and 1% by 2100. The share of zero emission energy sources, on the other hand, has to be increased to 21%, 43% and 85% by 2020, 2050 and 2100 respectively. This represents a quantum leap compared to the current share of RE and other zero emission energy sources.

1.2.4 Financial Challenges

Currently, the low carbon technologies are more expensive to implement compared to the conventional technologies. In addition, the cost of replacing the existing technologies which have not reached the end of life and the cost of upgrading the existing infrastructure to cater for the new technical requirements of low carbon technologies need to be taken into consideration. For example, RE sources such as PV panel typically are distributed and intermittent in nature. In order to overcome these limitations, the electricity grid will have to be upgraded with features to cater for distributed generation and additional energy storage devices will be required. Hence, additional budget will have to be allocated for the upgrading of infrastructure.

In the IPCC report (Lenny et al., 2007), it is estimated that the cost to reduce GHG emission is between US$20 to US$50 per ton CO_2-eq. Assuming an average cost of US$35 per ton CO_2-eq., it costs the world US$630 billion per year to reduce the GHG emission by 18 GtCO_2-eq. per year. The high cost is a hurdle for the world to adopt the low carbon technologies, especially for the lower income nations.

1.2.5 Unequal Level of Advancement in Low Carbon Technologies

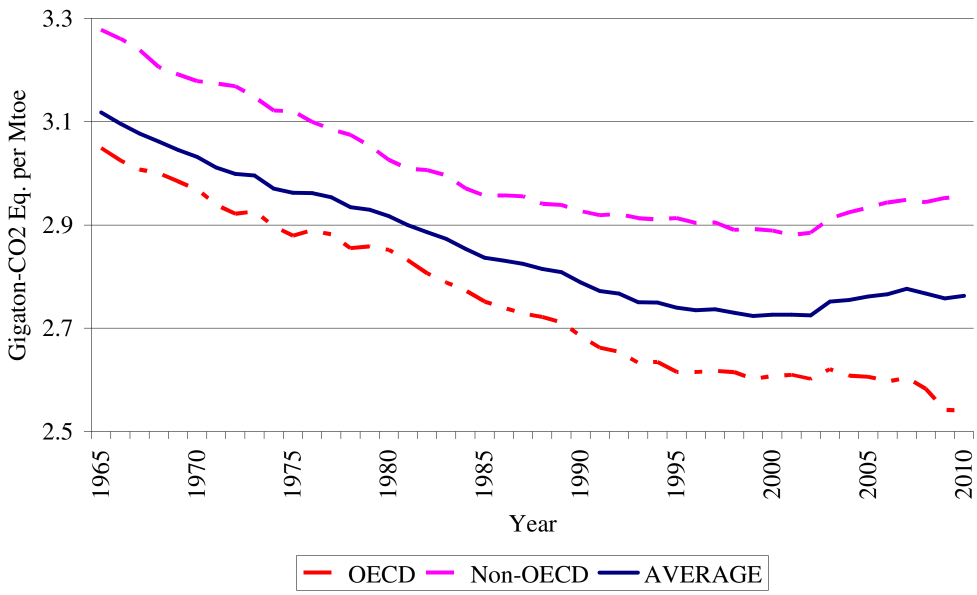


Figure 1-9: World Emission Factor for the Energy Sector(BP, 2011)

With the advantage of better financial resources and technological capability, the OECD countries have been able to respond well to the mandate from the Kyoto Protocol to reduce their GHG emission. Technologies with low or zero carbon emission have been developed and deployed to reduce the emission factor. Based on the data from the BP research (BP, 2011), the average emission factor of the energy sector for the OECD and non-OECD countries are computed and presented in Figure 1-9. It is found that the emission factor of the OECD countries has been kept consistently below that of the non-OECD countries. In the last decade in particular, the emission factor of the OECD countries has been reduced from 2.61 $GtCO_2$-eq. per Mtoe in 2000 to 2.54 $GtCO_2$-eq. per Mtoe in 2010. This is equivalent to a 2.68% reduction. For the non-OECD countries, in contrast, the emission factor has increased from 2.89 $GtCO_2$-eq. per Mtoe to 2.96 $GtCO_2$-eq. per Mtoe over the same period of time.

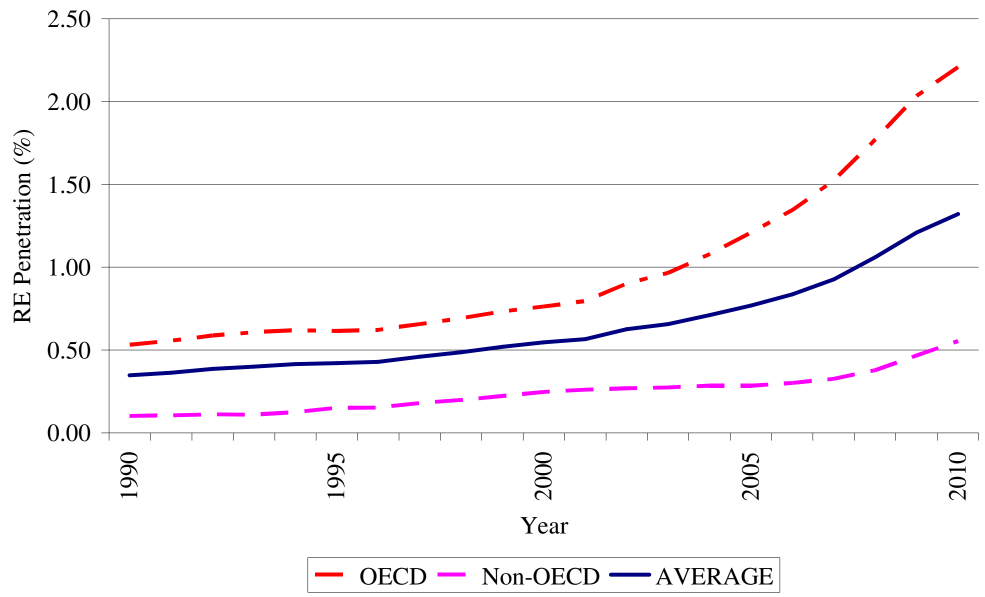


Figure 1-10: RE Penetration Rate for OECD and Non-OECD Countries

The reduced emission factor in the OECD countries is achieved in tandem with the higher RE penetration rate. As shown in Figure 1-10, the average RE penetration rate for the non-OECD countries in 2010 was 0.55%. For the OECD countries, it was 2.21%, which is 300% above that of the non-OECD countries.

This unequal level of advancement in emission reduction achievement between the OECD and non-OECD countries indicates that the non-OECD countries are having a bigger challenge in achieving the required emission reduction.

1.3 Outline of the Research

From the above data, it can be concluded that the non-OECD countries are now contributing to the bigger portion of the world GHG emission. From Figure 1-6, it can be seen that the GHG emission from the OECD countries have been kept almost constant at around 15 Gigaton per year. However, the emission from the non-OECD countries is on a rising trend. This may be due to the effect of the various low carbon technologies such as RE that have been developed and deployed in the OECD countries to successfully reduce their emission factor while the RE penetration rate in non-OECD countries is much lower. The higher emission level of the non-OECD countries is also due to the increasing energy consumption in these countries. Therefore, in the overall effort to reduce GHG emission, the non-OECD countries have an equally important role to play and they cannot be neglected.

With this in mind, this research is developed specifically to address the challenges of the developing countries or the non-OECD countries in meeting the GHG emission reduction requirements. All the options currently available to the policy makers for emission reduction are investigated in this research. A methodology is developed to assist the policy makers to systematically identify the most cost effective options with the highest impact in GHG emission reduction. Specifically, the research is designed with the following objectives:

- To identify unique characteristics common in developing economies, which are relevant to the development of sustainable power system;
- To develop a comprehensive methodology for the development of sustainable power system in developing economies;
- To apply the methodology in a developing economy to assess its effectiveness.

The power system in Sabah is selected for the case study in this research. The characteristics are typical to most developing as described in Chapter 2 and Chapter 3. Sabah is one of the thirteen states in Malaysia, which is a developing country. Similar to the other countries, Malaysia is facing the challenge of balancing between meeting increasing energy demand from the economic growth and protecting the environment. The power system in Sabah is ideal for the case study as it has an independent power grid not connecting to the rest of Malaysia. This presents the opportunity to study the various scenarios on the energy options for the power system in a contained environment.

The results from this research are presented in the following chapters of this thesis.

In Chapter 2 – *Energy Policy of Malaysia*, the background information on the importance of policy tools to foster the transformation of energy system based on low carbon technologies is first presented. The unique characteristics of Malaysia as a developing country are also analysed and presented in this chapter. This is followed by the analysis on the emphasis and transformation of the energy policy in Malaysia. The current emphasis on RE and GHG emission reduction is then investigated in details, with analysis on the financial, technological and environmental aspects. The chapter is concluded with the results from the analysis on the potential achievable emission reduction and associated cost based on the current policy.

In Chapter 3 – *Low Carbon Power Technologies*, the power system in Sabah is first analysed and presented. Then, all the technologies currently available for emission reduction are investigated. The potential for each low carbon technology in Sabah is analysed from the resource endowment, financial and environmental perspective. The chapter is concluded with the findings on the potential, cost and impact on the GHG emission reduction in Sabah for each technology investigated.

In Chapter 4 – *Advanced Combustion Technologies*, the advanced gas and coal power plant technologies are investigated. The significance of the gas and coal power as the world energy source is first investigated. This is followed by the findings on the latest development in the combustion technologies that has enabled lower emission factor for these energy sources. The impact of applying these advanced technologies in the energy system of

Sabah is then analysed. The chapter is then concluded with the findings from the analysis from the technological, financial and environmental perspective.

In Chapter 5 – *Nuclear Energy*, the debate between the proponents and opponents of nuclear power is first studied to understand the strengths and weaknesses of nuclear energy. Then, the technology and the design of a nuclear power plant are studied in-depth to understand its operational characteristics, strength and weaknesses. The cost of power generation for a nuclear power plant is also analysed. This is followed by the analysis in GHG emission reduction. Sensitivity analysis is carried out to study the competitiveness of the technology in terms of cost compared to other energy options. The chapter is then concluded with the findings from the studies.

In Chapter 6 – *Biomass Waste in Sabah*, the available biomass resources in Sabah is evaluated. As the oil palm waste is the main source of biomass in Sabah, a computer algorithm has been developed in this research to find the optimised location of biomass power plants for minimum fuel and transportation cost and maximum utilization of the palm oil waste. The algorithm is presented in details in this chapter followed by the results from output of the computer software. Based on the solution from the output, the chapter is concluded with the findings on the potential, cost and emission reduction from the energy options of palm oil biomass waste in Sabah.

In Chapter 7 – *Green Building Features*, the energy related aspects of GBI are studied in detail to establish its effectiveness in reducing energy demand from the building sector from the technical, environmental and cost effectiveness perspectives. First, the criteria of GBI are presented and compared to other popular rating tools. Then, criteria related to energy efficiency of building are identified. The associated government incentives for complying with these criteria are studied and taken into consideration in the subsequent cost effectiveness analysis. Two case studies are then presented to illustrate the effectiveness of the tool in reducing energy consumption of buildings. The findings are further analysed from the financial and GHG emission reduction potential perspective, based on the scenario in Sabah.

In Chapter 8 – *Scenario Planning with Energy Modelling Software*, a methodology is developed and presented to systematically identify the most cost effective option for GHG emission reduction, specifically for a developing economy. An energy model for Sabah is first constructed using the LEAP software, based on the business as usual scenario. Subsequently, various alternative scenarios are constructed based on the feasible options as found in the preceding chapters. With the results from the energy model, the methodology is applied to identify the most cost effective options with the biggest impact in GHG emission reduction.

In Chapter 9 – *Summary and Conclusion*, the Energy Policy is revisited to verify if its criteria are achieved with the optimal solution. The chapter is concluded with the discussion on the significance of the research findings and potential future research in this area.

1.4 Contribution

The main contributions of this research are:

- Identification of common characteristics in developing economies which are having the direct influence as the key constraints and considerations in the development of a sustainable power system;
- Identification of a wide array of options for the developing countries in GHG reduction technologies, in addition to the typical RE options;
- Findings from the in depth study of these GHG reduction options based on real industry data of the power sector in Sabah, from the technical, financial and emission reduction perspective;
- Development of an algorithm to identify the optimal location and size of oil palm waste biomass power plant based on the availability of biomass waste, distance to power grid, transportation cost, cost of biomass waste, plant capital cost and plant operation costs;
- Development of a methodology that enables the policy makers to systematically identify the most cost effective combination of the available options in GHG emission reduction for developing countries

1.5 Publications

Based on the findings from this research, the following papers have been submitted to peer review journals and international conferences, with some of them published as shown in the followings:

	Paper Title	*Journal / Conference*	*Impact Factor*
1	*"Meeting energy demand in a developing economy without damaging the environment—A case study in Sabah, Malaysia, from technical, environmental and economic perspectives"* http://dx.doi.org/10.1016/j.enpol.2010.04.044 **(Published)**	**Energy Policy**	**2.614 (ISI)**
2	*"Challenges in Meeting Increasing Power Demand of Developing Economies without Damaging the Environment "* http://dx.doi.org/10.1109/PECON.2010.5697711 **(Presented and Published)**	**2010 IEEE International Conference on Power and Energy in Kuala Lumpur, Malaysia on 29 November 2009**	**NA**
3	*"Cost Effective Options for Greenhouse Gas (GHG) Emission Reduction in the Power Sector for Developing Economies —A Case Study in Sabah, Malaysia"* http://dx.doi.org/10.3390/en4050780 **(Published)**	**Energies**	**1.830 (ISI)**
4	*" Potential of Advanced Coal and Gas Combustion Technologies in GHG Emission Reduction in Developing Countries from Technical, Environmental and Economic Perspective "* http://dx.doi.org/10.1016/j.egypro.2011.10.116 **(Presented and Published)**	**2011 IEEE International Conference on Smart Grid and Clean Energy Technologies at Chendu, China on 27-30 September 2011**	**NA**

	Paper Title	*Journal / Conference*	*Impact Factor*
5	*"Study on the Prospects of Energy Supply in Malaysia: Potential and Issues of Renewable Energy and Nuclear Power "* **(Commented and revised paper under review)**	**Energy Policy**	**2.614 (ISI)**
6	*"Potential of Advanced Coal and Gas Combustion Technologies in Reducing GHG Emission – A Case Study in Sabah, Malaysia"* **Published (September 2012 Vol 6(6) pp. 1125 – 1138)**	**International Review of Mechanical Engineering**	**6.46 (Copernicus)**
7	*"Methodology for Optimizing Geographical Distribution and Capacities of Biomass Power Plants in Sabah, East Malaysia"* **Under Review**	**Renewable Energy**	**2.978 (ISI)**
8	*"A Review of the Renewable Energy and Nuclear Power in Malaysia"* **Under Reveiw**	**Renewables and Sustainable Energy Review**	**6.018 (ISI)**

CHAPTER 2

ENERGY POLICY OF MALAYSIA

2.1 The Role of Energy Policy

As discussed in the previous chapter, the world will have to take a major reduction in GHG emission of up to 48% in order to avoid the catastrophic consequences of global warming. To achieve the target, the role of the developing countries is as important as that of the developed countries. From the technological perspective, a substantial portion of the current technologies in the energy sector has to be replaced with low carbon and zero carbon technologies. However, the existing low carbon technologies are expensive, limited in availability, or not sufficiently reliable for deployment at very large scale. Therefore, major R&D efforts need to be carried out to achieve the necessary breakthroughs and discoveries in low carbon technologies, which is a private sector driven initiative.

Private sector investments are driven by the demand and supply forces of a free market. However, it is found that the market forces will not always result in an optimal investment level by the private section. When this occurs, it is known as a market failure. In the low carbon technology sector there are two well documented market failures (Jaffe et al., 2005). The first market failure is the externality of GHG emission. In the current market, the cost of GHG emission is largely unaccounted for. Therefore, there is no incentive for the private sector to invest in GHG reducing technologies as this will not reduce their cost and increase their profit. Knowledge spill-over is another well known market failures in this sector. This is because a company may not reap the full financial benefit from its R&D efforts. Most of the knowledge resulting from its R&D efforts will be made available in the public domain, which is freely available to the competitors. It was found in other researches that as much as 75% of the R&D efforts would be enjoyed freely by the competitors. On the average, a company would enjoy only 25% of the total financial benefit exclusively from its R&D efforts (Jones and C.Williams, 1998, Goto and Suzuki, 1989, Bernstein and Nadiri, 1988). These market failures will prevent the private sector from investing to the optimal level because they will not be able to enjoy the full benefits of their investment. Therefore, the role of the government is important in applying the appropriate policy tools to achieve the optimal investment level. For example, carbon tax has been introduced in Costa Rica (Meyer, 2010) and India (Pearson, 2010) to overcome the first market failure as described above.

In this chapter, the national energy policy (NEP) of Malaysia is investigated in details. First, the unique characteristics of Malaysia as a developing country are first analysed. This is followed by the analysis on the emphasis and transformation process of NEP. The current emphasis of NEP on RE and GHG emission reduction is investigated in details, with analysis on the financial, technological and environmental aspects. The chapter is concluded with discussion on the results from the analysis with respect to the achievable emission reduction based on NEP and the associated cost.

2.2 Uniqueness of Developing Economies

Common to other developing economies, the following characteristics are applicable for Malaysia:

a. **Expertise**: There is limited local expertise and R&D capacity in advance power technologies;

b. **Demand**: The power demand is on an upwards trend fuelled by continuous GDP growth. Consequentially, more new power plants with large capacity are being built. In contrast, in a typical developed economy, the power demand is stagnant and few new power plants are required. Instead, the existing power plants are refurbished.

c. **Financial**: Per capita income is lower compared to that of developed countries; and

d. **Resources**: RE resource endowment is different from the developed countries.

These characteristics are investigated in more details and quantified with statistics from reliable sources as presented in the following sections.

2.2.1 Expertise

Based on a United Nations research, the global spending on R&D on sustainable energy in 2009 can be presented in the chart as shown in Figure 2-1 (McCrone et al., 2010).

From the chart, it is obvious that the USA and Europe are well ahead of the rest of the world. In fact, out of the total global spending of USD 24.6 billion, USD 18.9 billion or 77% are from the US and Europe.

There is very little R&D carried out outside the developed countries. In terms of expertise and technological capabilities, it can be expected that the developing countries are far behind the developed countries. Therefore, in their attempts to adopt the latest low emission power technologies touted by the developed world, the developing countries are having difficulties to recruit sufficient expertise to ensure the successful implementation and operations of these technologies.

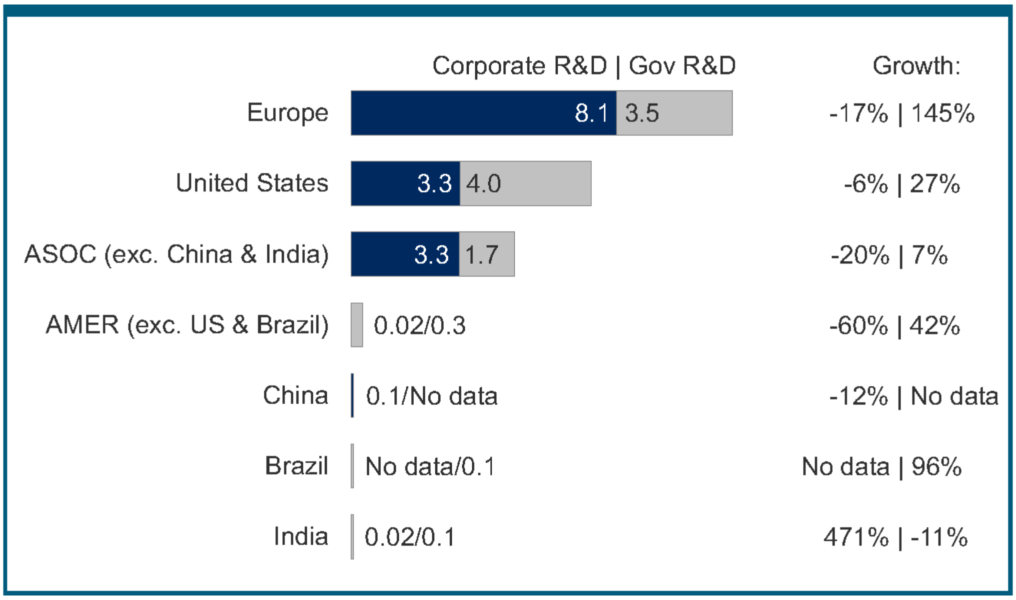


Figure 2-1: World R&D Expenditure on Sustainable Energy in 2009 (Source: United Nations Environment Programme and New Energy Finance, "Global Trends in Sustainable Energy Investment 2010")

2.2.2 Demand

With Sabah as an example, the chart in Figure 2-2 shows the plant-up plan for Sabah from year 2010 to 2030. Sabah is one of the 13 states in Malaysia and has an independent power grid not connecting to the rest of Malaysia. The projected plant-up plan is based on the planning of Sabah Electricity Sdn Bhd (SESB), the local electricity utility company (SESB, 2009a, SESB, 2009b).

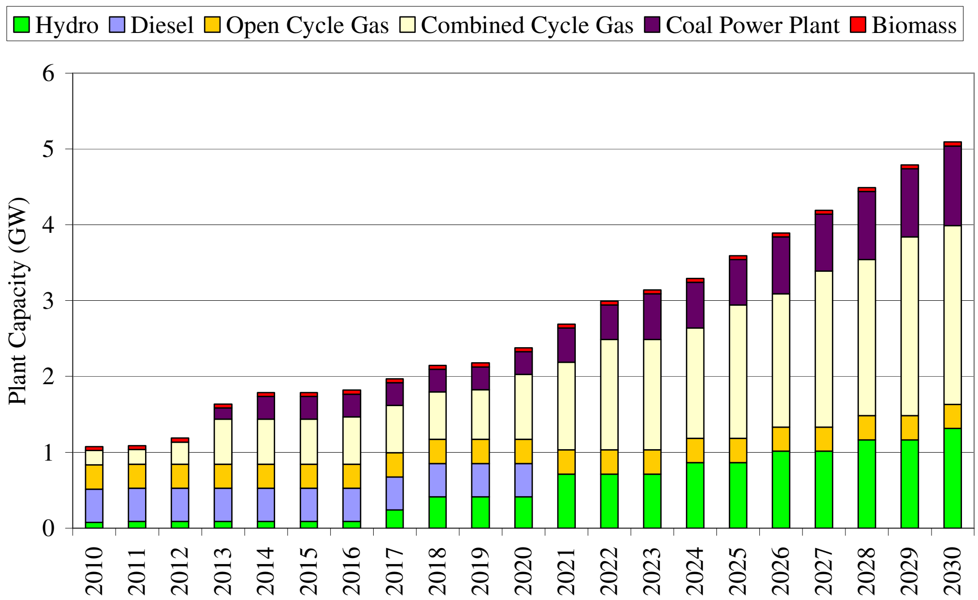


Figure 2-2: Plant-up Plan for Sabah, One of the 13 States in Malaysia

The plant capacity is to be increased from about 1 GW in 2010, to above 5 GW by 2030. There will be an increase of more than 4 GW within 20 years. On average, 200 MW of power plant is to be built every year. This represents a clear upwards trend of the power demand at a very rapid pace, typical to that of a developing country.

2.2.3 *Financial*

From the financial perspectives, the per capita income of the developed countries is much higher than that of the developing countries. As an example, the per capita income of Malaysia in 2009 is USD 7,600. For developed countries, it is at least USD 15,000. Therefore, consumers in developed countries have a lot more disposable income, and can better afford the additional cost required to reduce the GHG emission.

In the power sector, technologies with lower emission factor typically will incur a higher cost. The average electricity generation cost using different technologies can be computed by summing up the annualised capital cost, fixed operation and maintenance (O&M) cost, variable O&M cost and fuel cost, as shown in Figure 2-3.

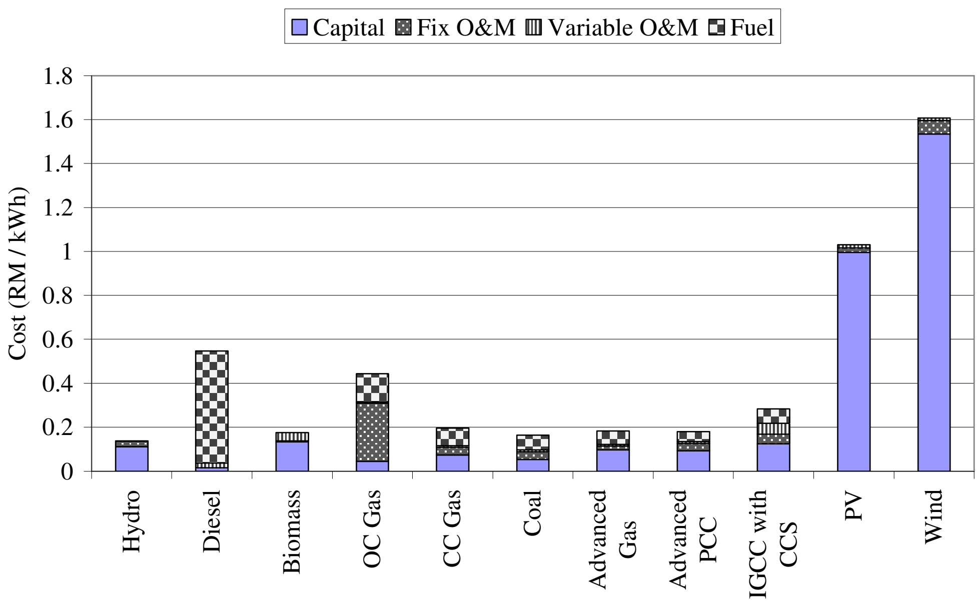


Figure 2-3: Average Cost of Electricity Generation Using Different Technologies

The annualised capital cost (ACC) is computed using Equation 2-1.

$$ACC = Total\ Capital\ Cost \times CRF \qquad \text{Equation 2-1}$$

Where:

$$\text{CRF (Capital Recovery Factor)} = \frac{i \bullet k}{(k-1)} \qquad \text{Equation 2-2}$$

$$k = (1+i)^n \qquad \text{Equation 2-3}$$

$i =$ annual interest rate

$k =$ plant lifetime (years)

The various cost components used in the above calculation are tabulated in Table 2-1. A plant factor of 0.80 is assumed for all technologies, except that of photovoltaic (PV) panel and wind turbine. The PV and wind output factor is based on actual wind and solar radiation resource profile measured in Malaysia computed in other researches (Lim et al., 2008, Sopian et al., 1995). The detailed computation of the costs for PV and wind energy is presented in Chapter 3.

From the above calculation, it is found that the costs of electricity from wind energy and PV would be much higher than that of the conventional power plants. The electricity cost is around RM 0.20 per kWh for most of the conventional power plants. The costs of the diesel plant and open cycle gas plant are slightly higher, at RM 0.40 to RM 0.50 per kWh. However, these plants are deployed primarily for the peaking power only and contribute to only a small percentage of the total electricity generated. The costs of wind energy and PV, on the other hand, are about RM 1.50 and RM 1.03 per kWh respectively, which is 5 to 7 times the average cost of current electricity price.

Table 2-1: Key Parameters for Cost Analysis

Technology	Plant Life Time (Years)	Capital (RM / kW)	Fuel cost[a] (RM / kWh output)	Fixed O&M cost (RM / kW / year)	Variable O&M cost (RM / GJ)
Hydro	50[b]	12270[c]	0	173.25[b]	0.4200[b]
Diesel	20	1200[c]	0.5100[d]	0[e]	6.0278[f]
Biomass	20[b]	10762[b]	0[g]	27.30[b]	10.2200[b]
OC Gas	20[b]	3600[c]	0.1272[h]	177.21[b]	1.9600[b]
CC Gas	20[b]	6000[c]	0.0808[h]	128.10[b]	2.2050[b]
Gas – Class H	20[b]	7820[i]	0.0608[h]	128.10[b]	2.2050[b]
PCC Coal	30[b]	5167[c]	0.0664[j]	241.50[b]	2.5200[b]
Ultra-super-critical PCC	30[b]	8877[k]	0.0440[j]	235.25[b]	2.6250[b]
IGCC with CCS	20 [b]	9983 [l]	0.0649 [j]	315.00 [b]	13.65[b]

Note:

a Fuel cost was computed separately and added to the analysis

b Data based on findings in (Rafaj and Kypreos, 2007)

c Cost computed based on SESB press release (SESB, 2009a, SESB, 2009b)

d Based on current subsidised diesel price of RM 1.70 per litre and average generator consumption of 0.3 litre per kWh output

e All O&M costs for diesel plant are lumped in the variable cost

f Cost obtained from (Tyler et al., 2010)

g Zero fuel cost was assumed for the biomass plant as all the existing plants are small scale plants using the waste from palm oil processing factories.

h The fuel price is computed using subsidised gas price of RM 10.70 per mmbtu (Zuraimi, 2010) in Malaysia and the corresponding plant efficiency for the respective technology

i Additional USD 520 per kW based on previous research (Alicia, 2008) is added to the capital cost of a standard combined cycle gas plant of RM 6000 per kW. A foreign currency exchange rate of USD 1 = RM 3.50 applied for all calculation

j The fuel cost is computed based on 2009 Indonesian coal price of USD30.72 per ton for the coal grade of 4200 kCal/kg (PT. Coalindo Energy, 2009) and the corresponding plant efficiency of the technology.

k Additional USD 1060 per kW based on previous research (Alicia, 2008) is added to the capital cost of a conventional PCC coal plant of RM 6000 per kW

l Additional USD 316 per kW based on previous research (Rafaj and Kypreos, 2007) is added to the capital cost of a conventional PCC coal plant of RM 6000 per kW

2.2.4 Resources

The adoption of RE is also dependent upon the availability of resources at the target country. For example, it can be seen from Figure 2-4 that, in the USA, the average wind velocity is higher than 5 m/s. In the Europe, it is even higher, exceeding 7 m/s.

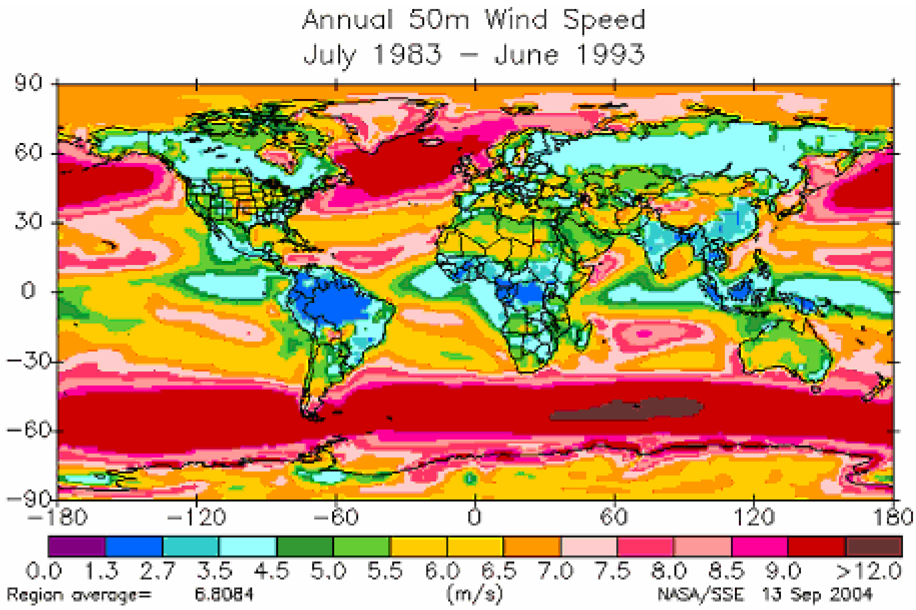


Figure 2-4: World Wind Resource Map (Source: University of Delawere, "Mapping the global wind power resource" assessed from http://www.ceoe.udel.edu/windpower/ResourceMap/index-world.html")

For comparison, in Malaysia, the wind velocity is only between 2 to 3 m/s. With a typical cut-in speed of 3 m/s (Sopian et al., 1995) for a wind turbine, there is little energy to be exploited.

The rapid increase in power demand of the developing countries also limits the options of power generation technologies that can be adopted. In developed countries, where the power demand has been stabilised, green energy sources can be added to merely reduce the usage of power plants of high emission factors. In developing countries, new power plants need to be installed to meet the increasing power demand.

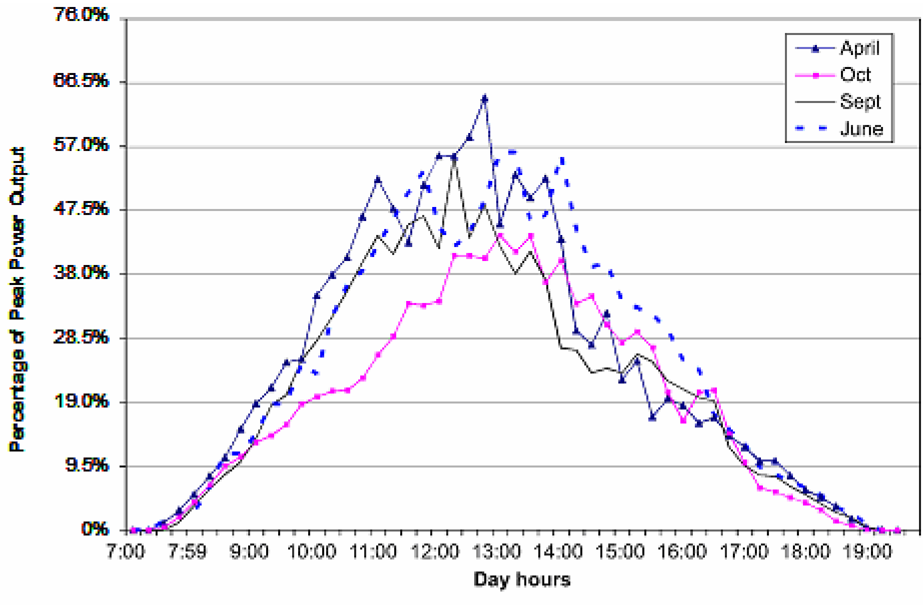


Figure 2-5: Output profile of a PV installation in Malaysia

This becomes a problem that can be illustrated by the output profile of a PV installation in Malaysia (Lim et al., 2008), as shown in Figure 2-5. The output power of the PV fluctuates according to the availability of solar radiation and it is beyond the control of the owner. Therefore, the peak output may not coincide with peak of the demand profile. As result, redundant power plant, such as gas power plant would be required to meet the peak demand, in additional to the PV panel. Taking into consideration the hourly and seasonal variations, it is computed that the output factor of PV installations in Malaysia is very low, at 0.18 whereas that of a power plant is typically as high as 0.80. Therefore, more units of panel are needed to produce the equivalent amount of electricity. With all these taken into consideration, the additional cost to replace conventional power plant with RE is tremendous and may not be affordable for the developing countries.

Also, the production process of PV panels consumes a lot of electricity. To produce 1kWp of PV, about 3030 kWh of electricity is consumed (Lim et al., 2008). As computed above, the average demand in Sabah will increase by 200 MW per year. To meet the demand with PV, additional 800 MW of PV panels will be required every year, considering that the output factor of PV is only about one fourth of the conventional power plant. The manufacturing process for 800 MW PV will consume 2400 GWh of electricity. To meet the additional electricity demand for the PV manufacturing, a 350 MW power plant operating at 0.8 plant factor is needed. As illustrated above, it is not practical to deploy PV at this scale to meet the rapid increase in demand of a developing country.

2.3 Energy Policy

2.3.1 Background

As presented in the previous section, the challenges faced by the developing countries are more intricate because they need to meet the increasing energy demands at a competitive price for their economic growths while reducing GHG emission for their countries. Typical to most developing countries, the rapid economic growth of Malaysia is mostly propelled by the growth in the industrial sector, which depends on the availability of cheap energy supply. As a result, the GDP growth is always positively correlated to the energy demand and this is proven to be also true in Malaysia (Abdul Hamid et al., 2008). The country has announced that it is targeting an average annual GDP growth of 6% until 2020 to become a developed country and a high income nation according to World Bank classifications (Dharmender, 2009). However, the reserve of oil and gas, which have been the main sources of energy in Malaysia, is fast depleting. It is estimated that Malaysia will become a net oil importing country in 2013 (Gan and Li, 2008).

To ensure the availability and security of energy to fuel the economic growth, Malaysia is actively looking for alternative sources of energy, especially for electricity generation. Coal, being among the most abundant and cheap energy sources worldwide, is constantly being considered in the NEP (Abdul Hamid et al., 2008). However, the increase use of coal has raised much concern because of its high GHG emissions. Higher emission factor of coal power plants is not consistent with objectives of the NEP to minimise negative environment impact from the energy sector. As announced by the Prime Minister himself early, the country is committed to cut down GHG emission intensity by 40% in 2020, benchmarked against that of 2005 (Choi, 2009). Therefore, Malaysia is facing a tough challenge of balancing the needs to increase energy production at a competitive price for the economic growth and the needs to cut down GHG emissions.

The first NEP in Malaysia was formulated in 1979 (Abdul Rahman and Lee, 2006), with three main objectives: (i) supply objective, which aims to ensure the provision of an adequate, secure, and cost-effective energy supply; (ii) utilization objective, which aims at promoting an efficient and clean utilization of energy patterns; and (iii) environmental objective, which aims to minimize the negative impacts of energy production to the environment (Energy Commission, 2007). The subsequent Four-Fuel Diversification Policy in 1981 and Five-Fuel Diversification Policy in 2000 inherit these objectives from the NEP.

Fuel diversification and low environmental impact are two key components consistently embedded in all versions of NEP described above. Consistent with these two key objectives, the RE and energy efficiency have been introduced as the "fifth fuel" in additional to the other key energy sources identified in the Four-Fuel Diversification Policy: oil, gas, hydropower and coal.

At the same time, Malaysia is also promoting the use of coal in electricity generation to achieve better fuel diversification and to reduce its over-dependency on natural gas. Coal, being the lowest cost and most abundant fossil fuel, also fulfils the "cost effective" and "fuel security" objectives of the NEP (Abdul Hamid et al., 2008). However, the emission factor of coal energy sources is much higher compared to the other conventional technologies and it does not fulfil the environmental objective of the NEP. In Chapter 3, the more advanced coal power plant technologies with higher efficiency and lower emission factors are evaluated to assess the effectiveness in reducing GHG emission from coal energy sources.

2.3.2 Renewable Energy Policy

In the Five-Fuel Diversification Policy of NEP, RE has been identified as potential source of energy to meet the increasing energy demand of the country with low or zero emission factor. A RE Policy is subsequently formulated for a long-term goal of increasing the use of native RE resources to improve the national electricity supply security for sustainable development. The following five key objectives have been identified in the policy:

(1) To increase RE contribution in the national power generation mix;

(2) To facilitate the growth of the RE industry;

(3) To ensure reasonable RE generation costs;

(4) To conserve the environment for future generation;

(5) To enhance awareness on the role and importance of RE (Ministry of Energy Green Technology and Water Malaysia, 2009).

The objectives are to be realised through the action plans as embodied in the following five strategic thrusts:

Thrust 1: Introduce appropriate regulatory framework

An appropriate, robust and efficient regulatory framework is to be formulated and implemented. Within the framework, appropriate incentive shall be introduced for the RE generation market. Consequently, feed-in-tariff (FiT) has been introduced within one of the agenda in the framework. The incentive of higher selling price of RE was design to be a catalyst for the entry of RE power generation businesses, RE industries and R&D in RE.

Thrust 2: Introduce conducive stimulus package for RE businesses

The stimulus package will encompass the provision of fiscal incentives, and indirect assistance in the form of reducing the transaction costs for financing RE business and providing assistance to SMEs to participate in the RE business.

Thrust 3: Intensify human capital development

RE industry is a new and emerging sector in Malaysia. Hence, it is critical that the required human capital to be developed in order to support the Industries in the long term. As a short-term measure, incentive will be provided for knowledge workers in the RE industry to relocate to Malaysia to fill the human capital void in Malaysia.

Thrust 4: Enhance RE research and development

A systemic R&D programme shall be formulated with the objective of leading to innovative products and services. The R&D programme is important in accelerating the growth of the local RE Industry as innovation will enhance the diffusion of RE technology by making the technology cheaper and easier to use. This can strengthen competitive edge of the local RE industry.

Thrust 5: Design and implement an RE advocacy programme

Advocacy programmes that are tailored with specific messages for specific audiences would be implemented. All advocacy programmes are aimed at increasing the awareness of all stakeholders on the benefits and advantages of utilising RE and participation in RE businesses.

All the activities organised under each thrust are designed to achieve the five policy objectives. It is envisaged by the policy maker that the RE Policy will result in the development and growth of the RE in Malaysia in a much progressive and predictable manner.

2.3.3 Renewable Energy Initiatives

Within the framework of RE policy, a number of initiatives have been implemented as described in details below.

2.3.3.1 PV Panel

Malaysia is an equatorial country that has a high irradiance level. The level of irradiance on Malaysia is in the range of 1470 to 1700 kWh/m^2. The high irradiance level will result in a higher output factor of PV panel and enhance the feasibility of electricity generation from PV panel. In view of the potential, the Main Building Integrated Photovoltaic (MBIPV) Project was introduced in 2005 with the long-term objective of reducing the cost of solar PV system through the development of a sustainable and widespread local market.

Generally, PV panels installed on a three-storey building in Malaysia over all the available roof area will be able to generate all the electricity that the building needs, provided that energy efficient features have been implemented in the building design. Taller urban buildings, however, will not be able to achieve self-sufficiency of energy generated solely from PV system because of higher density of occupancy and larger volume per square meter of roof area. Therefore, the real opportunity lies in residential households, warehouses, and other low-rise commercial buildings. A factory, though being low-rise, typically consumes high levels of energy due to heavy machineries and other equipment. It will not be able to achieve energy self-sufficient through solar PV. Nevertheless, the large roof area of factories is ideal for solar PV installation.

Based on 2003 national electricity data, the total roof area of 65 million m^2 is suitable for PV installation. This total area consists of 40% of the roof area of all residential houses (2.5 million houses) and 5% of commercial buildings (about 40,000 commercial buildings). If this area is covered by PV with capacity of 100 W/m^2, then the total installed capacity of these PV is

6,500 MW. Based on the output factor of 1 kW PV for 1200 kWh per year, the total electricity generated by the PV system is 7.8 TWh per year. This amount of electricity is equivalent to 21 % of the total residential and commercial electricity demand in 2005. The potential installed PV on the roof would increase in tandem with the additional new residential areas and commercial buildings. Based on the RE policy, the target capacity of grid-connected solar PV is 850 MW by 2030 and more than 8,000 MW by 2050. This is physically achievable based on the available roof space.

The main barrier to the growth of PV is very much related to the high initial cost of purchase of the PV system. FiT is designed to overcome the high capital cost by buying back the electricity generated from PV at higher than market price. However, a quota system has to be implemented for PV system eligible under FiT due to limitation in funding to purchase solar electricity that is exported to the grid. At present, the majority of the local PV panel productions are exported to market in Europe, USA and Japan where the demand of PV are high.

The MBIPV Project provides grants to homeowners and companies to partially finance the capital and installation costs of a PV system. Through the MBIPV programme, the cost of a PV system (on average) has dropped from RM 31,000 per kW to RM 26,000 per kW in two years. Subsequently, the cost has continued to reduce to the current level of RM 18,000 per kW. The installed capacity of PV technology has been increased by more then 330 % under the programme. The MBIPV programme has been successful in increasing the take-up of PV technology. It forms a good reference for the subsequent incentive programme under the RE policy.

2.3.3.2 Solid Waste Materials

Based on data obtained from the Ministry of Housing and Local Government, the solid waste collected in Malaysia is approximately 21,000 tonnes per day. It is forecasted that by 2022, the collected solid waste will reach 30,000 tonnes per day. The projection is based on an annual compounded growth rate of 2.5%, and the assumption that the Ministry's recycling and other waste reduction programmes are successful. Therefore, solid waste is a potential source of renewable energy.

Under the RE framework, an integrated waste management plant owned by Core Competency Recycle Energy has been established and operating in Semenyih, Selangor, with a capacity of sorting and treating a maximum waste of 1,000 tonnes per day. From the average intake of 700 tonnes per day of wastes, the plant is operating at a constant output of 8 MW, of which 5.5 MW is net output available for export to the grid. Based on the output ratio of this pilot plant, it is estimated that the potential of RE from solid waste will be 378 MW by 2022 when the daily solid waste collected is 30,000 tonnes per day.

2.3.3.3 Biomass Power Plant (Palm Oil Waste)

Biomass Power Generation and Demonstration (BioGen) Project was introduced in Oct 2002 with the main objective of utilizing excess oil palm biomass residues and further promote and demonstrate biomass and biogas grid-connected power generation projects to reduce GHG emissions from fossil fuels. Under the project, the first power plant with a rated capacity of 14 MW has been established in Tawau, Sabah, which uses oil palm residues.

Malaysia is the world‘s second largest producer of crude palm oil (CPO). In 2002, the country has 362 palm oil mills that processed about 59.8 million tonnes of fresh fruit bunches (FFB) and produced about 11.9 million tonnes of CPO. The by-products are 22.6 million tonnes of empty fruit bunches (EFB), mesocarp fibres and shells, as well as 41.9 million tonnes of palm oil mill effluent (POME).

The palm oil industry has been growing at an average rate of 7.5% per year. In 2006, more than 15.8 million tonnes of CPO were produced. By 2007, the numbers of palm oil mills in the country have grown to 407.

Mesocarp fibres and kernel shells are usually used to generate steam and power for palm oil mills across the country because of their high quality as fuels and the ease in preparation. Therefore, in evaluating the potential net export electricity of biomass power plants, this source of biomass should be excluded. Kernel shells are also used in the production of carbon black and have a high economic value with a market price of RM 120 and RM 140 per tonne. This higher price as compared to RM 20 for EFB also discourages the use of kernel shells as an RE fuel source.

The RE potential lies in the use of EFB and POME. However the EFB is used by the palm oil plantation for mulching, composting and being dumped somewhere in the plantation. Based on a conservative calculation and relying on the use of the excess EFB as a biomass fuel source, it is estimated that 254 MW can be generated from EFB, while about 438 MW can be generated from biogas from POME.

In 2008, the Roadmap for Palm Oil Industry and Latest Advances in the Industry was launched for the purpose of increasing industry productivity, empower technology, expand investment, modernize infrastructure and ensure sustainability. Apart from that, it improves the advancement in the industry towards increased yield and oil extraction rate (OER).

Taking into consideration of these factors, it is estimated that a realistic and achievable capacity of biomass power plants is 1,340 MW by 2030. This estimate can be conservative because the growth rate of biomass energy is expected to be much higher.

2.3.3.4 Mini-hydro

Mini-hydro projects are based on the run-of-the–river schemes with typical capacity of up to 10 MW. The installed capacity of mini-hydro power plants in Peninsular Malaysia, Sabah and Sarawak is about 13.361, 8.335 and 7.297 MW respectively. Most of the mini-hydro schemes are located in the remote areas. It is therefore difficult to determine the installed capacity of mini-hydro plants accurately because the data cannot be easily available. As Sabah and Sarawak have a large number of rivers, mini-hydro schemes could be a promising source of RE for the country. The only constraint is that the distance between the power grid and the mini-hydro schemes should not be more than 10 km in order to justify the economic viability of the plants. Therefore, a conservative target of 490 MW installed capacity of mini-hydro plants by 2020 has been set under the framework of the RE policy.

2.3.3.5 Wind Energy and Ocean Energy

Research has been funded by the government on the potential of wind and ocean energy. Based on the results as presented in (Sopian et al., 1995) and (Lim and Koh, 2010), it is found that it will not be technically and financially viable to harness wind and ocean energy for electricity generation. This is because of the extremely low wind and ocean energy density in the country compared to the US and Europe as discussed in Chapter 2.

2.3.3.6 Small Renewable Energy Programme (SREP)

Under the SREP programme, electricity generated from biomass, biogas, landfill waste, mini hydro, PV and wind can be sold to the utility company. The RE power plant eligible under the programme are limited to a maximum capacity of 10 MW. To date, various types of RE schemes have been launched under the programme. Majority of them are biomass using EFB and mini hydro. A total of 375 MW of RE plants have been connected to the grid.

2.4 RE Target

With the RE policy and the FiT implemented, the target RE installed capacity by 2030 is from RE is 3,484 MW or 13% of total peak electricity demand. With the target capacity, the total electricity generated from RE shall be 16.5 TWh per year. This is equivalent to 10% of total electricity generated in 2030. The breakdown of the target RE sources are given below (Badriyah, 2010):

1. Biomass (EFB, agro-based): 1,340 MW will be reached by 2028.
2. Biogas (POME, agro-based, farming): 410 MW will be reached by 2028.
3. Mini-hydro (not exceeding 30 MW): 490 MW will be reached by 2020.
4. Solar PV (grid-connected): 850 MW will be reached by 2030.

5. Solid waste (RDF-Refuse Derived Fuel, incineration, sanitary landfill): 378 MW will be reached by 2022.

Table 2-2: Predicted Growth of RE under the New RE Policy

Year Ending	Total RE (MW)	Share of RE Capacity (%)	Annual RE generation (GWh)	RE in Energy Mix (%)
2011	217	1	1,228	1
2015	975	6	5,374	5
2020	2,065	10	11,227	9
2030	3,484	13	16,512	10
2050	11,544	34	25,579	13

The projection on the growth of RE under the RE policy are shown in Table 2-2. Based on the data, non RE and RE electricity in Malaysia can be projected as shown in Figure 2-6. From the projection, it is calculated that, by 2030, an accumulated 197 TWh of electricity from RE resources will be generated.

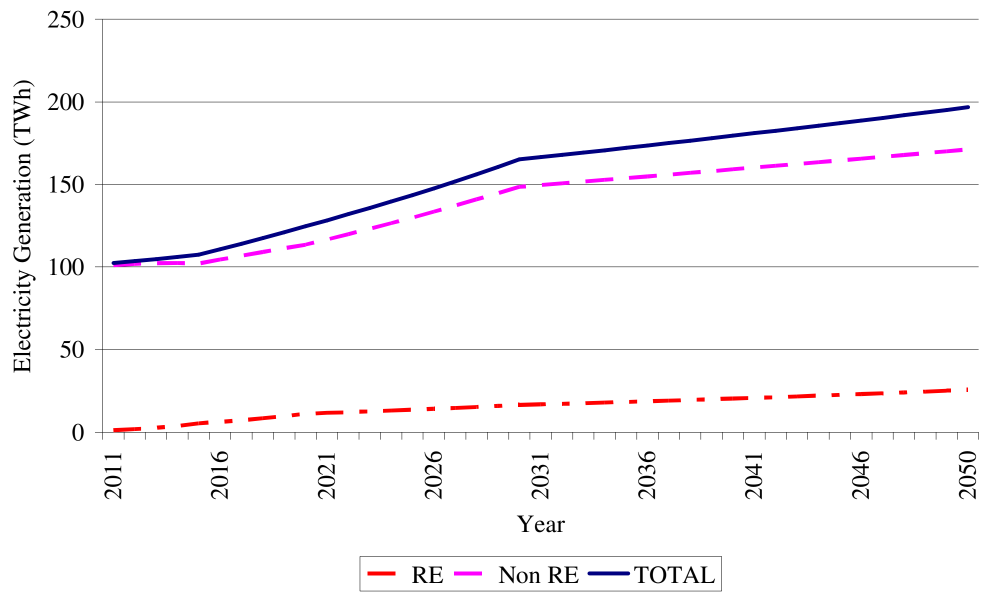


Figure 2-6: Projection RE and Non RE Electricity Generation in Malaysia

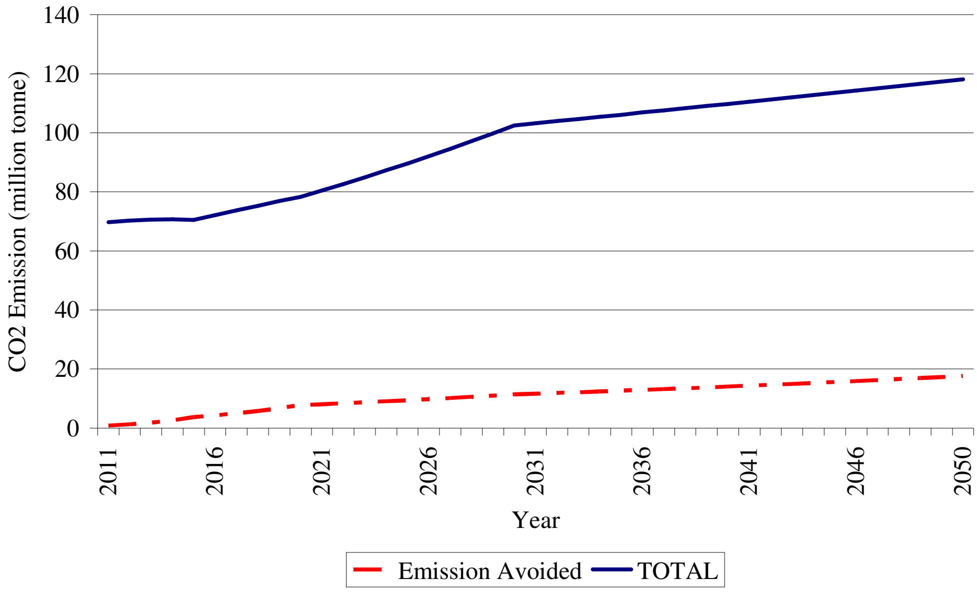


Figure 2-7: Projection of CO_2 Emission Avoided based on Projection under RE Policy Framework

2.4.1 *Emission Reduction*

The average emission factor for the power generation sector in Malaysia is found to be 690 tonne per GWh in Malaysia (Badriyah, 2010). Based on the projection in the RE policy framework, the reduction of CO_2 emission from the electricity generation is computed and plotted in Figure 2-7. It is found that a total of 439 million tCO_2–eq. emission will be avoided from 2011 to 2050, by adopting RE. In 2020, an annual reduction of 7.75 million tCO_2–eq can be achieved. That will result in the average emission factor of the power generation industry to reduce from 690 tonne per GWh to 628 tonne per GWh, or a 9% reduction. Assuming that the growth of Gross Domestic Product (GDP) is proportional to that of the electricity production, the emission intensity will also be reduced by 9%. This is substantially less than the 40% target committed by Malaysia. By 2050, the annual emission reduction from RE will reach 17.65 tCO_2–eq, which is equivalent to a 13% reduction in the emission factor.

2.4.2 *Cost of Emission Reduction*

It is envisaged by the policy maker that the projected RE uptake will be driven by the FiT. The proposed FiT rates are RM0.35, RM0.35, RM0.24, RM1.75 and RM0.46 per kWh for biomass, biogas, Mini Hydro, PV and solid waste power respectively. This is based on a displaced electricity cost of RM0.2214 per kWh. A RE fund will be created to finance the difference between the displaced electricity cost and the FIT rates. A surcharge will be levied on all consumers of electricity for the fund.

Based on the FiT rates and the displaced electricity cost, the cost for the RE is calculated and plotted in Figure 2-8. It is found that the annual expenditure on FiT will reach RM1.69 billion in 2020. If it is to be continued to 2050, the annual expenditure will be RM16.98 billion. The cumulative cost from 2011 to 2050 would be RM204 billion.

From the calculation of the emission avoided and the total cost of FiT, the average cost of emission avoided can be computed. It is found that through the current RE policy, the average cost of emission avoided will be RM465 per tCO_2-eq.

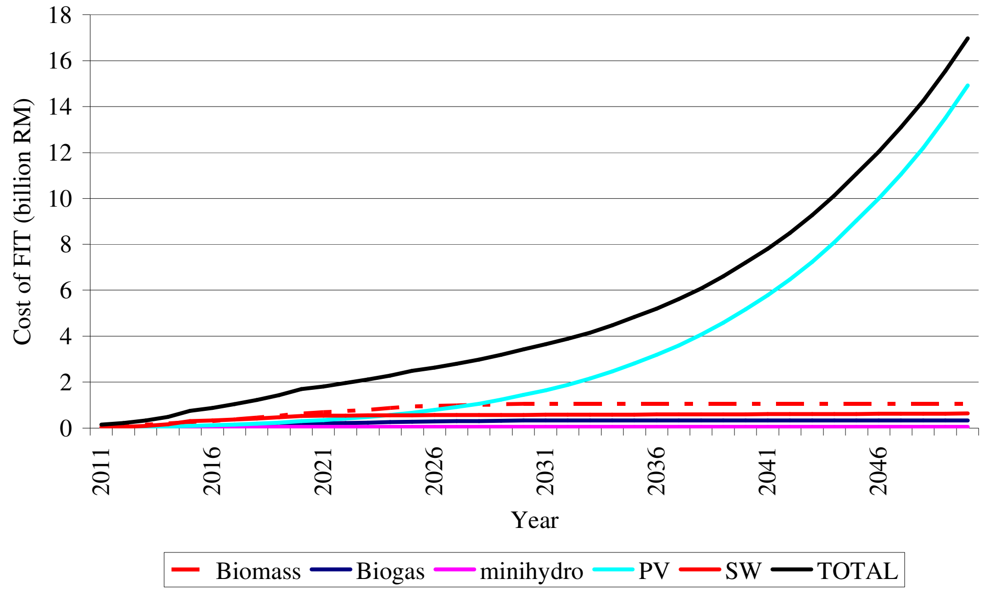


Figure 2-8: Cost of Implementing RE in Malaysia based on FIT Rates

2.5 Conclusion

From the above analysis on Malaysia Energy Policy, it is found that the emphasis of the current NEP is on RE to achieve the required emission reduction in the electricity sector. However, as shown in Section 2.4.1, the average emission factor and emission intensity of the energy sector will be reduced by only 9% by 2020 and 13% by 2050 based on the projected RE uptake rate under the policy. This is significantly below the targeted 40% reduction.

In additional, Malaysia has had difficulties in meeting the previous RE targets. Under the eighth Malaysia plan (2001 to 2005), a 5% target has been set for RE. However, the target cannot be achieved and subsequently in the ninth Malaysia plan (2006 to 2010), it has been revised down to 1.8%.

Eventually, only 0.25% was achieved in 2010 (Badriyah, 2010). The low adoption rate may be due to the high cost of the RE technology and requirements on high level of technical expertise for its implementation.

From the cost analysis, it is found that a total of RM204 billion will be required if the FIT were to be extended to 2050. In 2020, the annual expenditure will be RM1.69 billion. The average cost of emission reduction is found to be RM465 per tCO_2–eq, This is extremely high compared to the price of CO_2 that is currently traded in the market. For reference, at the European Climate Exchange, CO_2 is currently being traded at about 12.70 Euro (RM50.80) per tonne (European Climate Exchange, 2010).

Based on the current state of the energy policies analysed in this chapter, it is found that the RE option for GHG emission reduction is extremely expensive. In addition, with the option fully exploited as projected under the RE policy framework, the achievable reduction in the emission intensity is only 9% by 2020. This is much lower than targeted 40%. Furthermore, from the historical data, the targeted RE penetration rate may not be achievable due to the various challenges as discussed above. Therefore, it is critical that the policy makers explore other alternative options in GHG emission reduction. For the country to achieve its emission reduction target, the option investigated must be able to scale up to cater for the increasing electricity demand. It must be cost effective and based on proven technology. The technical challenges during the implementation stage must be minimised to reduce the technical risk and increase the chance of success for its implementation. The following chapters of this thesis are dedicated in exploring the options that meet the above criteria.

CHAPTER 3

LOW CARBON POWER TECHNOLOGIES FOR SABAH

3.1 Introduction

In this chapter, all the low carbon power options in Sabah are investigated to establish the potential of each option. First, the power system in Sabah is analysed and presented. Then, all the technologies currently available for emission reduction are investigated. The potential for each low carbon technology in Sabah is analysed from the resource endowment, financial and environmental perspective. The chapter is concluded with the findings on the potential, cost and impact on the GHG emission reduction in Sabah for each technology investigated.

3.2 Power System in Sabah

As discussed in Section 2.2 in the previous chapter, Malaysia as a developing country is also facing the challenge of reducing the GHG emission without hampering its development objectives. This has to be achieved within the constraints of the unique characteristics of developing countries, which include limitation in terms of financial resources, renewable energy endowment and technical expertise. Malaysia is divided into West and East Malaysia by the South China Sea as shown in Figure 3-1. Based on the geographical separation, the electric power is distributed by the following three independent grids: (a) West Malaysia Grid serving all the states in West Malaysia; (b) Sarawak Grid serving Sarawak state in East Malaysia; and (c) Sabah Grid serving Sabah state in East Malaysia (Energy Commission, 2009). Among the three grids, Sabah Grid is the most representative of that in a developing country where the demand is increasing fast while the reserve margin is low or non existent. Due to the independent power producer policy (Kamal, 24 June 2011), the reserve margin at West Malaysia Grid is consistently near 50%. This is exceptionally high and not representative of that in a developing country. Similarly, for the Sarawak Grid, power generated from the Bakun Dam totalling 2400 MW are coming online starting in 2011 (Leong, 2009b). This is much higher than the required power of about 900 MW in Sarawak in 2009 (Energy Commission, 2009). The high reserve margins found at both East Malaysia Grid and Sarawak Grid will limit the options for low GHG emission energy technologies in this study and are not representative of the power system in developing countries. Hence, the Sabah Grid has been selected for detail study in this research.

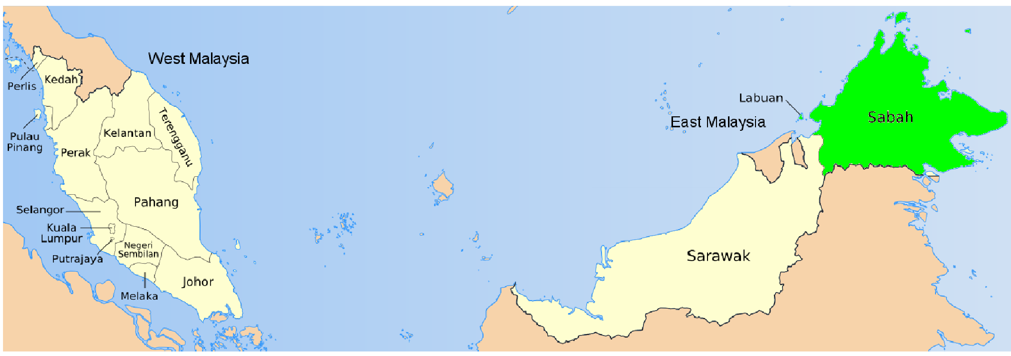


Figure 3-1: Map of Malaysia with Sabah as One of the 13 States (Source: http://en.wikipedia.org/wiki/Malaysia)

The existing Sabah Grid consists of the East Coast Grid and West Coast Grid, as shown in Figure 3-2. The West Coast Grid starts at Kudat and runs through Kota Belud, Kota Kinabalu, Beaufort and ends at Keningau. The East Coast Grid links Sandakan to Lahad Datu, Sempona and Tawau. A 275kV link-up, the East-West Grid Interconnection was completed in 2007 to connect the East Coast Grid and West Coast Grid into one integrated power grid (Bernama, 2009). The 247km link, connecting the West Coast Grid near Kota Kinabalu to the East Coast Grid near Sandakan, was carried out at a total project cost of RM 400 million (MRCB, 2010).

Figure 3-2: Sabah Grid Consisting West Coast Grid, East Coast Grid and East-West Grid Interconnection (Source: http://www.sesb.com.my/corporate_profile.cfm)

Over the recent decade, the state has experienced a large number of power interruptions especially at the east coast due to the serious shortage of power. Based on the statistics from Malaysia Energy Commission (Energy Commission, 2009), the total installed capacity in Sabah is 835 MW. However, it has been reported that among the power plants, there are a number of old and unreliable facilities which are experiencing frequent tripping. The total capacity of these unreliable power sources are 79MW. Hence, the dependable power plant capacity is effectively 756MW (The Star, 2009). Compared to the maximum demand of 730MW reported at the end of 2009, there is a very small reserve margin. This power shortage is reflected in the high number of power interruptions in the state. Based on the latest available statistics (Energy Commission, 2009), Sabah recorded the highest number of power interruptions per month among all the states in Malaysia for the first half of 2009, as shown in Figure 3-3. The average monthly power interruptions were 1759.

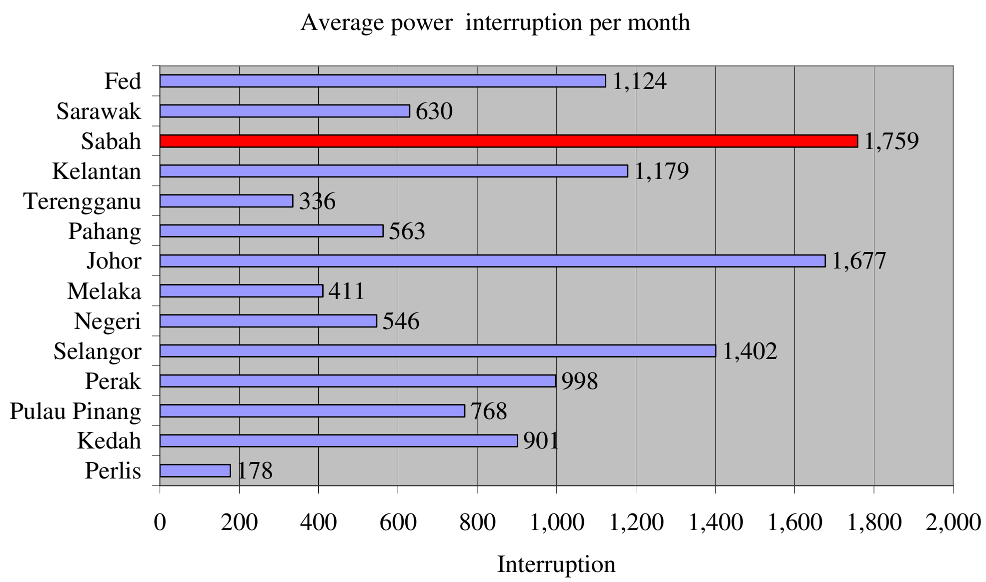


Figure 3-3: Average power interruption per month in Malaysia by state based on the latest available statistics for Jan-Jun 2009 (Energy Commission, 2009)

This power shortage is especially pronounced at the East Coast Grid, where 100MW of power is imported from the West Coast Grid through the East-West Interconnection Grid. The net imported power is estimated to reach 70% of the total power demand at east coast in 2010 (Sabah Electricity Sdn Bhd, 2008). Based on the installed capacity of 182 MW at the East Coast Grid (Bernama, 2009), the total imported power would be 420 MW. SESB has expressed great concern on the reliability of the power supply at the east coast due to this over dependence on the East-West Interconnection Grid. It is argued that, in the event that the interconnection grid broke down, the supply to the east coast will be interrupted.

Planning for low emission power system in Sabah is critical because Sabah is also renowned worldwide for its virgin forest reserve and diverse marine life that attracts a large number of tourists each year. It is a concern that a coal plant with its emissions may become a threat to these sensitive ecosystems. Hence, the tourism industry may suffer as a result.

3.3 Low Carbon Power Technologies

In this section, all existing power generation options with low carbon emission are investigated for their potential application in Sabah to address the power shortage.

3.3.1 Renewable Energy

RE is defined as 'energy flows which are replenished at the same rate as they are used' (Sorensen, 2000). The RE sources that are commonly being explored include solar, wind, waves, tides, biomass, and geothermal energy. Most of these sources, except for tidal and geothermal energy, derive their energy directly or indirectly from sun (Boyle, 2004).

Solar radiation can be converted directly into electricity using PV modules and solar-thermal electric power generation plants. Furthermore, solar energy is also the driving force behind the various natural phenomena including wind, ocean waves, rain and flowing rivers. All these natural phenomena can be tapped to generate useful energy. Solar energy is also the energy source that powers photosynthesis in plants to convert water and carbon dioxide into carbohydrates and biomass. The resulted biomass is a form of RE fuel for power generation.

Tides, on the other hand, are caused by the changing gravitational fields of the Moon and Sun as a result from the rotation of the Earth. The potential energy of the rising and subsiding of ocean water levels resulting from the tides can be harnessed for power generation. In addition, the kinetic energy from the flowing sea water is another source of RE.

Geothermal energy refers to the heat from within the Earth. It is also a source of energy for power generation. It is originally generated from the gravitational contraction during the Earth's formation stage. The decay of radioactive materials within the Earth's core continuously enhances the geothermal energy.

The costs for wind power plant has been found to be exceptionally high as computed in (Koh and Lim, 2010). This is due to the low available wind speed and hence a low effective plant factor of only 8.76%. Solar radiation, hydro and biomass from palm oil waste are found to be promising sources of RE in Sabah (Koh and Lim, 2010, Lim and Koh, 2010, Lim et al., 2008, Sopian et al., 1995).

3.3.2 Supply Side Energy Efficiency

The efficiency of the combustion technologies adopted by power plants has a significant impact on the GHG emissions, energy resources utilization, energy security and power generation costs. Fossil fuels are the main source of energy in the power generation industry. In 2005, coal contributed to 48% of the total power generation in the Asia Pacific Economic Corporation (APEC) countries, while natural gas contributed to another 18% (Alicia, 2008). Together, they contributed to more than 60% of the total power generated. Therefore, the fossil fuels will continue to play a major role in the foreseeable future.

There is a long history of fossil fuel power plants. The first coal power plant started more than 90 years ago while the first gas power plant started 60 years ago. The power plant technology has been continuously improved to lower the GHG emission and increase the efficiency via R&D works. However, the most advanced and efficient technology normally carries a premium price. Therefore, commercial power plant operators do not always adopt the most efficient option available due to the high capital costs. Therefore, it is a GHG emission reduction opportunity if the latest power generation technology with lower emission factor is to be adopted instead of some older technologies.

3.3.3 Demand Side Energy Efficiency

According to a study by the US Energy Information Administration, energy efficiency can potentially reduce more than half of the total required saving in GHG emissions in one of the scenario options, whereby the long range CO_2 concentration in the atmosphere is to be maintained at 450 ppm (EIA, 2009). A successful energy efficiency measure shall be comprehensive; be customizable; deliver additional benefits such as cost savings and increased productivity to the users, and involve partnerships (Kenneth et al., 2004, Figueres and Philips, 2007). The EE measures are typically implemented through the following frameworks:

1. Policy and regulatory: These measures include energy price rationalization, reducing import duties, subsidization, appliance efficiency standards and labeling, and building energy efficiency codes.

2. Institutional: These measures include public information programs and training on energy efficiency.
3. Financial: These measures include affordable financing schemes and financial incentives for the purchase of energy efficient appliances.

In Malaysia, the energy efficiency policy can be summarised in the following measures:

1. Enforcing the Efficient Management of Electricity Energy Regulation 2008 to ensure more efficient use of electricity among large users.
2. Incorporating the Code of Practice on Energy Efficiency and Use of RE for Non-Residential Buildings (MS1525:2007) into the Uniform Building By-Laws (UBBL).
3. Promoting the use of highly energy-efficient appliances and equipment.
4. Developing local expertise in manufacturing of energy-efficient appliances and equipment.
5. Improving energy efficiency in government buildings.
6. Developing human capital in the area of energy efficiency.

3.4 Existing Source of Energy in Sabah

In the following sections of this chapter, the various options available in Sabah based on current technologies and readily available energy sources to overcome the problem of existing power shortages are investigated. The GHG emission of these options is also evaluated. All the technologies selected for reviewed in this chapter are those available for immediate implementation. The option investigated must also be able to meet the immediate shortage of electricity in Sabah. Based on the findings by SESB, there is a shortage of 300 MW (The Star, 2009). Therefore, the options evaluated in this chapter will have to meet the shortage of 300 MW, which is equivalent to 2102.4 GWh of electricity per year, based on a plant factor of 0.8.

Detail analysis on other low carbon power sources are presented in the subsequent chapters, with long term projection on the demand and supply of the power system in Sabah.

3.4.1 Coal Fired Plant

Coal power plant supplies to 41% of the world electricity generation in 2006 and is projected to continue to be the main source of energy, accounted for 43% of electricity generation in 2030 (EIA, 2009). Therefore, the technology associated with the coal fired plant is mature and poses little technological risk during the implementation and operation. To meet the current shortage of power in Sabah, a 300 MW coal plant will have to be constructed.

The drawback of coal power is its relatively high GHG emissions. To overcome this problem, a number of technologies have been developed, such as integrated gasification combined cycle (IGCC), pressurized fluidised bed combustion (FBC) and carbon dioxide scrubber. These latest and greener technologies are available at a relatively higher cost. Currently, the coal power plants being built in Malaysia typical do not apply the latest technologies because of the financial considerations. The emission standard observed by the power plant operators is World Bank emission standard, which specifies the limit of harmful emission from the plants (Sabah Electricity Sdn Bhd, 2008). However, the standard does not specify for a limit on CO_2 emission. It only states the limits on emissions of other gases such as SO_X, NO_X and particulate matter (Energy Sector Management Assistance Program, 2007).

3.4.2 PV Panel

Being a tropical country gifted with abundant sunshine throughout the year, the PV technology is being actively pursued in Malaysia by the researchers and government as one of the feasible RE sources (Lim et al., 2008).

The technology of PV panels is fast maturing with wide application throughout the world. Therefore, the technological risks involved are relatively small. Large scale application of this technology is mainly hindered by the high cost of PV panels.

Based on the measurement data on the solar intensity at Kota Kinabalu, the annual energy output of 1 kWp of PV panel is 1,600 kWh (Lim et al., 2008). This represents the highest output factor among all the other surveyed sites in Malaysia. By applying this same energy output factor, 1,314,000 kWp of PV will be required to generate the equivalent annual energy output of 2,102.4 GWh. This translates to a plant factor of only 0.19. The 300 MW coal plant has a plant factor of 0.80.

To evaluate the practicality of this PV option, the scale of the installation is further investigated. Based on the current available technology for mass production, the efficiency of the panel is typically between 10% and 20% (Rafaj and Kypreos, 2007, Mackay, 2009). The solar power at noon in the tropical area is about 1000 W/m^2. Based on these numbers, the size of the PV panel would be between 5 to 10 m^2/kWp. A survey of the websites of PV panel suppliers shows that the typical size is 8 m^2 / kWp. Therefore, the total area required for this installation will be 6.57 km^2 for a centralized power plant using PV panels. Based on the total land area of 76,115 km^2 in Sabah, this constitutes only 0.0086% of the total land area.

Alternatively, the PV panel can be implemented in a distributed configuration. The consumers can be encouraged to install the PV panels on their roofs. The total number of residential consumers in Sabah was 318,955 in 2007. To distribute evenly over this group of customers, the average installation per customer will be 4.12 kWp each, occupying 33 m^2 of roof area.

Another technical consideration is the matching of existing load profile to the power output profile of the PV panels. The PV panels can generate electricity only when there is sufficient sun light. Therefore, no electricity can be generated during the nights or cloudy days when power is still required by the consumers. Therefore, energy storage devices need to be considered to meet the peak energy demand in these situations. Alternative, a higher reserve margin of the power system needs to be specified.

3.4.3 Hydropower Plant

Based on the findings in the report by World Energy Council (Clark and Trinnaman, 2004), Sabah has great hydro-electric potential. The technically feasible potential of hydropower in Sabah is estimated to be 20 TWh per year. Currently, the hydropower is under utilized as the current hydro-electric generation in Sabah is only 538 GWh per year or a mere 2.69% of the total available hydropower. The additional requirement for 2,102.4 GWh of electricity is equivalent to 10.51% of the total potential hydropower in Sabah. This may increase the utilization factor to 13.20%.

From the data available from (Malaysia Energy Commission, 2007), the plant factor of existing hydropower plants in Sabah is calculated as shown in Table 3-1. The lowest plant factor is 75.58% recorded in 2002 and the highest being 94.61% in 2006. The average plant factor is 82.90%, which is higher than the typical plant factor of 80% used in the analysis of the coal plant. Applying the same plant factor of 80 % for the proposed hydropower plant, the required capacity of the plant will be 300 MW. With such a high average plant factor, the matching of plant power output profile to the demand load profile will not be an issue.

Table 3-1: Plant Factor of Existing Hydro-electric Power Plants in Sabah

Year	*Capacity (MW)*	*Energy Generated (GWh)*	*100% Capacity (GWh)*	*Plant Factor*
2001	66	461	578.16	79.74%
2002	66	437	578.16	75.58%
2003	66	453	578.16	78.35%
2004	66	450	578.16	77.83%
2005	66	469	578.16	81.12%
2006	66	547	578.16	94.61%
2007	66	538	578.16	93.05%
			Average	**82.90%**

3.4.4 Biomass Power Plant (Palm Oil Waste)

As described in (Shuit et al., 2009), power plants using biomass as feedstock are based on processes with proven technology that are currently being practiced commercially in Malaysia and elsewhere in the world. This is confirmed by the statistics published by Malaysia Energy Commission (Malaysia Energy Commission, 2007), whereby there are seven registered independent power producers in 2007 using biomass from palm oil waste as feedstock, with a total capacity of 70 MW.

Malaysia is among the top palm oil producers in the world. There is abundant of biomass from the palm oil waste available for electricity generation. As reported in the (New Sabah Times, 14 December 2009), Sabah is the top palm oil producing state in Malaysia, with 1.36 million hectares of oil palm plantation. Based on the average of 13.76 ton of waste per hectare of oil palm (Shuit et al., 2009), Sabah is producing 18.71 million ton of palm oil waste per year. The average energy contained in the palm oil waste is 0.5415 toe per ton (Shuit et al., 2009). Therefore, a total of 10.14 Mtoe per year is available from the palm oil waste. By applying a typical process efficiency of 0.333 for biomass power plants as found in (Rafaj and Kypreos, 2007), a total of 3.38 Mtoe or 39,247 GWh of electricity can be generated using the palm oil waste per year. The 2,102.4 GWh of electricity needed constitutes only 5.36% of the total electricity that can be converted from the biomass waste. Therefore, it can be concluded that the required feedstock for a 300 MW biomass power plant is readily available and can be obtained on a sustainable basis in Sabah.

3.4.5 Supply from Bakun Dam

The Bakun Dam in Sarawak, which was commissioned in 2011, will have an installed capacity of 2400 MW (Leong, 2009b). The capacity is more than sufficient for the local application in Sarawak and can be supplied to Sabah to overcome the power shortage.

The power grids in Sabah and Sarawak are not interconnected. Therefore, a 500 km HVAC transmission line (Razavi, 1990a) would need to be constructed. A 500 km HVAC overhead transmission line rated above 300 MW is technically feasible as it is common in Malaysia and other countries to have transmission lines exceeding this distance and capacity. The cost of installation such a transmission line is analysed in details in Section 3.5.

3.4.6 Second East-West Interconnection Grid

As explained by SESB in (Sabah Electricity Sdn Bhd, 2008), the potential risks of depending on a single linkage between the East Coast Grid and West Coast Grid has to be taken into consideration in the planning of the new power plants in Sabah. Under such constraint, the proposed new power plant will preferably be located at the east coast to minimise the dependency on the East-West Connection Grid and lower the risk of power outages at the east coast. This has imposed a constraint on the options available to address the power shortage at the east coast, where there is no natural gas.

To overcome this constraint, a second connection through HVAC overhead line can be installed between the East Coast Grid and West Coast Grid. For maximum redundancy and minimum risk of double jeopardy, the location of the second link should be located furthest away from the existing link. From Figure 3-2, it can be seen that the ideal location to install the link will be at the southern part of Sabah, linking Keningau on the West Coast Grid to Tawau on the East Coast Grid, over a distance of about 227 km. The distance is about the same as the existing link of 247 km and is technically feasible.

With the second link in place, the proposed 300 MW plant can be located at the west coast, hence opening up the option for other fuels. For the subsequent analysis for this option, a new 300 MW gas power plant is proposed together with the second east-west link.

In relation to this option, an alternative option of building the gas plant at the east coast and relying on gas transport from the west coast has also been considered. The option to transport the gas through pipeline or barge is found to be too costly based on the research carried out by SESB (Sabah Electricity Sdn Bhd, 2008). The next alternative will be to transport natural gas using natural gas carrier truck. However, the road network in Sabah is under-developed and road transportation is costly. With the unfavourable road conditions, the transportation of gas may pose significant risk to transporters and local commuters as a result of possible road accidents. It is calculated that the cost of road transportation is about RM0.023 per kWh of electricity generated, based on the following data:

- **Gas Energy Density: 1031 btu/ft3** (obtain from Gas Malaysia: http://www.gasmalaysia.com/about_gas/impress_your_friends.htm)
- **Transportation Cost: RM0.20 / ton-km** (Based on container haulage in West Malaysia (Malaysian Industrial Development Authority, 2005). The actual cost for natural gas carrier truck in Sabah is expected to be higher due to the poorer road network and additional safety requirement for Gas transport)
- **Distance: 780 km** (Round trip between West Coast – Kota Kinabalu and East Coast – Sandakan)
- **Carrying Capacity: 55,000 litres** (per standard 40 ton truck).

The transportation cost is significantly higher than transmission cost calculated in the option whereby a second east-west link is to be constructed. In the financial assessment in the following sections, the transmission cost is found to be only RM0.0068 per kWh. Therefore, this option of gas transport is not pursued further in the subsequent sections of this chapter.

3.4.7 Wind Turbine

The wind data for Tawau as presented in (Sopian et al., 1995) is used in this analysis to represent the typical wind condition at the east coast. The key parameters are extracted and computed as presented in Table 3-2.

Table 3-2: Key Parameters Computed for Wind Turbine Installation Based on Wind Speed at Tawau

No	*Description*	*Value*
1	Average Wind Power	7.37 W/m^2
2	Cut-in speed of wind turbine	3.0 m/s
3	Percentage time above cut-in speed	40%
4	Average wind speed **above cut in speed**	4.82 m/s
5	Maximum wind speed	8.0 m/s
6	Plant Factor	8.76%
7	Total turbine capacity required	2,740 MW
8	Air Density	1.16 kg/m^3
9	Average wind turbine efficiency	50%
10	Average output of wind turbine of diameter d (m)	$1.1577d^2$ (W)
11	Land area per turbine installation, spacing at 5d (m)	$25d^2$ (m^2)
12	Wind turbine output power per unit land area	0.04631 W/m^2
13	Energy generated per unit land area per year	0.4057 kWh/m^2
14	Total land area required for 2,102.4 GWh per year	5,182 km^2

The turbine output power per unit land area is derived based on the following equations.

Wind turbine average output power $P_t = \frac{1}{2}\varepsilon LA\rho v^3$ Equation 3-1

where

A is the area swept by the wind turbine.

ρ is the density of air, which is 1.16 kg/m^3

v is the velocity of air (wind speed)

ε is the efficiency of the turbine, which is 50%

L is the percentage of time where the wind speed is above the cut-in speed of turbine (40% as per Table 3-2)

$\frac{1}{2}\rho v^3$ is the average wind power per unit area (7.37 W/m^2 as per Table 3-2) (Sopian et al., 1995)

The area swept by the wind turbine can be calculated using Equation 3-2.

$$A = \pi(\frac{1}{2}d)^2 = \frac{1}{4}\pi d^2 \qquad \text{Equation 3-2}$$

where *d* is the diameter (m) of the swept area.

Based on the above, the wind turbine output power in Equation 3-1 can then be computed as:

$$P_t = \frac{1}{2}\varepsilon LA\rho v^3 = (\frac{1}{2}\rho v^3)\varepsilon LA = 7.37\times 0.5\times 0.4\times(\frac{1}{4}\pi d^2)$$

$$P_t = 1.1577d^2 \qquad \text{Equation 3-3}$$

Based on Equation 3-3, it is computed as in Table 3-2 that a total area of 5,182 km^2 will be required to install the wind turbines for the required capacity of 2,740 MW. Although technically feasible, the area required is large. It is equivalent to 6.8% of the total land area in Sabah, hence making this option unfavorable.

3.4.8 Ocean Energy (Tidal Current Power Plant)

From the study carried out in (Lim and Koh, 2010), it is found that, among the various forms of ocean energy, there is little potential in wave energy and ocean thermal energy available from the ocean around Malaysia. However, the potential in tidal energy is promising, with the following two locations identified around Sabah: (a) Kota Belud with an estimated exploitable potential of 8,188 GWh per year; and (b) Sibu with 386 GWh per year.

As Kota Belud is located along the west coast of Sabah, it is excluded from the potential solution for this study due to the grid configuration. The 386 GWh per year from tidal energy at Sibu is only 18.3% of the required 2,102.4 GWh. Therefore, it is not considered as a solution to overcome the current power shortage in Sabah.

Another technical consideration is the constraint of tidal cycle which is periodic in nature and may not coincide with the demand load profile. The tidal cycle is highly predictable at a 12.4-hour- cycle and the peak power output varies from day to day. Therefore, the output profile will not coincide with the demand load profile most of the time. Moreover, most tidal turbine plants are currently in pilot phase and the technology may pose considerable technological risk to the investors (Hammons, 2009).

3.5 Financial Assessment

The financial assessment is based on the Net Present Value (NPV), which is a standard way of evaluating the financial benefits of long-term projects. It is used to assess the economic viability of each option in this study. As the financial benefit is directly proportional to the value of NPV, this method has been used to evaluate the financial benefits of all proposed options.

3.5.1 Equations for NPV Analysis

Using the method derived in (Lim et al., 2008), the NPV is calculated using Equation 3-4. The annual revenue and expenditure is computed using Equation 3-5 and Equation 3-6.

$$\mathrm{NPV} = -\mathrm{C} + \sum_{j=1}^{N} \frac{\mathrm{I}_j - (\mathrm{E}+\mathrm{F}) * (1+\mathrm{g})^j}{(1+\mathrm{r})^j} \qquad \text{Equation 3-4}$$

$$I = p \times (L \times P \times 365 \times 24) \qquad \text{Equation 3-5}$$

$$E = E_f \times P + E_v \times Q \qquad \text{Equation 3-6}$$

Where C : Capital cost of the project (RM)

I : Annual income of the project (RM)

E : Annual O&M expenses (RM)

F	:	Annual fuel cost (RM)
g	:	Annual inflation rate
r	:	Annual discount rate
N	:	Lifespan of the project
p	:	Unit price of electricity (RM per kWh)
L	:	The plant factor of the power plant
P	:	The rated power of the power plant (kW)
Q	:	Total amount of energy sold per year (kWh)
E_f	:	Fix O&M cost (RM / kW / year)
E_v	:	Variable O&M cost (RM /kWh)
j	:	Index for each year within the lifetime of the project concerned

In this study, the NPV is used to carry out the following two analysis:

a. NPV Based on Prevailing Electricity Price: The NPV of the investment for each option is first computed based on the expected lifetime of the technology, to establish the financially feasibility. The revenues of the power plant are computed based on the prevailing selling price.

b. Minimum Electricity Price at Break Even Point: In the second analysis, the unit electricity price is varied to find a break-even point for the investment such that the NPV = 0 at the end of the lifetime of each power plant. This price represents the minimum selling price in order for the project to be financially feasible.

3.5.2 NPV Based on Prevailing Electricity Price

The NPV for the coal power plant is first calculated as the benchmark to the other alternative solutions. The annual income of the project (I) is calculated to be RM 433 million using Equation 3-5. This is based on a 300MW coal power plant. Hence, the rated power (*P)* is 300,000 kW. The plant factor (*L)* is assumed to be 0.80, which is typical to modern coal power plant (Rafaj and Kypreos, 2007). As discussed above, the unit price of electricity (p) is RM 0.206 per kWh (Malaysia Energy Commission, 2007). The total annual O&M cost is calculated to be RM 90 million, using Equation 3-6. In this calculation, the fix O&M cost is assumed to be RM 236.35 / kW / year (Rafaj and Kypreos, 2007). The variable O&M cost is assumed to be RM 0.00945 / kWh. A currency conversion rate of USD 1= RM 3.5 is applied. The total energy sold (Q) is calculated to be equal to 2,102,400,000 kWh or 2,102.4 GWh, with L = 0.80.

It is reported that, for the proposed coal power plant, the fuel will be imported from Indonesia. The price of coal from Indonesia is USD30.72 per ton in 2009, for the coal grade of 4200 kCal/kg as stated in (PT. Coalindo Energy, 2009). Based on this, the unit fuel cost is RM 0.0221 per kWh, at the input of the plant. As it is an infrastructure project fully funded by the government without any loan, no interest rate is included in the computation. Based on the historical data in Malaysia, both the annual inflation rate (g) and annual discount rate (r) are assumed to be 3% in the calculation. The capital cost of the coal plant (C) is reported in (Muguntan, 2008) to be RM 1.3 billion With the above parameters, the NPV of the project and the cumulative cash flow can be obtained from Equation 3-4. The results from the calculation are plotted in Figure 3-4.

It can be seen from Figure 3-4 that the curve reaches the maximum value of RM 1,278 million at N = 26 years before it starts to decrease. At N = 30 years, the NPV is equal to RM 1,230 million, which represents 95% of return on the investment of RM 1.3 billion. This trend is to be expected as an inflation rate is applied to the O&M cost (E) as well as the fuel cost (F), which results in the total expenditure to increase by 3% annually. However, the unit price of electricity (p) is held constant over the 30-year-period making the annual income of the project constant. At N = 26 years, the total annual expenditure has increased to RM 428.4 million, which is equivalent to the annual income from the sale of electricity. This results in the net income being reduced to zero. Beyond N = 26 years, the expenditure continues to increase at the rate of 3% and becomes larger than the annual income. Hence, the project suffers from a net annual loss reducing the value of cumulative cash flow.

This trend is reflective of the current situation in Malaysia whereby the electricity is subsidised by the government, which is also commonly practised in other developing economies. The electricity price is controlled by the government and not adjusted according to the inflation rate and cost of production. In fact, the electricity price in Sabah has not been changed for more than 20 years.

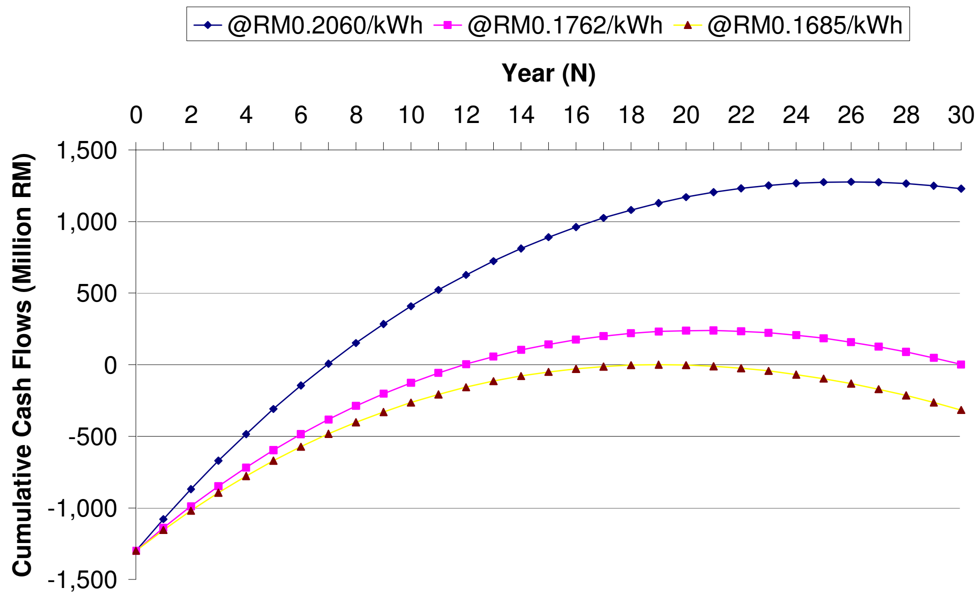


Figure 3-4: Cumulative Cash Flows of 300MW Coal Fired Power Plant at Different Electricity Prices

3.5.3 Minimum Electricity Price at Break Even Point

Second analysis is carried out by varying the unit price of the electricity (p) to find a break-even point such that the NPV is equal to zero when N = 30 years. With the rest of the parameters held constant, the break-even point is found at p = RM 0.1762 per kWh. From Figure 3-4, it is observed that the curve cut through the x-axis twice, which results in two break-even points, one at N = 12 years and another at N = 30 years. The curve reaches the maximum value of RM 239 million at N = 21 years. As discussed previously, this unique trend is mainly due to subsidised price of electricity not being revised by the government according to the inflation rate.

In order to have a unique break-even point, the unit price is varied further such that the curve cut through the x-axis only once over the 30-year-period. With the rest of the parameters being held constant, a minimum value of p is found at RM 0.1685 per kWh, such that the cumulative cash flow is equal to 0 when N = 19 years. This unit electricity price can be interpreted as the minimum price in order to make the power plant project financially feasible. At RM 0.1685 per kWh, the project will break even when N=19 years.

Using the same methodology, the NPV and cumulative cash flows are evaluated for each proposed option, using the input values as provided in Table 3-3. The option of ocean energy is not included in this analysis as there will not be sufficient potential to meet the required energy demand at the east coast, as discussed above.

The same values, for g = 3%, r = 3 %, and Q = 2,102.4 GWh per year, are applied in the analysis of all options. The same methodology described above is carried out in the NPV analyses for all options except option 5 and 6.

Table 3-3: Key Parameters Computed for NPV Analysis for Each Option

	1	***2***	***3***	***4***	***5***	***6***	***7***
Option	***Coal***	***PV***	***Hydro***	***Biomass***	***Bakun Link***[a]	***2nd Link***[a]	***Wind***
Capital (RM-billion)	1.300[b]	36.792[c]	3.610[d]	3.229[d]	0.810[e]	0.368[e]	11.029[d]
Life-time (years)	30[g]	20[g]	50[g]	20[g]	50[j]	50[j]	20[g]
Plant efficiency[h]	0.43	0.1	0.4	0.33	NA	NA	0.33
Annual fuel cost[i] (RM-million)	107.901	0	0	0	0	0	0
Plant factor of the power plant	0.8	0.18	0.8	0.8	NA	NA	0.088
Rated power of the power plant (MW)	300	1,314	300	300	1,000	1,000	2,740
Fix O&M cost (RM / kW / year) [f]	236.25	31.5	173.25	27.3	NA	NA	47.25
Variable operation and main-tenance cost (RM / kWh) [f]	0.00945	0.01575	0.00151	0.03679	NA	NA	0.01046

Note:
- a. The cost quoted for the Bakun Link and 2nd Link option include only the interconnection HVAC overhead line
- b. The cost of the coal plant obtained from (The Star)
- c. The unit cost of PV obtained from (Lim et al., 2008)
- d, f, g, h Values as concluded in (Rafaj and Kypreos, 2007)
- e. The unit cost of the overhead transmission line construction in Sabah obtained from (MRCB, 2010, Bernama, 2009)
- i. The fuel cost were computed based on the required plant output, using the plant efficiency stated in the previous column of the table
- j. The lifetime of transmission line conservatively set at 50 years, as a large portion of the grid are in operation for more than 50 years in the country

For the grid connection to Bakun dam supply in option 5, the electricity price at the gate of Bakun dam is assumed to be RM 0.11 per kWh as reported in (Leong, 2009b). Based on this, the revenue for this option is calculated using the net selling price (p) of RM 0.096 per kWh. This is calculated by deducting RM 0.11 from RM 0.206. Similarly, the break-even price at the end of the 30-year- period also includes the electricity purchasing price of RM 0.11 per kWh from Bakun dam.

For the second link in option 6, the purchase price of electricity from independent power producer at RM 0.206 per kWh is added to the electricity price (p) in the analysis. This is based on the assumption that the link will facilitate the transfer of electricity generated by the independent power producers at west coast to meet the power shortage at east coast.

3.5.4 Results from NPV Analysis

From the above calculations, the results from the NPV and cumulative cash flows analysis for all the options are summarised in Table 3-4.

The financially attractive options are: (a) hydro; (b) biomass; and (c) Bakun link. The returns on investment for these options are between 47% and 541%. In comparison, the return on investment for coal power plant is 95%. The break-even prices, which are between RM 0.1161 and RM 0.1580, are also lower than that of the coal power plant, which is RM 0.1687 per kWh. The break-even period for the hydro and biomass option is 12 years, which is longer than the 9-year-period of the coal plant. The longer period is due to the higher initial capital cost required by these two options. However, with the saving in fuel cost for these options, the cumulative cash flows increase much faster and exceed that of the coal plant after the break-even period.

Table 3-4: Summary of Results from NPV and Cumulative Cash Flows

No	Option	p = RM0.206 / kWh		Break-even price p (RM / kWh)
		Return (NPV/S)	Break-even period (N, years)	
1	Coal	95%	7	0.1685
2	PV	-87%	>20	1.2240
3	Hydro	135%	12	0.1161
4	Biomass	47%	12	0.1580
5	Bakun Link	541%	5	0.1250
6	2^{nd} Link	NA	NA	0.2128
7	Wind	-69%	>20	0.4500

Compared to the above three options, option 6 is financially less attractive. However, it is still a viable option. The break-even price of RM 0.2128 in this option is higher than the whole sale rate of RM 0.206 per kWh paid by SESB to the independent power producers. However, it is still lower than the average retail rate of RM 0.253 per kWh in Sabah (Malaysia Energy Commission, 2007).

The PV and wind turbine option are not financially viable. The PV option suffers a loss of 87% at the end of the 20-year-period. To break even, the project needs to sell electricity at the rate of RM 1.2240 per kWh which is about 484% of the current rate. The wind turbine in option 7 suffers a 69% loss at the end of the 30-year-period. The break-even price is very high, at RM

0.4500 per kWh. In addition, if the large land area of 5,182 km^2 required for this option is taken into consideration, it will become even less favourable. The minimum price of land in Sabah is estimated to be RM 100 per m^2 at current value (Sabah Town & Regional Planning Department, 1998). The total land cost required for the project will be RM 518.2 billion. However, the wind turbine can co-exist with other economic activities. For example, the land can be planted with oil palm or paddy while being used for wind turbine farm. Therefore, the project needs to account for only a portion of the land cost. Based on this consideration, with a mere 5% of the land cost added to the capital cost, the total capital cost of the project will increase to RM 37 billion. At this level of investment, the break-even price for 30 years will increased to RM 1.2778 per kWh, or 505% of the prevailing electricity price.

3.6 GHG Emission

The coal fired plant proposal is not well accepted by the local residents and environmental groups mainly because of its negative environmental impact. In additional to the GHG emissions, it also raises concerns in particulate emissions, which is not emitted from the other type of power plants.

In this study, however, the environmental assessment will be primarily focused on GHG emissions to facilitate comparisons with other alternative proposals. In this study on the GHG emissions, the target set by the Prime Minister to reduce GHG emission intensity by 40% by 2020 is used as the benchmark. In order to achieve the required reduction, efforts must be exerted by all states in all sectors of the economy. Therefore, the reduction is assumed to be shared equally in all sectors and hence the power industry in Sabah will have to achieve a 40% GHG emission intensity as well over the 15-year-period from 2005 to 2020. This is equivalent to an average of 2.67% reduction per year.

In the analysis, the GHG emission intensity in 2005 is first calculated. Then, the new GHG emission intensity in 2010 is calculated. The different fuel mixes based on each option are taken into consideration in the computation of the emission intensity in 2010. Comparing the two emission intensities, each option is assessed to ascertain if it can achieve the target reduction in emission intensity, which is equivalent to 13.33% reduction over the five-year-period from 2005 to 2010

Table 3-5 summarises the results from the calculation for the coal plant. The CO_2 emission factor in Malaysia is obtained from (Saidura et al., 2007, Mahlia, 2002). The fuel mix in Sabah for electricity generation and the total sales in 2005 are extracted from (Malaysia Energy Commission, 2006). The GDP of Sabah in 2005 can be found at (Department of Statistics Malaysia, 2009). Based on these data, the total CO_2 emission from electricity generation in Sabah is calculated to be 2.091 million ton and the GHG emission intensity is 0.076 million ton per billion RM in 2005.

Table 3-5: Changes in GHG Emission Intensity for Sabah from 2005 to 2010 with the Proposed 300MW Coal Fired Plant

Fuel Type	*CO_2 Emission (kg/kWh)*	*2005*		*2010*	
		Generation (GWh)	*CO_2 Emission (mil ton)*	*Generation (GWh)*	*CO_2 Emission (mil ton)*
Coal	1.18	0	0.000	1,712	2.020
Diesel/MFO	0.85	2,124	1.805	0	0.000
Gas	0.53	539	0.286	1,930	1.023
Hydro	0.00	469	0.000	538	0.000
Biomass	0.00	0	0.000	67	0.000
TOTAL		3,132	2.091	4,247	3.043
Total Sales		2,769	-	3,755	-
Total Sales/Generation		88.41%	-	88.41%	-
GDP (billion RM)		27.395		36.661	
GHG Emission Intensity (million ton/billion RM)		0.076		0.083	
% Changes		-		**9.21%**	

The ratio of total electricity sale to electricity generated in 2005 can be calculated as 88.41%. Applying the same ratio for 2010 and the projected electricity demand in Sabah of 3,755 GWh (Malaysia Energy Commission, 2007), the total electricity to be generated in 2010 is estimated as 4,247 GWh. The diesel power plants, as concluded by SESB in (Sabah Electricity Sdn Bhd, 2008) to be unreliable and inefficient, are to be substituted by the new proposed coal plant. It was further assumed that the total energy generated from the other existing power plants will remain unchanged in 2010 from the 2007 level. With these pre-conditions, the total energy to be generated by the new coal plant can then be calculated to be 1,712 GWh in 2010. The total CO_2 emission from electricity generation in Sabah is calculated to be 3.043 million ton in 2010. By applying an average 6% of GDP growth, the GDP of Sabah in 2010 is estimated to be worth RM 36.661 billion. This translates to an emission intensity of 0.083 million ton per billion RM.

From the calculation, it is found that the emission intensity will increase by 9.21% or 7,000 ton per billion RM from 2005 to 2010. This is in stark contrast to the required reduction of 13.33% as committed by the country.

Table 3-6: Summary of Results from GHG Analysis

No	***Option***	***CO_2 Emission Factor - Fuel Combustion (kg/kWh)***	***Annual CO_2 Emission (mil ton)***	***2010 GHG Emission Intensity (million ton / billion RM)***	***% Changes compared to 2005***
1	Coal	1.1800	2.4808	0.083	9.21%
2	PV	0.0000	0.0000	0.028	-63.15%
3	Hydro	0.0000	0.0000	0.028	-63.15%
4	Biomass	0.0000	0.0000	0.028	-63.15%
5	Bakun Link	0.0113	0.0238	0.028	-63.15%
6	2nd Link [a]	0.5300 [a]	1.1143	0.053	-30.26%
7	Wind	0.0000	0.0000	0.028	-63.15%

Note: a. The CO_2 emission factor from gas power plant, assuming that the second link transfer the required power from west coast gas power plant by independent power producers (IPP)

The same methodology described above is applied to assess the changes in GHG emission intensity for all the other options. The results are summarised in Table 3-6.

As presented in (Shuit et al., 2009), the carbon in the oil palm biomass is assimilated from the atmosphere and hence the utilisation of biomass as fuel for power generation does not contribute to a net increase of CO_2 in the atmosphere. The transportation of the biomass to the power plant does contribute to the release of carbon into the atmosphere. However, with the wide availability of oil palm plantation in Sabah, the transportation can be minimised and the carbon contribution is negligible.

From the results, it can be concluded that all the options result in reduction in GHG emission intensity of more than 40%, except the coal plant and second link. The second link option results in a reduction of 30.26% while the coal plant results in an increase of 9.21%.

3.7 Sensitivity Analysis

Sensitivity analysis is carried out on the results for the coal plant as well as the other three viable options, to ascertain the robustness of the results obtained in the economic and GHG emission analysis. For the economic analysis, the effects from variation of fuel price and capital cost on the break even price for electricity are studied. For the GHG emission result, the life cycle emission factors are varied to study its effect on the GHG emission intensity reduction.

3.7.1 Fuel Price

The effect of the variation of coal price on the break even price of electricity in the coal plant option is analysis. Liquid fuel can be produced from coal through coal liquefaction. Therefore, coal is a competitive alternative to oil as a form of energy and the coal price has fluctuated and increase in tandem with the oil price. The coal price has increased by 400% in the last 10 years (Index Mundi, 2010). This is much higher than the inflation rate applied in the previous analysis. Therefore, a sensitive analysis on the effect of the coal price on the break even price of electricity from the coal plant is analysed and the results are presented in Figure 3-5.

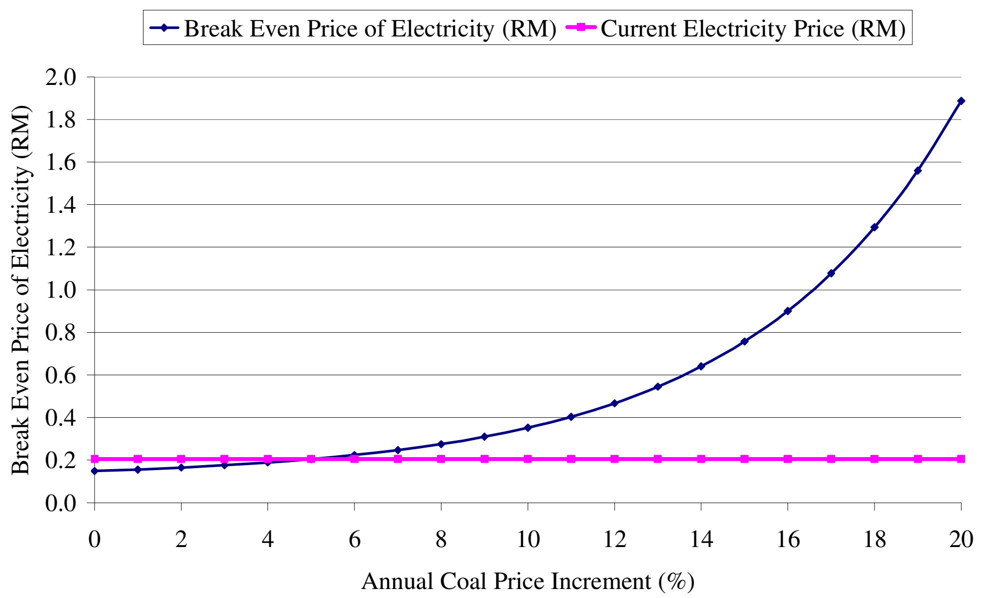


Figure 3-5: Sensitivity Analysis on the Effect of Variation of Coal Price Annual Increment Rate on the Break Even Price of Electricity (Coal Plant Option)

From the analysis, if the annual price increases rise from 3% to 5%, the electricity price will increase to RM0.2060 (current Sabah price). For a 20% annual price increment, the electricity price will be RM1.8868 or 900% above current price. This is not a distant possibility as, from the historical data, the coal price has increased by an average of 40% annually for the last 10 years. Therefore, the volatility of the coal price may result in an unacceptable electricity price using the coal plant option and may violate the supply objective of the NEP for competitive price of energy supply.

Fuel price fluctuation is not relevant to the other options being considered.

3.7.2 Capital Cost

The capital cost adopted in the economic assessment is an average price and may vary with the physical site conditions. Therefore, the effects from the increase of capital costs of the three recommended options on the break-even prices of electricity are studied, with the results tabulated in Figure 3-6.

From the analysis, for both the Hydro and Bakun dam options, the electricity price can be maintained below the current price level of RM0.2060 per kWh even if the capital cost increases by 100%. For the Biomass, the electricity price can be maintained below the current level even when the capital cost increases by 45%. Therefore, there is a very large margin for the three options to remain feasible. This margin will be able to cater for any possible increase in capital cost during the project implementation due to the selected site conditions, without affecting the financial feasibility of the project.

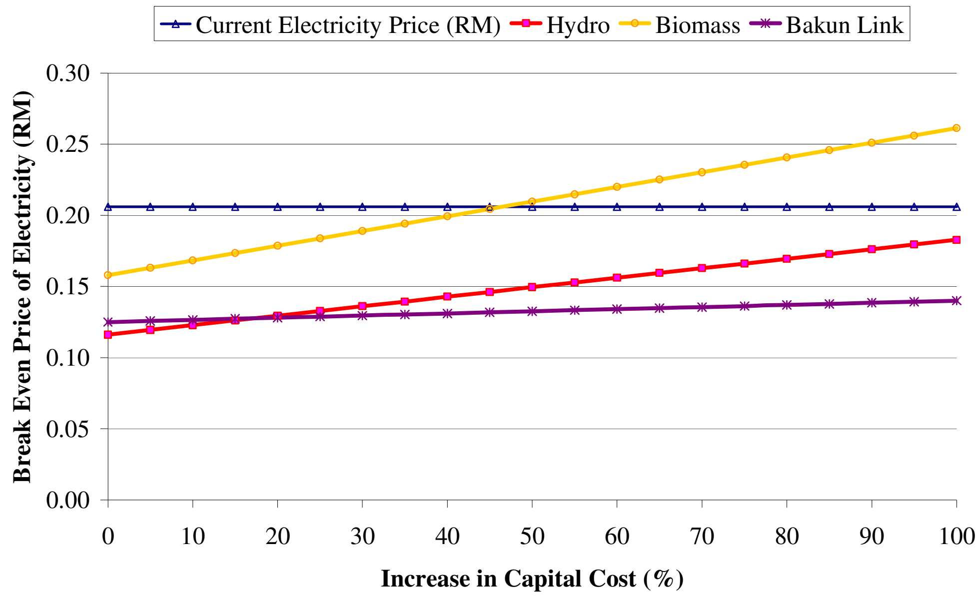


Figure 3-6: Sensitivity Analysis on the Effect of Variation of Capital Cost on the Break-even Price of Electricity

3.7.3 Life Cycle Emission Factor

In the study of the GHG emission intensity, the results are calculated based on the CO_2 emission factors from both the fuel combustion and life cycle analysis. As the fuel combustion emission factors are established with actual data, they are expected to be fairly accurate with little variation. Therefore, the sensitivity study is carried out only on the life cycle emission factor. The results from the analysis are tabulated in Figure 3-7.

From the analysis, it is found that even with 100% increase in the life cycle emission factor, the hydro option will still be able to achieve a reduction in GHG emission intensity of 12.4% per year. In the biomass and Bakun dam link options, the average annual reduction in GHG emission intensity are 9.8% and 12.3% respectively. These are much higher than the targeted annual reduction of 2.67% of the country. This large margin will be able to comfortably account for any unaccounted for emission in the computation of the GHG emission assessment.

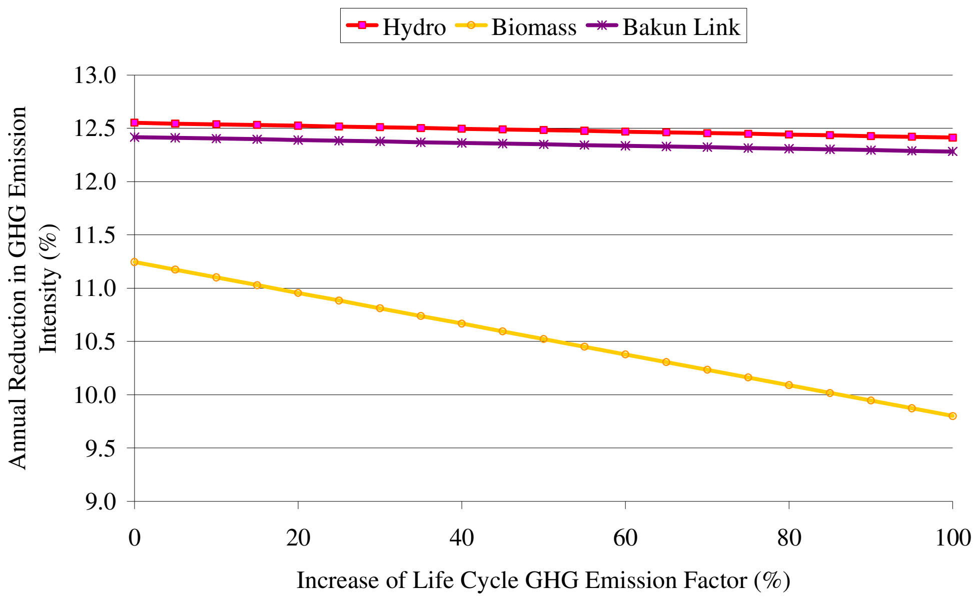


Figure 3-7: Sensitivity Analysis on the Effect of Life Cycle GHG emission Factors on the Annual Reduction in GHG Emission Intensity

3.8 Conclusion

From the above technical, economic and environmental assessments, it is found that there were three feasible alternative options to the coal plant in meeting the power demand at east coast of Sabah. These three options are: (a) hydropower; (b) biomass; and (c) link to Bakun dam.

The hydropower plant is based on proven technology with wide application worldwide. Hence, there is little technological risk associated with the option. In addition, the project has a major benefit of achieving a reduction in GHG emission intensity of 63.15% in 2010, surpassing the 40% reduction target of the country. A 135% return can be achieved at the end of the 50-year-period, based on the prevailing electricity price of RM0.206. The break-even selling price of electricity is found to be RM 0.1161 per kWh, which is also lower than that of the coal fired plant.

The biomass power plant, which is also based on proven technology, reduces the overall GHG emission intensity of Sabah power sector by 63.15% in 2010. A 47% return is achieved based on the prevailing electricity price of RM0.206. The selling price of electricity in order for the investment to break even over a 20-year-period is found to be RM 0.1580 per kWh, which is also lower than that of the coal fired plant.

For the option of Bakun dam link, the GHG emission intensity reduction, return on investment and break-even electricity selling price are 63.15%, 541% and RM 0.1250 respectively. It is also concluded that there is little technological risk to install the 500 km HVAC overhead transmission line linking Sabah to Sarawak Grid.

All the three options described above are more environmental friendly than the coal plant. The financial performance from the investment is also superior to that of the coal plant. The higher returns are mainly due to the savings from the fuel cost. All these three options have higher capital cost. However, with zero fuel cost, the annual running cost of the plant is much lower than that of the coal plant, hence resulting in the low lifetime cost.

From the perspective of Malaysia energy policy, the recommended three options meet the key objectives of NEP. As illustrated above, any of the three options have more than adequate potential energy to meet that of the 300 MW coal plant. The energy sources and feedstock are secured for the foreseeable future in the lifetime of the plant. They are all cost effective and environmental friendly. Therefore, there shall be a minimum barrier for these options to be adopted by SESB and the government. All legitimate concerns raised by any parties or lobbying groups could be neutralised by the merits of the options found in the above analyses.

The potential of these options can be enhanced further by encouraging private participation. With the competition from the private investors, the adoption of greener technologies as investigated in this chapter can be expedited. As part of the effort to promote RE, the government has launched a SREP program in 2001(Abdul Rahman and Lee, 2006), under which any small power plant utiliaing RE will be given a license for a period of 21 years to enable it to sell electricity to the grid. However, its maximum limit of 10 MW on the power plant has prevented large private investors from being benefited under this program. With the advancement in technology, RE plants are able to scale up to the level of conventional power plants. Therefore, the government should review such limitation in its programs to keep up with the advancement of technology and to encourage faster take up by the private investors.

With the positive outcomes from the technical, economical, environmental and NEP assessment for the three selected options as found in the above analyses, it is expected that all the implementation issues on the ground during the project design and implementation stage can be overcome without any major setbacks. These implementation issues to be addressed by the project developer shall include the technical, environmental, legal and social aspects of the project. The technical aspects encompasses the availability of lands, adequacy of the plant locations relative to the demand sites, availability of biomass or water resource to the plants and the geological structure for the plants. Environmental impact assessment has to be carried out to identify the potential impacts of the three options on the environment based on the selected location. The legal aspect includes current property rights, competitive uses of lands, the liability of potential hazard or risk to the public, and electricity supply contract between the developer and the utility company. For the social aspect, a social impact assessment has to be carried out to identify the positive and negative impacts of the project to the local community, with mitigation measures recommended to minimise the negative impacts.

The sensitivity analysis also shows that the three identified options will remain viable even if the capital costs are increased with a large margin, to account for any unforeseen factors during the implementation stage.

It is important for a country not to be overly dependent on the others for its energy needs, for the security of the country. This can be achieved by reducing the needs to import energy from other country. The proposed coal plant is to import the required fuel from Indonesia and will not be favourable in terms of fuel security for Malaysia. The other three alternative options, on the other hand, do not require any import of fuel.

CHAPTER 4

ADVANCED COMBUSTION TECHNOLOGIES

4.1 Introduction

As found in the preceding chapters, the developed countries have invested a lot more than the developing countries in the R&D of RE technologies. Currently, RE is promoted as the key long-term solution for minimising GHG emissions from the power sector. However, the adoption threshold of RE is very high for the developing countries. The "adoption threshold" in this thesis is defined as the minimum requirements in terms of financial resources, technical capability and natural resource endowment to adopt a new technology. This is because most of the RE technologies are still under development and need a high level of technical expertise for the implementation. Developing nations may not have the necessary technical expertise in RE technologies. It is expensive and technically challenging for large-scale implementation because of its low energy density (Lim and Koh, 2010, Koh and Lim, 2010). As a result, the cost of electricity from RE technologies is very high. Therefore, RE technologies may not be financially and technically viable for many countries, especially the developing countries.

With these constraints, any technologies with lower adoption threshold in terms of technological and financial requirements will be beneficial to the developing countries in reducing their GHG emissions. The advanced combustion technologies for coal and gas fired power plants appear to be a promising candidate in satisfying these criteria.

Coal and gas power plants contribute to more than 60% of the fuel for the world power generation. Coal, in particular, is certain to continue to be a major energy source in the future because it is the cheapest fossil fuel and is widely available across the world in both the developing and developed countries. The coal consumption globally is projected to increase from the current 510 quadrillion Btu to 722 quadrillion Btu in 2030 (Katzer, 2007). Therefore, it is important to reduce the emission factor of coal power as this will have a substantial long-term impact on our efforts in GHG emission reduction.

In this chapter, the advanced gas and coal power plant technologies are investigated in details. First, the latest development in the combustion technologies that had enabled lower emission for these energy sources is reviewed. The impact of applying these technologies in the energy system of Sabah is then analysed. The chapter is concluded with the findings from the analysis from the technological, financial and environmental perspective.

4.2 Advanced Combustion Technologies

In this section, the development in the combustion technologies for both the coal and gas power plants is described. The scenario planning in the subsequent sections is based on the data summarised in this section.

4.2.1 Natural Gas Power Plant

The natural gas-fired power generation was first started in 1950. The technology has been developed continuously and improved tremendously with many proven applications worldwide.

One of the major improvements is the overall efficiency of the gas power plant. From the laws of thermodynamics, it can be proved that the maximum efficiency of the gas turbine system cannot exceed that of the Carnot cycle in an ideal heat machine, and is expressed as:

$$\eta_{\max} = 1 - \frac{T_c}{T_h} \qquad \text{Equation 4-1}$$

Where $\eta_{\max}$: The maximum efficiency of a heat machine

T_c : Absolute temperature of the cold sink (K)

T_h : Absolute temperature of the hot source – firing temperature of the turbine (K)

As per Equation 4-1, the efficiency of the power plant can be improved by increasing the firing temperature of the gas turbine (T_h). In addition, the thermal efficiency of the plant can be further improved substantially through the implementation of combined cycle arrangement, such as the heat recovery steam generator (HRSG) system. The latest generation of Class H turbines produced by General Electric has achieved a thermal efficiency of 60%. This is a significant improvement over the average thermal efficiency of 45.2 % for combined cycle and 28.7% for open cycle in Malaysia (Malaysia Energy Commission, 2007). Although such a highly efficient technology is available, the old generation turbine technology is still the preferred choice. This is because the average cost of an advanced gas power plant based on the latest Class H turbine, is USD 1,172 per kW of installed capacity. This is 80% higher than the average capital cost of USD 652 per kW for a typical gas power plant (Alicia, 2008). All costs used in this thesis are nominal current price and the corresponding discount rate is the nominal rate.

4.2.2 Coal Fired Power Plant

The key combustion technologies used in coal fired power plants are based on steam turbines. The coal is used as the fuel to generate steam, and the resultant steam is then used to drive a turbine. There are two main types of steam turbine technology: (i) pulverised coal combustion (PCC); and (ii) Fluidised Bed Combustion (FBC).

PCC is the oldest and most widely used steam turbine technology. This type of plant has been constructed with plant capacity larger than 1000 MW. As shown in Table 4-1, the technology is further divided into three categories: sub-critical, supercritical, and ultra-supercritical based on the operating temperature of the steam. The sub-critical PCC plant operates at a steam temperature of around 375^{o} C while the ultra-supercritical plant operates at a temperature exceeding 580^{o} C. As shown in Equation 4-1, the higher the steam temperature, the higher the thermal efficiency of the plant will be. The sub-critical PCC plant has a maximum efficiency of 40% while the ultra-supercritical plant has an efficiency of up to 50% (Alicia, 2008).

The latest FBC technology has an advantage over the PCC technology because it emits lower SO_x and NO_x gases. The emission of SO_x and NO_x gases are reduced by injecting limestone into the fluidised bed and ammonia into the vapour space of the FBC system to react with these gases. The FBC can be further categorised into three categories: sub-critical, supercritical and pressurised FBC. Based on the current technology, the FBC has a lower plant capacity, with an upper limit of 350 MW. As shown in Table 4-1, the highest efficiency achieved by the pressurised FBC is 44%, which is lower than that of the PCC technology.

The latest development in the gasification process has enabled coal to be used as the fuel for the gas turbine. The technology is known as the Integrated Gasification Combined Cycle (IGCC) system. In the gasification process, the coal reacts with oxygen and steam to produce hydrogen and carbon monoxide. The resultant combined gas is known as syngas. The syngas can then be used as the fuel for the gas turbine in a combined cycle system. The IGCC technology is currently under intensive development. Based on the current available system, IGCC has a thermal efficiency of only 45% and the capital cost is USD 1300 per kW. Financially, it is not competitive with other coal power plant technologies. However, the Department of Energy, USA has established a R&D programme with its main target to increase the efficiency to 50% by 2010 and 60% by 2020 (Alicia, 2008). Under this programme, the capital cost is to be reduced to USD 900 per kW by 2020.

Table 4-1: Comparison of Different Coal Fired Power Plant Technologies

	PCC			*FBC*			*IGCC*
	Sub-critical	*Super-critical*	*Ultra-super-critical*	*Sub-critical*	*Super-critical*	*Pressu-rised*	
Typical Unit Size (MW)	≤ 1300	≤ 1300	≥ 1000	≤ 350	≤ 350	≤ 350	≤ 600
Plant Efficiency	≤ 40%	42 - 47%	47 - 50%	38 - 40%	43%	44%	≤45%
Steam Tempera-ture (^oC)	375	≥ 540	≥ 580	375	≥ 540	375	N/A

As the coal is projected to remain a major source of fuel for the power industry in many countries, concerted efforts have been expended in developing clean coal technology. Carbon capture and storage (CCS) is one among the promising ones. The CCS process involves three distinct sub-processes: (i) capturing CO_2 from the gas streams, (ii) transporting the captured CO_2, and (iii) storing CO_2 in geological formation. In a previous study (Othman et al., 2009), it was found that, while the CCS technology reduces the plant efficiency by up to 15%, it is an effective alternative in mitigating global warming. It can potentially reduce the CO_2 emission factor of coal plants by 92%. In the study, it was also found that the CCS is more efficient when applied to the IGCC technology, compared to PCC. When applied to the IGCC technology, the overall capital cost of the plant is USD 2 million per MW. This is cheaper than the capital cost of a PCC plant with CCS, which is USD 2.5 million per MW. The thermal efficiency of an IGCC-CCS plant is also higher at 33.9%, compared to the 28.0% of a PCC-CCS plant (Othman et al., 2009). Consequently, the emission factor of the IGCC-CCS plant is much lower, at 0.089 ton / MWh, compared to 0.108 ton / MWh of the PCC-CCS.

There are a number of challenges, however, to be overcome for large scale implementation of CCS, from the technological, financial and legal perspectives. While the basic processes of CCS are technologically proven, the additional process of CCS incurs significant cost and consumes heat in the generation process. This reduces the overall process efficiency. Based on current technology, the maximum efficiency achieved is 33.9%. Locating safe and sustainable storage location for the large amount of CO_2 is another challenge. International treaties and legal framework are being amended to allow storage of CO_2 in formations under the international waters. To increase its financial appeal, the CCS is also being reviewed to enable it to receive carbon credits under the Clean Development Mechanism (CDM) scheme (IEA, 2008).

4.3 Energy Model of Sabah

Energy model is an effective way to evaluate the impact of an alternative power generation options on the energy system of a country. The outputs from the energy model can be used to analyse in details the various results from the technical, financial and GHG emission perspective. In order to assess the impact and effectiveness of the above advanced combustion technologies, an energy model of Sabah was created using the Long-range Energy Alternatives Planning (LEAP).

LEAP is an energy modelling tool that can be used to track energy consumption, production and resource extraction in all sectors of an economy. It is maintained by Stockholm Environment Institute. LEAP is selected for this study based on its features as found in a recent research (Connolly et al., 2010), where a total of 37 commonly used tools have been investigated in detail. Based on the study, LEAP is found to have the right set of features required for this study. These features includes: energy system simulation for the electricity sector at annual time step, bottom-up modelling approach, scenario planning, computation of total cost including annualised capital cost, GHG emission computation, ability to include all energy conversion technologies, and modelling at a national and state level. It has a wide user base of over 5000 in 169 countries, with more than 40 reports published based on its simulation results (Stockholm Environment Institute, 2010).

4.3.1 Input Data for LEAP

In constructing the energy model of Sabah, the following data are included as the inputs to the model:

- Sabah electricity demand projection from 2010 to 2030.
- The power plant-up plan from 2010 to 2030.
- Hourly load demand profile.
- Life-span, capital cost and other essential operating and maintaining expenditures of fuels and combustion technologies

Sabah electricity demand projection is obtained from the Sabah Development Corridor (SDC) Blueprint (IDS, 2007) as per Figure 4-1.

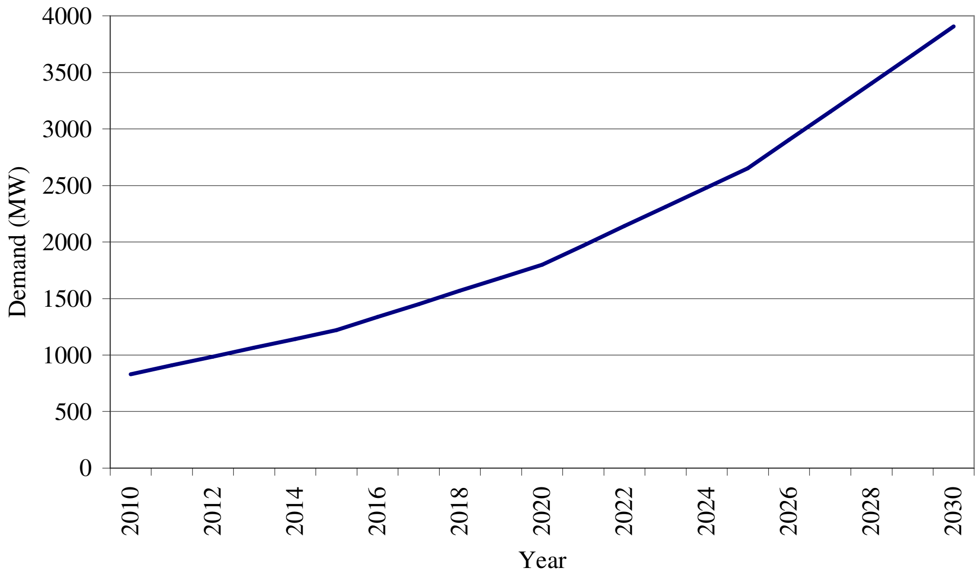


Figure 4-1: Sabah Power Demand Projection

The existing and new power plants from 2010 to 2020 are modelled based on SESB plant-up plan (SESB, 2009a) as shown in Figure 2-2. For the next 10-years period from 2021 to 2030, new plants are to be built based on a capacity ratio of 2:1:1 for gas, coal and hydro power plants respectively. The required plant capacity is computed dynamically by LEAP to maintain a minimum reserved margin of 30% (IDS, 2007). The system load curve is computed based on the average daily load profile (Tyler et al., 2010) and daily maximum demand obtained from SESB. The hourly demand load profile is computed and compiled from the source data as in Figure 4-2 and Figure 4-3. It is noted from Figure 4-3 that the load reaches the peak at 100% on day 270, which is corresponding to the maximum demand of 704 MW. The computed system load profile is presented in Figure 4-4. From the resultant load profile, the average load factor is calculated to be 73.34%. This has been verified for consistency against the statistics published by the Energy Commission, Malaysia (Malaysia Energy Commission, 2007).

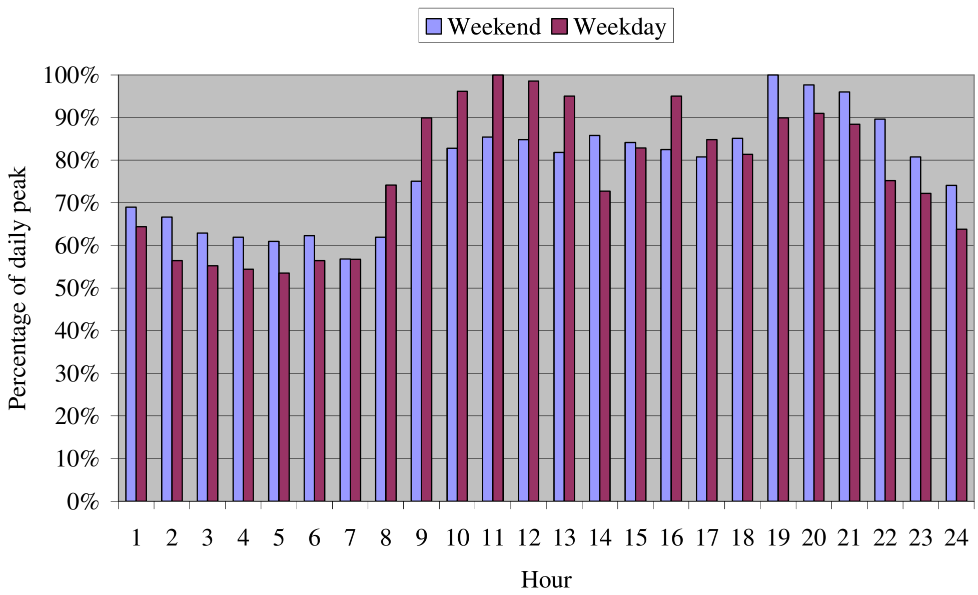


Figure 4-2: Hourly-load Profile of Sabah Electrical Grid

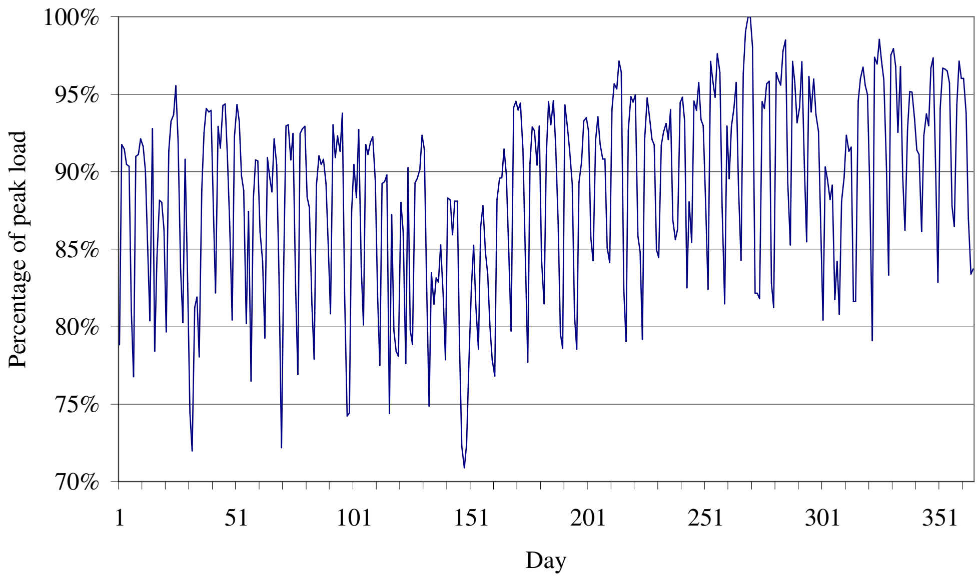


Figure 4-3: Daily Maximum Eemand of Sabah Electrical Grid from 1 September 2008 to 31 August 2009 (Note: 100% Load Corresponding to 704 MW)

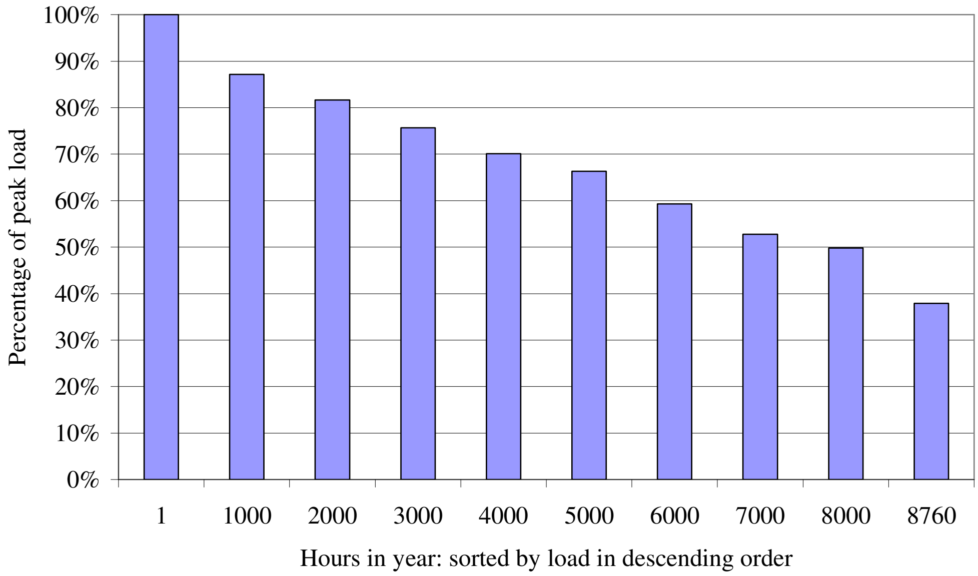


Figure 4-4: System Load Profile for Sabah Electrical Grid

Key cost related parameters of fuels and combustion technologies are obtained and verified from various sources as summarised in Table 4-2. The plant efficiencies, expected lifetime, capital cost and operation cost of the conventional technologies are obtained from the previous study of life power plants. For the advanced technologies, the costs are derived from the latest researches as noted in the footnotes of the table. The fuel costs are based on prevailing fuel cost in the market. A sensitive analysis has been included in the later section of this thesis to study the impact of increasing fuel prices.

Table 4-2: Key Parameters for Cost Analysis in LEAP

No	Technology	Plant Life Time (Years)	Effi-ciency (%)	Capital cost (RM / kW)	Fuel cost[a] (RM / kWh output)	Fixed O&M cost (RM / kW / year)	Variable O&M cost (RM / GJ)
1	Hydro	50[b]	47[b]	12270[c]	0	173.25[b]	0.4200[b]
2	Diesel	20	31[b]	1200[c]	0.5100[d]	0[e]	6.0278[f]
3	Biomass	20[b]	33[b]	10762[b]	0[g]	27.30[b]	10.2200[b]
4	Open Cycle Gas	20[b]	28.7[b]	3600[c]	0.1272[h]	177.21[b]	1.9600[b]
5	Combined Cycle Gas	20[b]	45.2[b]	6000[c]	0.0808[h]	128.10[b]	2.2050[b]
6	Advanced Combined Cycle Gas – Class H	20[b]	60[b]	7820[i]	0.0608[h]	128.10[b]	2.2050[b]
7	Conventional PCC Coal	30[b]	33.15[b]	5167[c]	0.0664[j]	241.50[b]	2.5200[b]
8	Advanced Ultra-supercritical PCC Coal	30[b]	50[b]	8877[k]	0.0440[j]	235.25[b]	2.6250[b]
9	IGCC with CCS	20 [b]	33.9[b]	9983 [l]	0.0649 [j]	315.00 [b]	13.6500 [b]

[a] Fuel cost was computed separately and added to the LEAP analysis

[b] Data based on findings in (Rafaj and Kypreos, 2007)

[c] Cost computed based on SESB press release (SESB, 2009a, SESB, 2009b)

[d] Based on current subsidised diesel price of RM 1.70 per litre and average generator consumption of 0.3 litre per kWh output

[e] All O&M costs for diesel plant are lumped in the variable O&M cost

[f] Cost obtained from (Tyler et al., 2010)

[g] Zero fuel cost was assumed for the biomass plant as all the existing plants are small scale plants using the waste from palm oil processing factories.

[h] The fuel price is computed using subsidised gas price of RM 10.70 per MMbtu (Zuraimi, 2010) in Malaysia and the corresponding plant efficiency for the respective technology

[i] Additional USD 520 per kW based on previous research (Alicia, 2008) is added to the capital cost of a standard combined cycle gas plant of RM 6000 per kW. A foreign currency exchange rate of USD 1 = RM 3.50 applied for all calculation

[j] The fuel cost is computed based on 2009 Indonesian coal price of USD30.72 per ton for the coal grade of 4200 kCal/kg (PT. Coalindo Energy, 2009) and the corresponding plant efficiency of the technology.

[k] Additional USD 1060 per kW based on previous research (Alicia, 2008) is added to the capital cost of a conventional PCC coal plant of RM 6000 per kW

[l] Additional USD 316 per kW based on previous research (Rafaj and Kypreos, 2007) is added to the capital cost of a conventional PCC coal plant of RM 6000 per kW

The LEAP program in this study has been configured to dispatch the available plant capacity dynamically according to the hourly load profile, based on the following parameters:

- **Maximum availability**: The maximum plant factor of all power plants has been set to 80% in this study. This sets the upper limit of any power plant that can be dispatched.

- **Merit order**: The merit order determines the order in which plants are to be dispatched when the load increases, in ascending order. The following merit order was used:

  1. Hydro and biomass
  2. Coal plants
  3. Gas plants
  4. Diesel plants

As found in the previous chapter, the hydro plants in Sabah are enjoying a very high plant factor of more than 80%. Therefore, the hydro plants can be configured to cater for the base load as reflected in the above merit order. The biomass plants, being RE plants, are also a preferred source of energy. The above merit order of 1 is to ensure that both energy sources are to be utilised to the maximum.

The merit order of the coal plant is set 2, after the hydro and biomass because of the low generation cost. This is followed by the gas plant, which is able to respond fast to load changes and are suitable to meet the peak load.

The diesel plants are being phased out because of the high cost and high emission factor. They are assigned the lowest priority and are to be dispatched only when all other plant capacity is exhausted.

4.3.2 Scenario Planning

Various scenarios are designed to study the effectiveness of the advanced combustion technologies, taking into considerations the following factors: (i) The current electricity market, (ii) The current stage of advancement for each technology, and (iii) The typical adoption process of a new technology. First, a reference scenario is constructed based on the data from the current official projection. This is also known as the business-as-usual scenario. A second scenario is then constructed with the adoption of more advanced technologies which are commercially available with proven applications. As discussed in the previous section, these technologies include the high efficient coal and gas combustion technologies. The CCS technology is not included in the second scenario as it is relatively new, with a number of drawbacks as discussed in the earlier sections. Instead, it is included in the third scenario. The last scenario is created to study the retrofit approach. The new technologies are retrofit to the existing plants here, whereby additional cost will incur in the writing off of the existing equipment in the plants. This is different from the second and third scenarios, whereby new technologies are applied only in the green field plants

The four scenarios are described in detail in the following sections:

Scenario A (Reference): This is the reference scenario in which no effort was included to reduce the CO_2 emissions. All new gas and coal power plants to be procured after 2010 are assumed to have the national average efficiency of 33.15% and 45.2% respectively (Malaysia Energy Commission, 2007). Combined cycle gas power plant is assumed in this scenario as all the recent gas power plants installed in the recent years belong to this type.

Scenario B (Efficient): In this scenario, all the new gas and coal power plants to be procured after 2010 are assumed to be of the most efficient types available. Based on the discussion in Section 4.2, the coal power plant is to be the ultra-supercritical PCC type with a thermal efficiency of 50%. The gas power plant is to be based on the most advanced Class H turbine in combined cycle configuration to achieve the plant thermal efficiency of 60%.

Scenario C (B + CCS): In this scenario, the advanced combined cycle gas turbine power plant with the thermal efficiency of 60 % as per scenario B is assumed for all new gas plants to be installed after 2010. For the new coal power plants, CCS technology is to be adopted. As elaborated in Section 4.2, the CCS technology has been found to be more effective when used in conjunction with the IGCC technology. The overall thermal efficiency of the resulted IGCC-CCS plants is 33.9%.

Scenario D (C + Retrofit): In this scenario, the same advanced gas power plants and coal power plants are adopted for all the new plants after 2010. In addition, CCS is applied to all the new coal plants. With CCS, the calculation has taken into consideration the reduction of thermal efficiency of the coal plants from 50% to 33.9%. In addition, all gas power plants commissioned before 2010 are to be upgraded to increase their thermal efficiency to 60%. The timing of the upgrade is chosen to coincide with the time for major refurbishments of all the power plants. Generally, a power plant requires a major refurbishment once every 10 years (Alicia, 2008). The refurbishment exercise will not involve coal power plants because all coal power plants are commissioned after 2010.

4.4 Results

4.4.1 Financial Assessment

The annual power generation costs from LEAP for the four scenarios are plotted in Figure 4-5. The costs considered include annualised capital costs, fixed O&M costs, variable O&M costs and fuel costs. In the LEAP program, only the annualised capital costs for power plants added during the simulation period are taken into consideration. The capital costs of the existing power plants at the start of the simulation are not included in the calculation. In order to maintain consistency from the analysis of the unit generation cost for the various technologies, the annualised capital costs are computed and added manually in the graph for all existing power plants. It is noticed that the cumulative costs of scenarios A, B, C and D are RM 56.098, RM 58.508, RM 65.277 and RM 66.694 billion respectively. The annual generation cost for scenario D is the highest throughout the period, followed by scenario C, B and A.

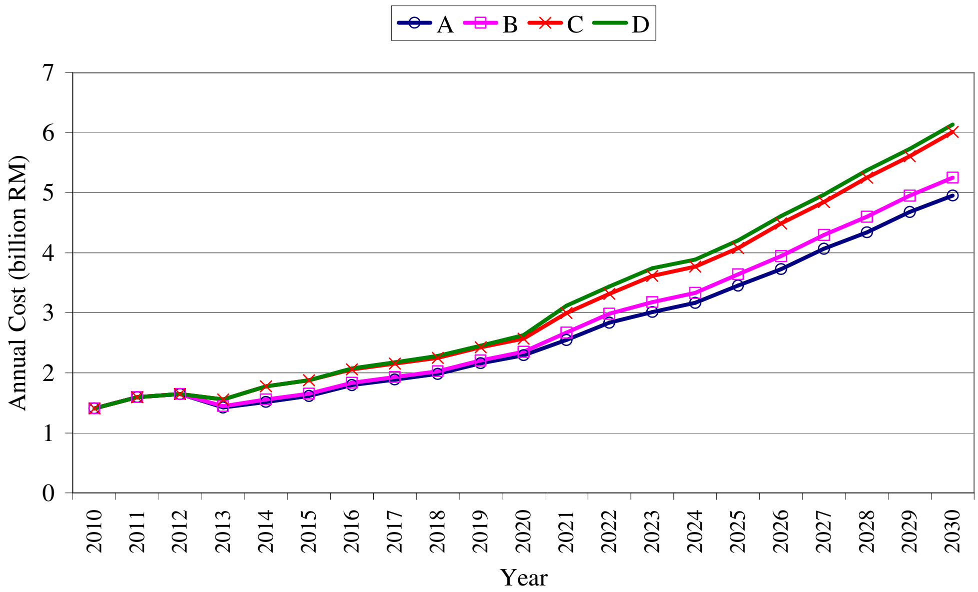


Figure 4-5: Annual Power Generation Costs for the 4 Scenarios

Figure 4-6 shows the computed average unit cost of electricity generation. It is consistent with the trend observed in Figure 4-5, whereby the generation cost is higher for the scenario with the more advanced technology. The generation cost in scenario D is the most expensive. It is also observed that the prices in 2013 drop for all the scenarios. This is due to the commissioning of a 300 MW coal plant in the same year. With the lower generation cost of a coal power plant, the average electricity cost in all the scenarios become lower with the commissioning of the plant. It is also noted that the cost in scenario A stabilises around RM 0.20 per kWh towards 2030.

The costs in scenarios B, C and D were RM 0.21, RM 0.24 and RM 0.245 per kWh respectively in 2030.

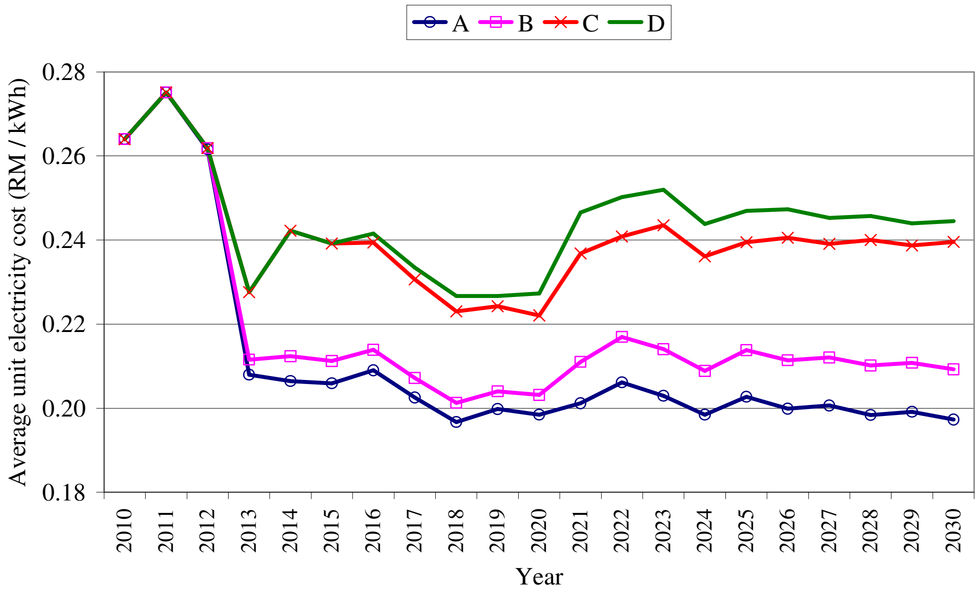


Figure 4-6: Average Unit Cost of Power Generation for the 4 Scenarios

In Figure 4-7, the results from the analysis of electricity generation cost encompassing annualised capital cost, fixed O&M cost, variable O&M cost and fuel cost are presented for the 4 scenarios. For the annualised capital cost, it is increasing as more efficient and cleaner technologies are adopted. The highest capital cost is RM 34.554 billion in scenario D, which is 34% higher than that of scenario A. For the fixed O&M cost, it is quite similar for all the four scenarios. The difference between the highest (scenario C) and the lowest (scenario B) is only 9%. For the variable O&M cost, it increases sharply from scenario B to scenario C by 127%. This is mainly due to the additional carbon capture, transport and storage cost required by the CCS technology. For the fuel cost, it decreases by 19% from scenarios A to B when the more efficient technology was adopted. With CCS included, the cost increases by 10% from scenarios B to C, due to the penalty in decreasing efficiency associated with this technology. There is a slight saving of 3% in the fuel cost from scenarios C to D, with the replacement of old gas power plants with more efficient equipment.

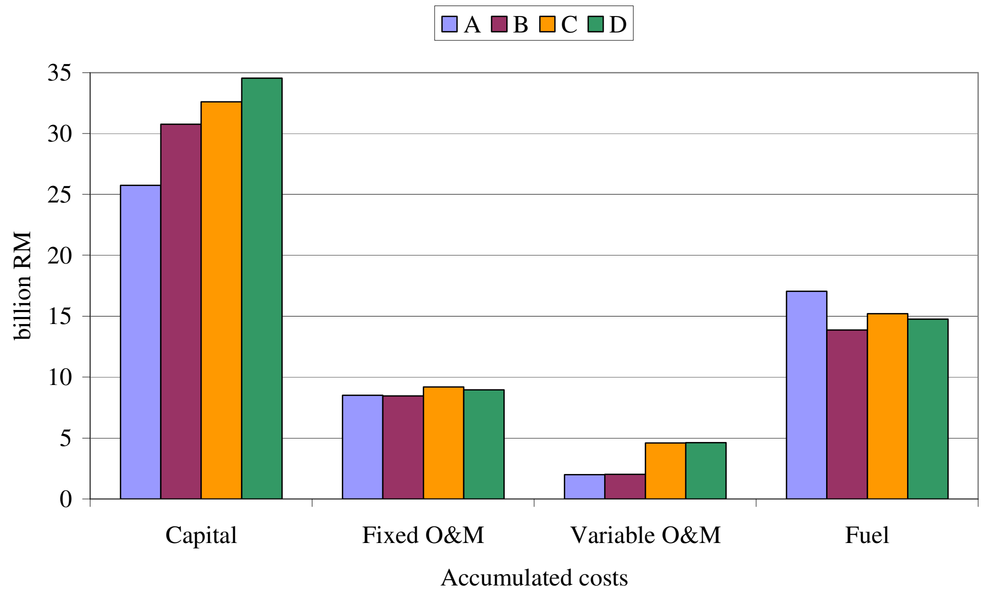


Figure 4-7: Accumulated (2010 to 2030) Cost for the 4 Scenarios Divided into Annualised Capital, Fixed O&M, Variable O&M and Fuel Costs

Based on the costs computed in LEAP, the unit costs of power generation using the various technologies are computed and presented in Figure 4-8. The costs for PV panel and wind power plant are computed based on findings from the previous chapter. The exceptionally high cost of wind farm is due to the low wind speed and hence a low effective plant factor of only 8.76% as discussed in the previous chapter (Koh and Lim, 2010). The effective plant factor for PV is 19%. For the other plants, a plant factor of 80% is adopted in this calculation. Other RE technologies are not included as Sabah is found to have poor endowment of other RE resources. From the analysis, it is concluded that the cost of electricity generated from renewable sources is at least 4 times higher than the most efficient and cleanest combustion technology discussed above. Among the advanced combustion technologies considered, the generation cost using IGCC with CCS is the highest at RM 0.28 per kWh. When compared to cost of PV and wind turbines of RM 1.56 and RM 1.60 respective, it is still substantially cheaper.

Among the gas power plants, the advanced class H gas plant with 60% efficiency is found to be cheaper to run, with a generation cost of RM 0.18 per kWh. This is lower compared to that of the conventional open cycle (RM 0.44) and combined cycle gas plant (RM 0.20). For the coal technology, the cost increased from RM 0.16 to RM 0.18 per kWh when advanced ultra-supercritical PCC plant is adopted. For the much cleaner IGCC with CCS plant, the electricity cost is RM 0.28 per kWh.

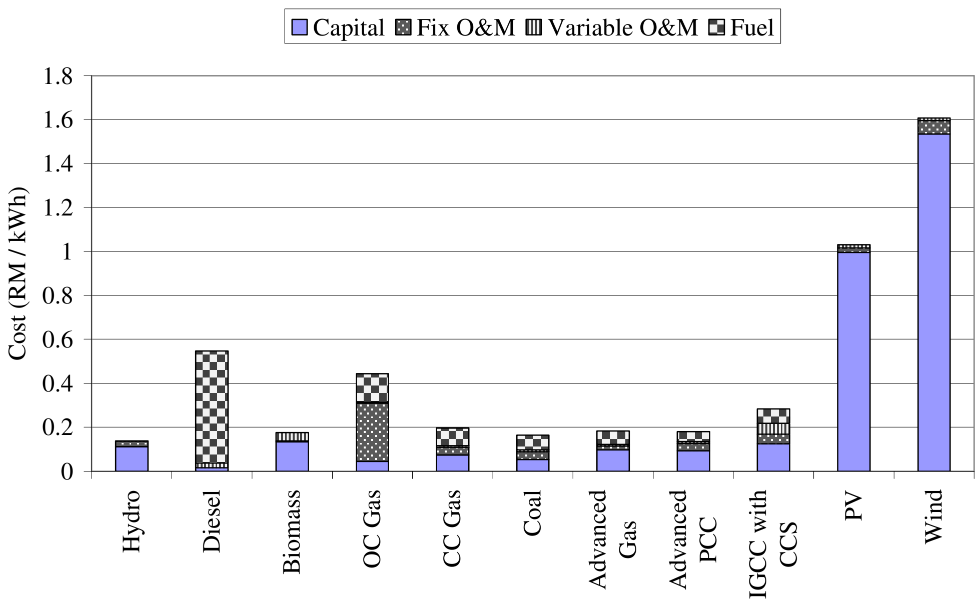


Figure 4-8: Average Cost of Electricity Generation Using Different Technologies

4.4.2 GHG Emission Assessment

With the LEAP energy model as outlined in Section 4.3, GHG emission analysis has been carried out. The IPCC tier 1 emission factors from the LEAP database are applied for all the power generation process except for the CCS technology. A CO_2 emission factor of 0.089 ton / MWh is adopted for IGCC-CCS technology as described in Section 4.2 (Othman et al., 2009). For the purpose of clarity, this CO_2 emission factor of 0.089 ton / MWh is based on the output energy. Using an overall plant thermal efficiency of 33.9% and a conversion factor of 1 TJ = 277.778 MWh, the equivalent CO_2 emission factor based on input energy is calculated to be 8.3808 ton / TJ.

The results from the LEAP analysis are plotted in Figure 4-9. For scenario A, the cumulative GHG emission from the Sabah power generation sector over the 20 years period is found to be 125 million ton CO_2-eq. In scenario B, with the adoption of advanced gas and coal combustion technologies, the cumulative emission is reduced to 93 million ton. This represents a 25% reduction in the GHG emission. In scenario C, when CCS technology is applied, the total GHG emission is further reduced to 56 million ton. This is a very significant reduction of 55% from scenario A or 40% from scenario B. In scenario D, with the additional retrofitting of old gas power plant with high efficiency equipment, the total emission is reduced further to 53 million ton. This represents a marginal improvement of 5% from scenario C. Overall, in scenario D, the GHG emission is reduced by 58% compared to scenario A.

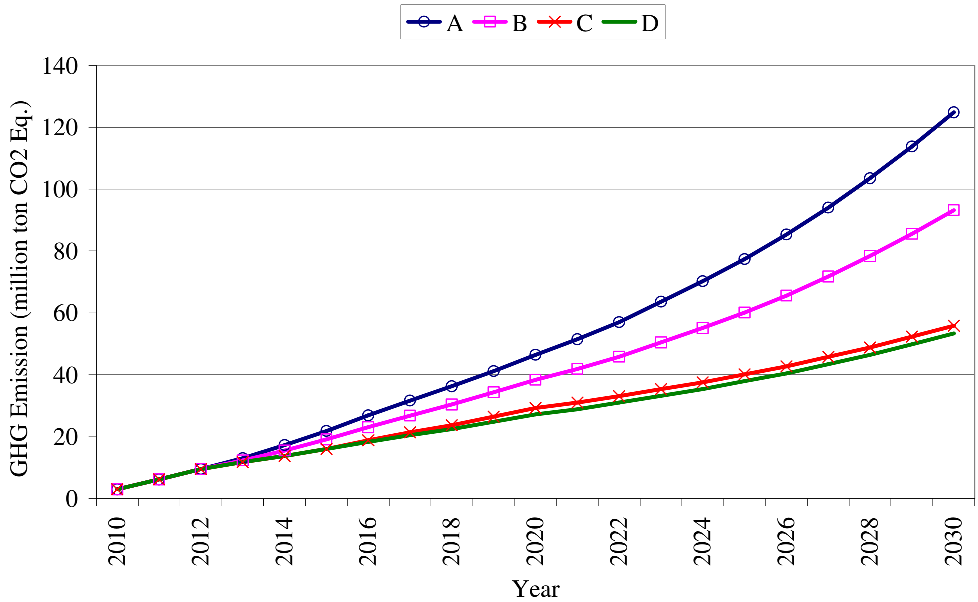


Figure 4-9: Cumulative CO_2 Equivalent GHG Emissions for the Power Generation Sector in Sabah from 2010 to 2030 for 4 Scenarios

With the projected GDP data, the GHG emission intensity is computed and plotted as in Figure 4-10. The GDP projection is based on data obtained from (IDS, 2007). The projection is interpolated from the data point (2010, RM 21.9 billion), (2015, RM 32.0 billion), (2020, RM 45.7 billion), (2025, RM 63.2 billion) and (2030, RM 87.4 billion). From Figure 4-10, the emission intensity of scenario A starts at 134 ton per million RM and ends at 127 ton per million RM. Compared to other scenarios, the variation is the smallest. The emission intensity reduces when hydro power plants are commissioned. The emission intensity increases with the increased utilization of the fossil fuel power plants as a result of the growing power demands and reducing reserve margin. In scenarios B, C and D, the emission intensity is lowered with the adoption of cleaner and more efficient power plants. In scenario B, the emission intensity is reduced by 34.1% in 2030 compared to 2010 level. The emission intensities in scenario C and D are reduced by 70.0% and 70.5%

respectively. There is only a small improvement from scenario C to D as the refurbished power plants only constituted a small percentage of the total power plant capacity.

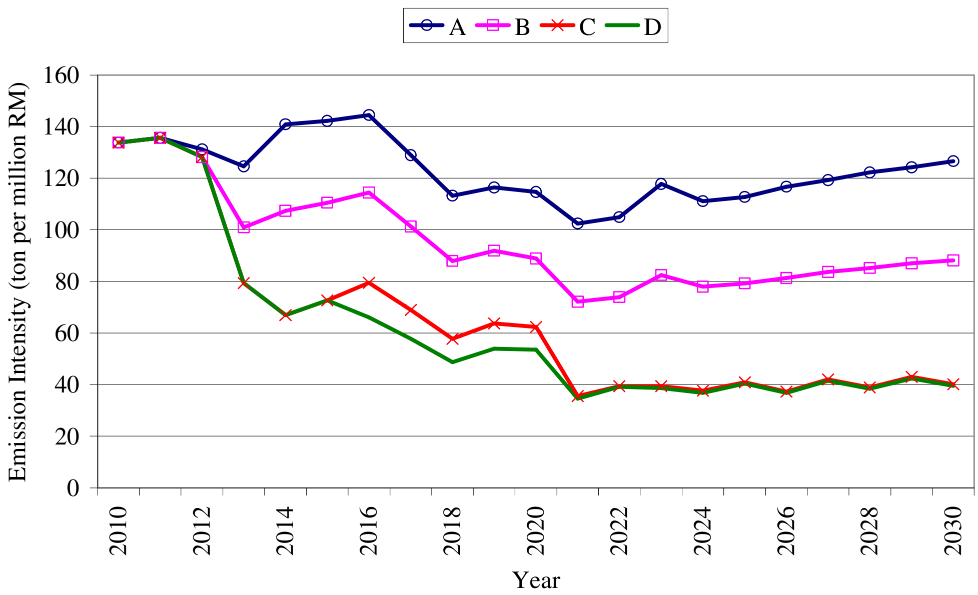


Figure 4-10: GHG Emission Intensities for Power Generation Sector in Sabah

By type of power plants, the GHG emissions of coal and gas power plants are computed and presented in Figure 4-11 and Figure 4-12 respectively. From the analysis, it is noticed that the cumulative GHG emissions of the coal power plants is reduced from 66 million ton in scenario A to 6 million ton in scenario C. This represents a 91% reduction. The curves for scenario C and scenario D in Figure 4-11 are exactly the same as there is no coal plant involved in the refurbishment option.

For the gas power plants, the GHG emission is reduced from 54 million ton in scenario A to 42 million ton in scenario D. This represents a

22% reduction in GHG emission. It is also noted that the curves for scenario B and scenario C in Figure 4-12 are the same as there was no difference in the gas power plant technologies adopted in these two scenarios.

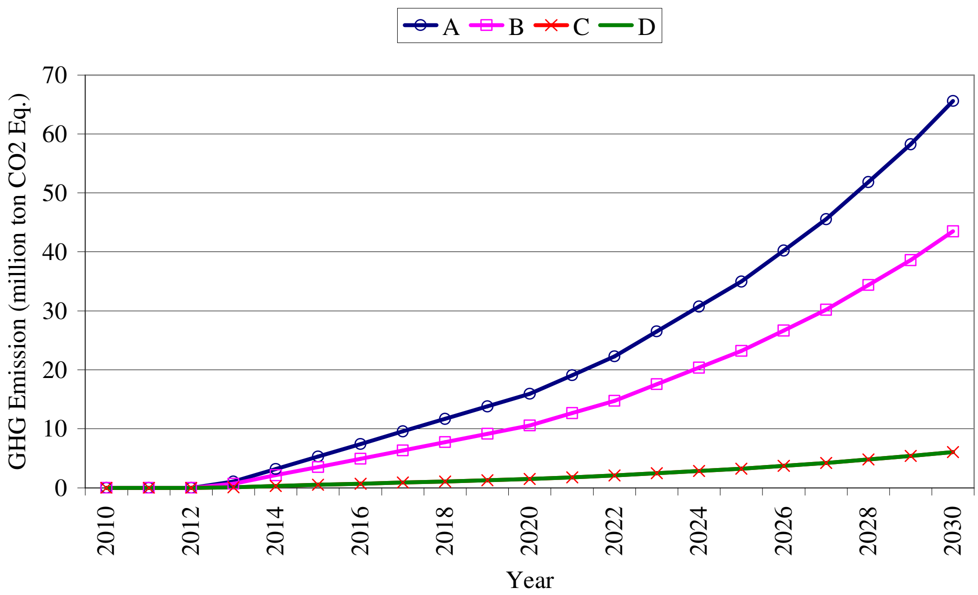


Figure 4-11: Cumulative GHG Emissions of Coal Power Plants in Sabah

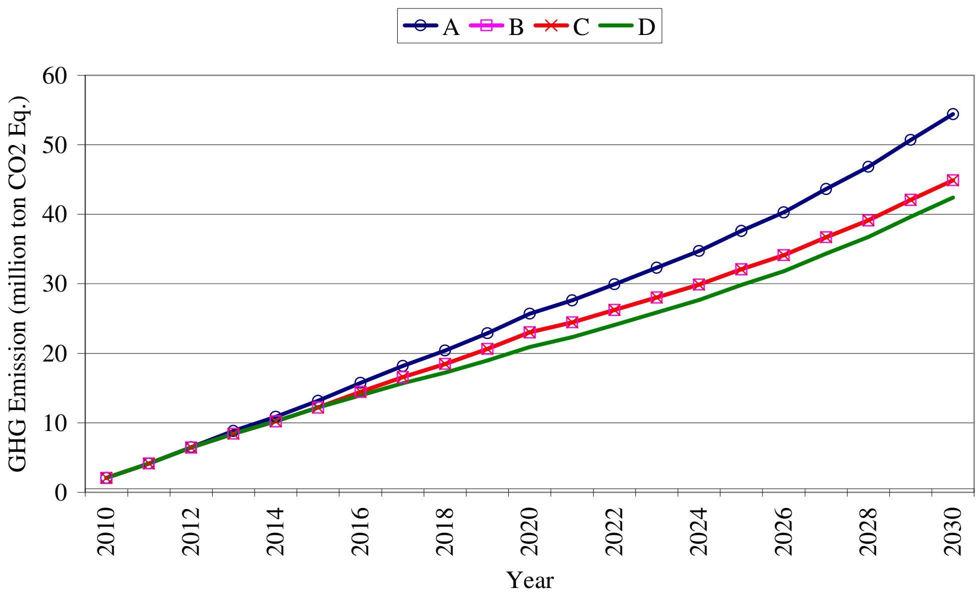


Figure 4-12: Cumulative GHG Emissions of Gas Power Plants in Sabah

4.5 Sensitivity Analysis

4.5.1 Impact of Coal Price Increase

Coal is a competitive alternative to oil and the coal price has fluctuated and increased in tandem with the oil price. The coal price had increased by more than 300% in the last 10 years (Index Mundi, 2010). The impact of increasing coal price on the generation costs using different coal power plant technologies were computed and plotted in Figure 4-13. From the reference price of USD 30.72 per ton of coal, an increase of 0% to 300% was applied in this study. At the reference price based on the current coal price, the generation cost of conventional coal plants is found to be the cheapest at RM 0.1635 per kWh, followed by that of ultra-supercritical PCC at RM 0.1790 per kWh and IGCC plants with CCS at RM 0.2832 per kWh. With a 70% increase in coal price, the costs of conventional coal plant and ultra-supercritical PCC plants are equal at RM 0.2099 per kWh. With an increase of more than 70% in coal price, the cost of ultra-supercritical PCC plants becomes the lowest among the three technologies. The generation cost of the IGCC plants with CCS remains the highest throughout the range in this sensitivity study.

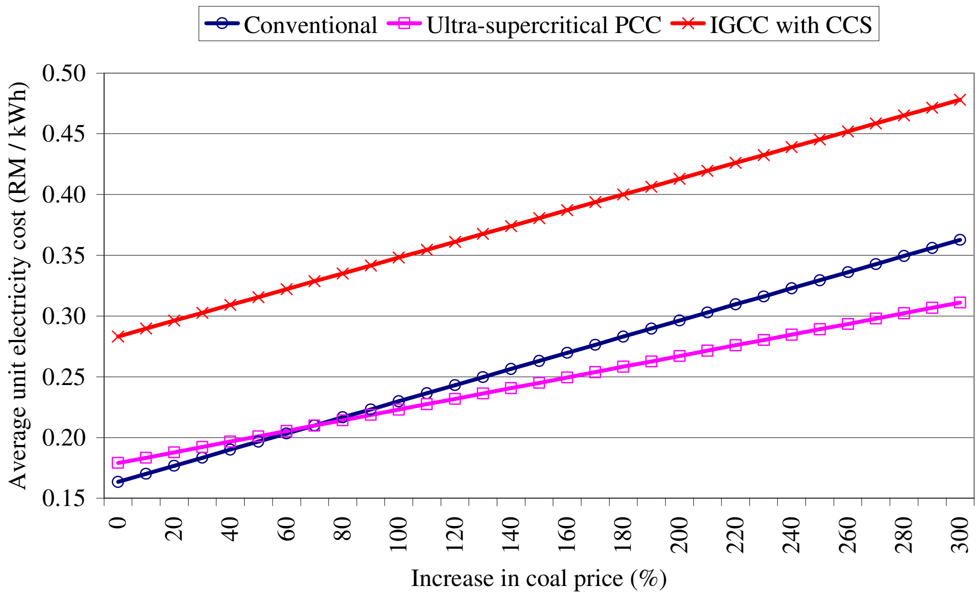


Figure 4-13: Impact of Increasing Coal Price on the Electricity Generation Cost using Different Coal Power Plant Technologies

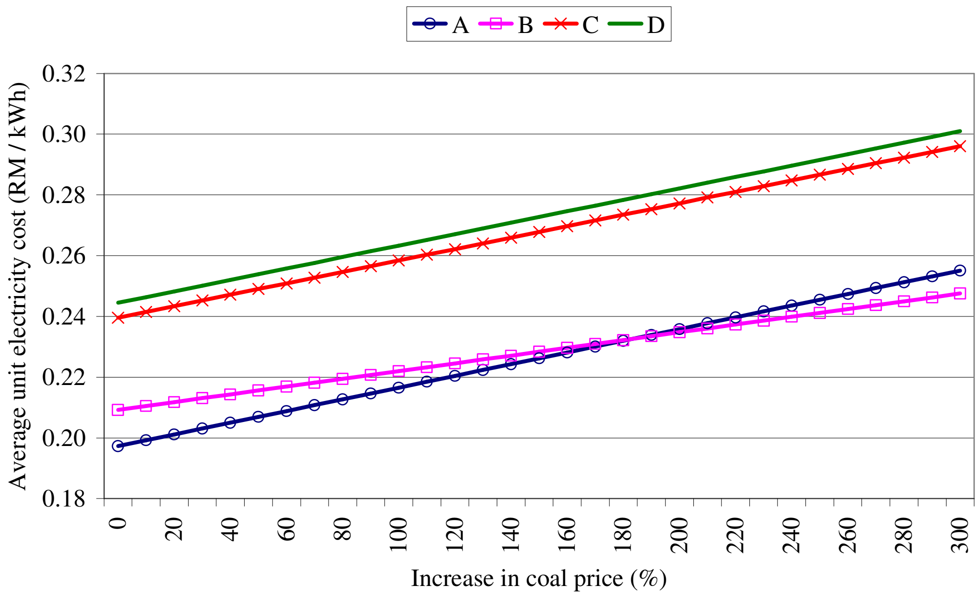


Figure 4-14: Impact of Increasing Coal Price on the Electricity Generation Cost Based on the Fuel Mixes in the 4 Scenarios

The variation in the coal price is then applied to the fuel mixes in 2030 based on the above four scenarios. The average electricity generation costs are computed for each scenario as shown in Figure 4-14. Based on the current coal price, it is observed from the graph that the generation cost in scenario A is the lowest, followed by that in scenarios B, C and D in ascending order. With the increase in coal price, the curve representing scenario B intersects at 190% increase before it undercuts that of scenario A. Scenario B becomes the cheapest option from this point onwards, followed by scenario A, C and D.

4.5.2 Impact of Gas Price Increase

The impact of the increase in natural gas price is then studied. In Malaysia, the natural gas is heavily subsidized in the power generation sector. The price of natural gas for power sector is fixed at RM 10.70 per MMBTU (million BTU), compared to the market price of RM 41.16 per MMBTU in December 2009 (Zuraimi, 2010). In the event that the subsidy were to be withdrawn, the fuel cost for gas power plants would increase by 285%. The impact of increased natural gas price on the generation costs using different gas power plant technologies are computed and plotted in Figure 4-15. From the reference price of RM 10.70 per MMBTU, an increase of 0% to 300% is applied in this study. At the reference price based on the current natural gas price, the generation cost of advanced gas plants is found to be the cheapest at RM 0.1826 per kWh, followed by that of conventional combined cycle gas plant at RM 0.1969 per kWh and open cycle plants at RM 0.4432 per kWh. It is interesting to note that, despite the much higher capital cost, the generation cost of the advanced class H gas plant is the lowest among all the other technologies. The order in terms of unit electricity generation cost remained in this order throughout the range of this sensitivity study. With a 285% increase in natural gas price if the subsidy were to be removed, the generation cost of advanced gas plants will be still the cheapest at RM 0.3560 per kWh, followed by that of conventional combined cycle gas plant at RM 0.4271 per kWh and open cycle plants at RM 0.8057 per kWh.

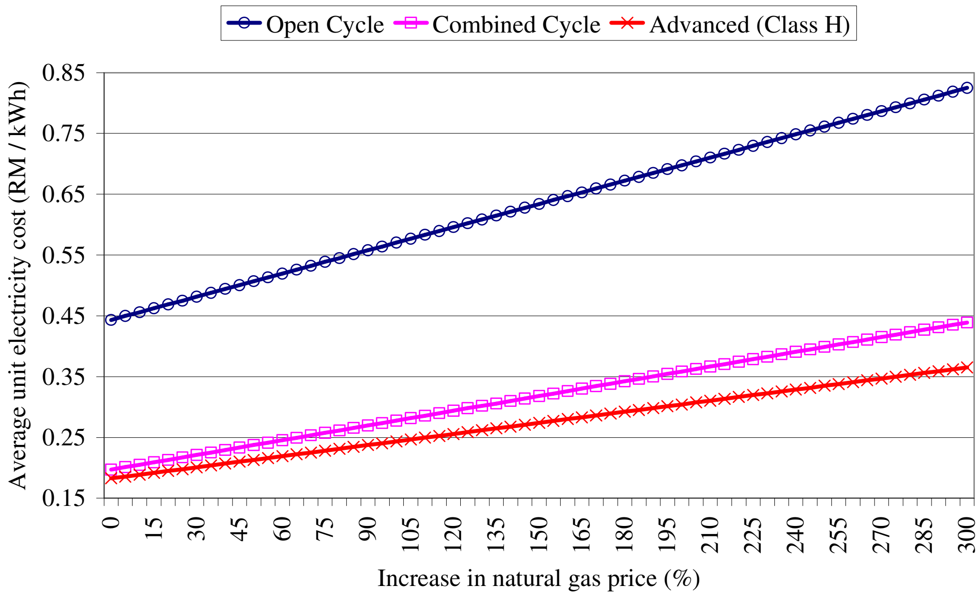


Figure 4-15: Impact of Increasing Natural Gas Price on the Electricity Generation Cost Using Different Gas Power Plant Technologies

The variation in the natural gas price is again applied to the fuel mixes in 2030 based on the four scenarios. The average unit electricity generation costs are computed for each scenario as shown in Figure 4-16. Based on the current gas price, it is observed from the graph that the generation cost in scenario A is the lowest, followed by that in scenarios B, C and D in ascending order. With the increase in gas price, the curve representing scenario B intersects curve A at 180% increase before undercutting that of scenario A. Scenario B becomes the cheapest option from this point onwards, followed by scenarios A, C and D. It is noted that, at the current natural gas price, the unit electricity cost in scenario B is still higher than that in scenario A, despite the lower generation cost of the advanced class H gas power plant. This was partly caused by the lower average plant factor of the advanced gas plant of 47%. Therefore, the saving in fuel cost is not sufficient to offset the much higher annualised capital cost of the advanced gas plant. Also, scenario B had adopted the ultra-supercritical PCC coal plant which had a higher generation cost compared to the conventional coal plant as shown in Figure 4-13.

From the above sensitivity studies, it can be concluded that scenario A is most sensitive to the increase in fuel prices. For an increase of 300% in coal and gas prices, the average electricity cost will increase by 29% and 41% respectively. Scenario B is most resilient to the increase in coal price. Moreover, it is observed that the electricity cost increased by a mere 18% when the coal price is increased by 300%. This is followed by the 23% and 24% increase in scenarios D and C respectively. With respect to the gas price increase, scenario D is most resilient. The electricity cost increased by 24%, 26% and 29% respectively in scenarios D, C and B, when the gas price is increased by 300%. It can be concluded from the above that all the scenarios with advanced combustion technology are more resilient to the increase in fuel price. These scenarios are more desirable to ensure a more stable electricity price in the long term.

The above sensitivity analysis can also be used to assess the impact of carbon tax. With a carbon tax of 3.5% on the fossil fuel as implemented in Costa Rica (Meyer, 2010), it will effectively increase the coal and gas price by

3.5% to make the high efficient combustion technologies more attractive. Similarly, the carbon tax of INR 50 (USD 1.11) (Pearson, 2010) per ton of coal in India will increase the effective coal price by 3.6%.

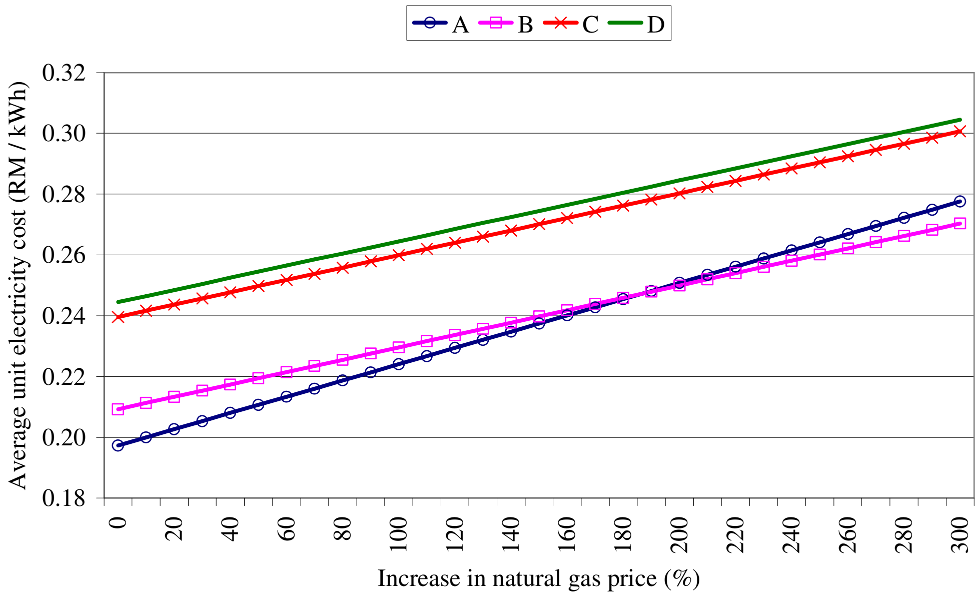


Figure 4-16: Impact of Increasing Natural Gas Price on the Electricity Generation Cost Based on the Fuel Mixes in the 4 Scenarios

4.5.3 Impact of Reduced Electricity Demand

With the current emphasis of EE measures, it is anticipated that the actual electricity demand of a country may be lower than the projection. In such a scenario, the effectiveness and cost attractiveness of a particular option may differ from the results presented above due to the lower electricity demand. Therefore, a sensitivity analysis is carried out to evaluate the impact of lower electricity demand on the effectiveness of the advanced combustion technologies in GHG emission and electricity generation cost. In this study, the projected annual electricity demand is reduced by an amount for between 0% and 40%. The LEAP model is re-run for each demand curve to analysis the impact on each scenario. The GHG emission and total generation cost are then computed from the LEAP outputs.

In Figure 4-17, the results from the study are summarised. The impact of reduced electricity demand on the GHG emission reduction in scenarios B, C and D is plotted with respect to scenario A. It is observed that the performance of all the 3 scenarios is quite consistent when the annual electricity demand was reduced by up to 40%. In scenario B, the saving in GHG emission remains consistently in the range of 25% to 28%, when the projected electricity demand is reduced by up to 40%. In scenario C, the GHG reduction also consistently falls between 55% and 62%. In scenario D, it is between 57% and 63%.

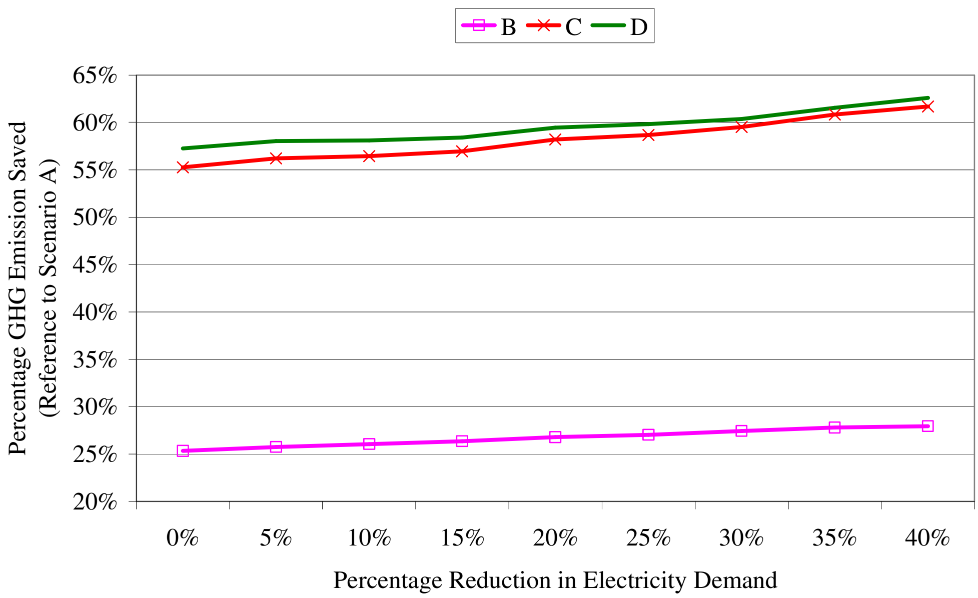


Figure 4-17: Impact of Reduced Electricity Demand on the GHG Emission Reduction in Scenario B, C and D with Respect to Scenario A

The results from the study on the impact of reduced electricity demand on the electricity generation cost based on the fuel mixes in the 4 scenarios is summarised in Figure 4-18. It is observed that the unit generation costs for all the 4 scenarios varied within a narrow band when the electricity demand is reduced by up to 40%. The cost in scenario A varies between RM 0.21 to RM 0.23 per kWh. In scenarios B, C and D, it is between RM 0.22 and RM 0.23; RM 0.24 and RM 0.26; and RM 0.24 and RM 0.26 per kWh respectively.

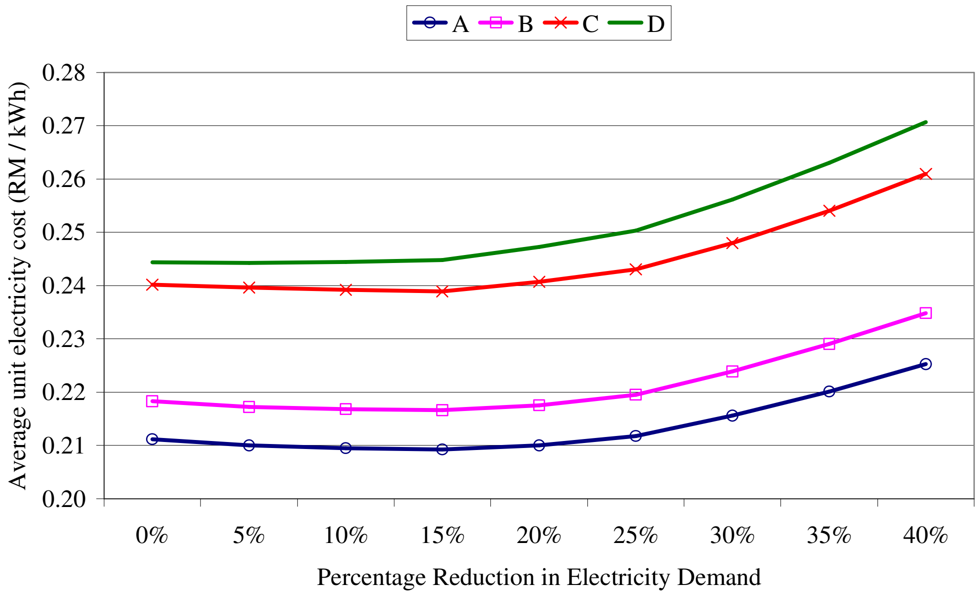


Figure 4-18: Impact of Reduced Electricity Demand on the Electricity Generation Cost Based on the Fuel Mixes in the 4 Scenarios

From the above analysis in Figure 4-17 and Figure 4-18, it can be concluded that the performance of the advanced combustion technology in terms of GHG emission reduction and generation cost are consistent, despite the reduction in projected annual electricity demand by up to 40%. The marginal increment of the generation cost can be attributed to the lower average plant factors and hence higher capital cost being attributed to each unit of electricity generated.

4.5.4 Impact of Reduced PV Cost

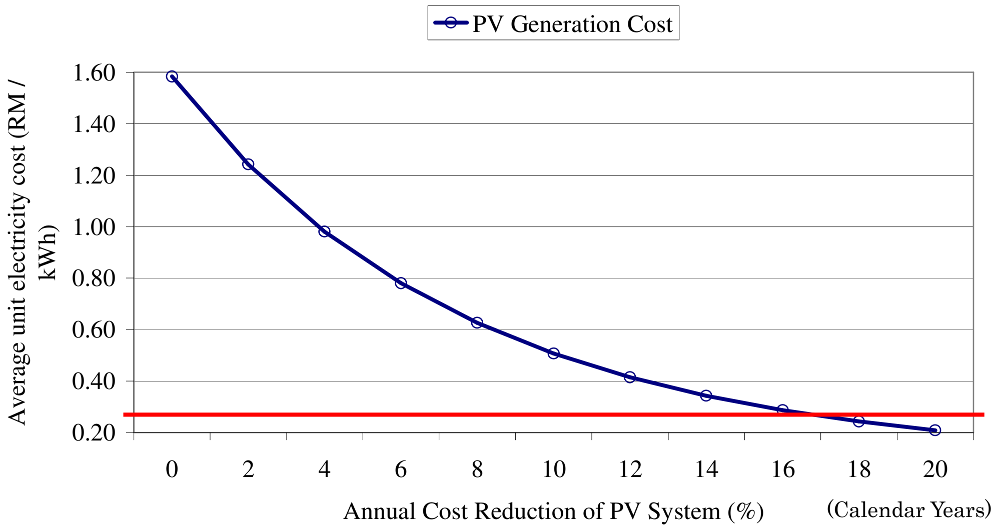


Figure 4-19: Impact of Reduced PV System Capital Cost on the Electricity Generation Cost of PV System Benchmark with Current Retail Electricity Price

Based on the trend of PV system (Key and Peterson, 2009), the PV system cost has been reduced by 3.6% per year, in average, for the past 10 years. A sensitivity study is carried out to investigate the impact of the reduced price on electricity generation price. PV panel is added to the fuel mix in scenario A. The target set in the Renewable Energy Policy (Badriyah, 2010) for PV penetration of 3.63% by 2030 is adopted. The PV panel capacity is ramped up from 0% in 2010 to the 3.63% in 2030 in this scenario. The capital cost of PV system is set at RM 18,000 per kW (Lim et al., 2008), and reduced at a constant annual rate of between 0% and 20%. The result is presented in Figure 4-19. At 3.6% annual reduction in price, the average PV generation cost is still high at RM 0.67 per kWh. To be competitive, the capital cost will need to be reduced at an annual rate of 14% to achieve a generation cost of RM 0.23 per kWh. This will result in the PV system cost being reduced to RM 49 per kW in 2030.

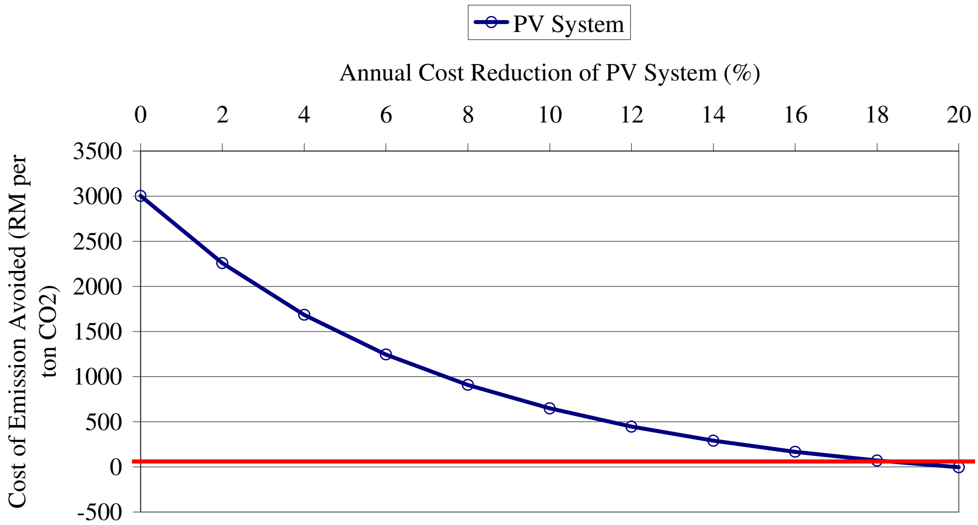


Figure 4-20: Impact of Reduced PV System Capital Cost on the Cost of Emission Avoided

The cost of emission avoided is also calculated and shown in Figure 4-20. At the rate of 3.6% annual price reduction of the PV system, the cost of emission avoided is computed to be RM 1012 per ton CO_2. It is still expensive compared to the cost of RM 60.67 per ton CO_2 in Scenario B. In order to achieve the cost competitiveness as in Scenario B, the cost of PV system will need to be reduced by an average of 14% per year.

4.6 Summary of Results

Based on the results obtained above, the effectiveness of the advanced combustion technologies in addressing the climate change can be summarised from perspectives of technology, GHG emission reduction, cost, and national and international energy policies.

4.6.1 Technology

As found in Section 4.2, the advanced combustion technology applied in scenario B is based on commercially available products, with proven applications. CCS in scenarios C and D is also technologically proven although there are still some practical limitations to be overcome.

4.6.2 GHG Emission Reduction

From the above analysis, the advanced combustion technology adopted in scenario B reduces the GHG emission intensity by 34% in 2030. With the CCS technology in scenario C, the reduction is increased to 70%, surpassing the 40% target committed by Malaysia. In scenario D, with the refurbishment of old power plants, the reduction was improved marginally to 70.5%.

In absolute term, the total GHG emission reduction in scenario B is 32 million ton CO_2-eq and that in scenario C is 69 million ton CO_2-eq. In comparison, the 17% RE target (Badriyah, 2010) in the fuel mix by 2030 from the RE policy will result in the GHG emission reduction of only 22.56 million ton CO_2-eq. To meet the target 40% reduction consistently over the 20 year period, a reduction of 53 million ton CO_2-eq. is required. The above reductions is computed based on the following data:

- In the business as usual scenario in scenario A, the total GHG emission for Sabah power industry is 132 million ton CO_2-eq from 2010 to 2030
- Assuming 17% of the output is to be from the renewable sources with zero GHG emission, the saving in GHG emission will be 21 million ton CO_2-eq.

4.6.3 Cost

From Figure 4-8, it is found that the total cost of electricity generation using the advanced combustion technologies is much lower than the wind and solar technologies. The cost of IGCC with CCS is RM 0.2831 per kWh and that of advanced class H gas power plant is RM 0.1826. In comparison, the current wholesale rate of electricity in Sabah is RM 0.206 per kWh and the average retail rate is RM 0.253 per kWh (Malaysia Energy Commission, 2007). The total generation cost of the advanced gas plant is lower than the wholesale rate and hence it is commercially viable even without any incentives from the government. The total generation cost of IGCC with CCS plant is, however, higher than both the wholesale and retail price of electricity in Sabah. Comparing with the RE options, the electricity costs using PV and wind turbine are RM 1.0307 and RM 1.6064 respectively.

The cost of GHG emission avoided is computed and given in Table 4-3. From the table, it is found that the costs are between RM 60.67 and RM 126.08 per ton of GHG emission avoided.

For PV technology, the cost of emission avoided will be reduced from RM 1,793 to RM 1,012 per ton if the capital cost of the system is reduced over the next 20 years at a constant annual rate of 3.6%, in consistent with the trend in the past 10 years. To be as competitive as scenario B, the capital cost of PV will need to be reduced at an annual rate of 14%.

Table 4-3: Cost of GHG emission avoided

No	Description	Average electricity cost (RM / kWh)	Total GHG emission, CO_2 eq. (mil ton CO_2 eq.)	Total electricity output (GWh)	Average emission Factor, CO_2 eq. (g / kWh)	Cost of emission avoided[a] (RM / ton)
1	Scenario A (reference)	0.2112	125	273,424	457.165	-
2	Scenario B	0.2183	93	273,424	340.131	60.67
3	Scenario C	0.2402	56	273,424	204.810	114.92
4	Scenario D	0.2444	53	273,424	193.838	126.08
5	PV	1.0307	-	-	0.000	1,949.55
6	Wind	1.6064	-	-	0.000	3,051.85

Note:

a In computing the cost of emission avoided, the incremental cost of the option is first computed with respect to the reference scenario (scenario A). For example, the incremental cost for scenario B is RM 0.0071 per kWh. The average GHG emission factor is then computed by dividing the total emission by the total electricity output. The avoided emission is computed with reference to the reference scenario again. For scenario B, it is 117.034 g / kWh. The cost of emission avoided can be obtained by dividing the incremental cost (RM 0.0071 per kWh) by the emission avoided (117.034 g / kWh).

4.7 Conclusion

The advanced combustion technology satisfies the objectives set out in the NEP for fuel diversification, low environmental impact, cost effectiveness and fuel security. It can be implemented in a large capacity to ensure adequate supply. The proven technology will be able to ensure the stability of the supply. It is cost effective in comparison to the RE technology. The cost is only marginally higher than that of the conventional power plant technology. It can also reduce the GHG emission significantly, consistent to the clean utilization and environmental objectives. The technology also has great fuel input flexibility to satisfy the fuel diversification objective. It can accept coal, natural gas, oil, biomass and other fuel as feedstock. Furthermore, it is more energy efficient and hence it can extend the usage of our limited natural gas reserve and reduce the import of coal to enhance our national energy security.

As an illustration, based on the cost of emission avoided for scenario B computed above, a budget of RM 10 million will result in GHG emission reduction of 164,826 ton CO_2-eq. With the equivalent amount spent on PV technology, the reduction will be 5,129 tons CO_2-eq, or a mere 3% of that in scenario B. This means that the CO_2 emission reduction achieved with advanced combustion technology is more than 30 times of that using PV technology, with the same amount of money spent.

Therefore, the advanced combustion technologies may play a significant role in addressing the climate change issue. It is effective to reduce the GHG emission in this case study. Furthermore, it is more cost effective. The incremental cost in scenario B is well within the acceptable level based on the current electricity market in Sabah. As computed above, the cost of emission avoided is RM 60.67 per ton CO_2-eq. At the European Climate Exchange, CO_2 is currently being traded for about 12.70 Euro (RM50.80)

(European Climate Exchange, 2010). Hence, more than 80% of the additional cost may be financed through carbon trading, subject to meeting the criteria of CDM or other similar mechanism.

The density of RE resource has a significant impact on the generation cost. The low wind speed in Sabah, for example, has resulted in extremely high cost of wind turbine technology in electricity generation. Therefore, for countries with low RE resource, the advanced combustion technology will be a very competitive and effective alternative. It can be a more viable option for the policy makers to consider under such circumstances.

CHAPTER 5

NUCLEAR ENERGY

5.1 Introduction

As discuss in the previous chapters, Malaysia is actively looking for alternative sources of energy, consistent with the fuel diversification objective of the NEP. Nuclear power is one of the main sources of energy for power generation and there is a growing interest of the government in nuclear power. It is being investigated as a potential solution to address the key issues in the power industry, which include the rapidly rising and volatile fossil fuels prices, concerns about the security of energy supplies and global climate changes. The government of Malaysia announced at the end of 2010 that two nuclear power plants of 1000 MW each would be built, with the first plan to be commissioned by 2021 (Ministry of Enegry Green Technology and Water Malaysia, 2010).

Nuclear power does not generate GHG. However, nuclear power is among the most controversial means in power generation. Although nuclear power is a well-established technology for generating electricity, it is not supported by many environmental groups and ordinary citizens because of the potential hazards of reactor meltdowns and operational issues related to nuclear disposal. To assess the potential of nuclear power, its key advantage of being a secure and largely carbon-free alternative to fossil fuels must be weighed against its technical risks.

In this chapter, the debate between the proponents and opponents of nuclear power is first studied to understand its strengths and weaknesses. Then, the technology and the design of a nuclear power plant are studied in-depth to understand its operational characteristics. Subsequently, the cost of power generation for a nuclear power plant is studied and this is followed by the analysis in GHG emission reduction potential of the technology. Sensitivity analysis is carried to study its competitiveness in terms of generation cost as compared to that of other energy options. The chapter is then concluded based on these findings.

5.2 The "Debate" on Nuclear Power

The proponents of nuclear power believe that nuclear power plants can play a major role in addressing the energy need of the world because of its advantages in energy security, lower fuel cost, and low GHG emission. The opponents, however, argue that the technology is not mature for wide implementation because of its un-resolved issue in containment of nuclear accidents and disposal of nuclear waste. These arguments are investigated in details below.

5.2.1 Advantages of Nuclear Energy

Energy security: Nuclear fuel is of high energy density. Therefore, it is possible to stockpile sufficient imported uranium to operate the nuclear supply systems for many years. This will be able to shield a country from any nuclear fuel supply interruptions. Although other energy resources, such as coal, can also be stockpiled, the cost of doing so will be much higher because of the relatively lower energy density. In addition, uranium will not degrade in storage.

Stability of Energy Price: The cost of electricity generation plants using nuclear power consists of four major components: capital costs, operations and maintenance costs, fuel costs and decommissioning costs. The first three cost components are common for all power plants while the decommissioning cost is negligible for other power plants and specific only to nuclear power plant. The decommissioning cost includes decommissioning of the old plants and long-term management and disposal of radioactive waste. Among the cost components, annual capital charges are fixed. Operation, maintenance and decommissioning costs are consistent and predictable. The major fluctuation is from the fuel costs, which may create major electricity cost volatility for other power plants. However, the cost of nuclear fuel consists of very small percentage in the overall cost of nuclear generation. A doubling in the price of uranium will cause only a 5-6 % increase in the total cost of generation. Hence, a less volatile energy cost of the country could be achieved. A detailed analysis on costs has been carried out as presented in the later part of this chapter.

Emission Reduction: Nuclear power has lower GHG emission compared to fossil fuel power. In addition, nuclear power plants emit little airborne pollutants. Only a small amount of radioactive gases is regularly emitted under controlled conditions. Strict regulations imposed and supervised by regulatory authorities are in place to ensure that there will be no significant threat to plant workers or surrounding populations. In comparison, the main emission from fossil fuels plants include particulate matter, sulfur dioxide, nitrogen oxides and a variety of heavy metals such as mercury. These emissions will have significant negative effects to human health and the environment.

5.2.2 Disadvantages of Nuclear Energy

Nuclear Accidents: A unique risk of nuclear plants is nuclear accidents whereby public may be exposed to unplanned and excessive radiation. Potentially, accidents may happen at all phases of the nuclear cycle. By design, under normal operation, the level of radiation is limited below a limit that will not impose any health and safety risks to the public and plant workers. However, when an accident happens, a significant portion of the radioactive inventory in the core of a nuclear reactor may be released into the atmosphere. Current technology can only plan and design the facility to prevent such accidents from happening. Once it happens, the effect from the radioactive material cannot be reversed with our current technology. In the history of nuclear power, such accidents did happen. The major accidents include the

Chernobyl disaster and the recent Fukushima Nuclear Power Plant melt down on March 11, 2011.

Nuclear Waste: The nuclear fuel cycle produces various radioactive wastes. Certain nuclear waste, such as the spent fuel and other long-lived waste can remain hazardous to human and the environment for hundreds of thousands of years. The current method of handling the nuclear wastes is to store them away for as long as they are hazardous. Typically, they are put in glass or ceramic containers, further encased in corrosion-resistant containers and isolated geologically from populated areas. There are current researches being carried out to use various methods such as the accelerator-driven systems to reduce the volume and radioactive toxicity of nuclear waste. However, the waste cannot be completely removed. Hence, the sustainability and long term safety of the storage method remains as one of the key contentious issue.

Proliferation of Nuclear Weapon Concern: Plutonium is one of the materials in the nuclear waste produced in the nuclear power plant. Since plutonium is a key material for nuclear weapon, the opponents of nuclear power plants argue that it may become a convenient source of material for producing nuclear weapon. Without the nuclear power plants, the plutonium can be controlled and make inaccessible from the undesired parties. Hence, the nuclear power plant will indirectly impede the effort to stop the nuclear weapon from proliferating.

Locally, the Malaysian government has an even bigger challenge to convince the public on the ability to handle the associated risks of a nuclear power. The public is very reluctant to accept the nuclear power plants because of the poor track record of the government in handling such cases. One such incidence is the rare earth plant disaster in Bukit Merah. In 1992, a rare earth refinery plant owned and operated by a Japanese company called Mitsubishi Chemical was closed down at Bukit Merah, north-central Malaysia. The residents had objected to the operation of the plant because the radioactive leaks from the refinery process of the plant. Several birth defects and eight leukemia cases had been reported in the nearby community of 11,000. The birth defects and leukemia cases happened during the plant operation. Seven of the leukemia victims had died. Mitsubishi Chemical had to spend about USD 100 million to clean up the site after the closure (Keith, 28th March 2011). In addition, it donated USD 164,000.00 to the community's school. The cleanup is one of Asia's largest radioactive waste cleanup sites and has created a negative psychological impact on the public.

This hostile public sentiment towards projects with radioactive risks is still present until today as evidenced in the Lynas incidence. Recently, the government has approved a new rare earth refinery plant to operate in Gebeng, north-eastern Malaysia. This new plant is owned by the giant Australian mining company Lynas to refine low radioactive ore from the Mount Weld mine deep in the Australian desert. The ore will be transported from Australia to Malaysia by container ship for refinery. The waste from the refinery plant contains thorium which is radioactive. The public is strongly against the plant due to the potential radioactive risk from the process and the lack of long term management plan of the radioactive waste. As a result, the operation of the plant is halted (Mazwin, 20 March 2012). Many dialogues and forums among the public, government officers, international experts and Lynas personnel have been held to address the issue. However, the deadlock is unresolved until today.

5.3 Nuclear Power Plant Technology

Nuclear power plants generate electricity using the thermal energy released from nuclear fission. Typically, the thermal energy is used to generate steam. Subsequently, the steam will drive the steam turbine, which is connected to a generator to generate electricity.

5.3.1 Nuclear Fission

Nuclear fission is a chain reaction whereby a large atomic nucleus absorbs a nuetron and split into two or more nuclei as shown in Figure 5-1. The large atom that is capable of sustaining chain reaction of nuclear fission is called the fissile material. The common fissile materials include uranium-235 and plutonium-239. In the fission process, kinetic energy, gamma radiation and free neutrons are released. The kinetic energy of the nuclei is converted to thermal energy when these nuclei collide with other atoms. The gamma radiation is absorbed by the reactor and also converted into heat. The free neutrons are later absorbed by other fissile nucleus and trigger the subsequent fission reaction. This results in a sustainable chain fission reaction to continuously provide thermal energy for the nuclear power plant.

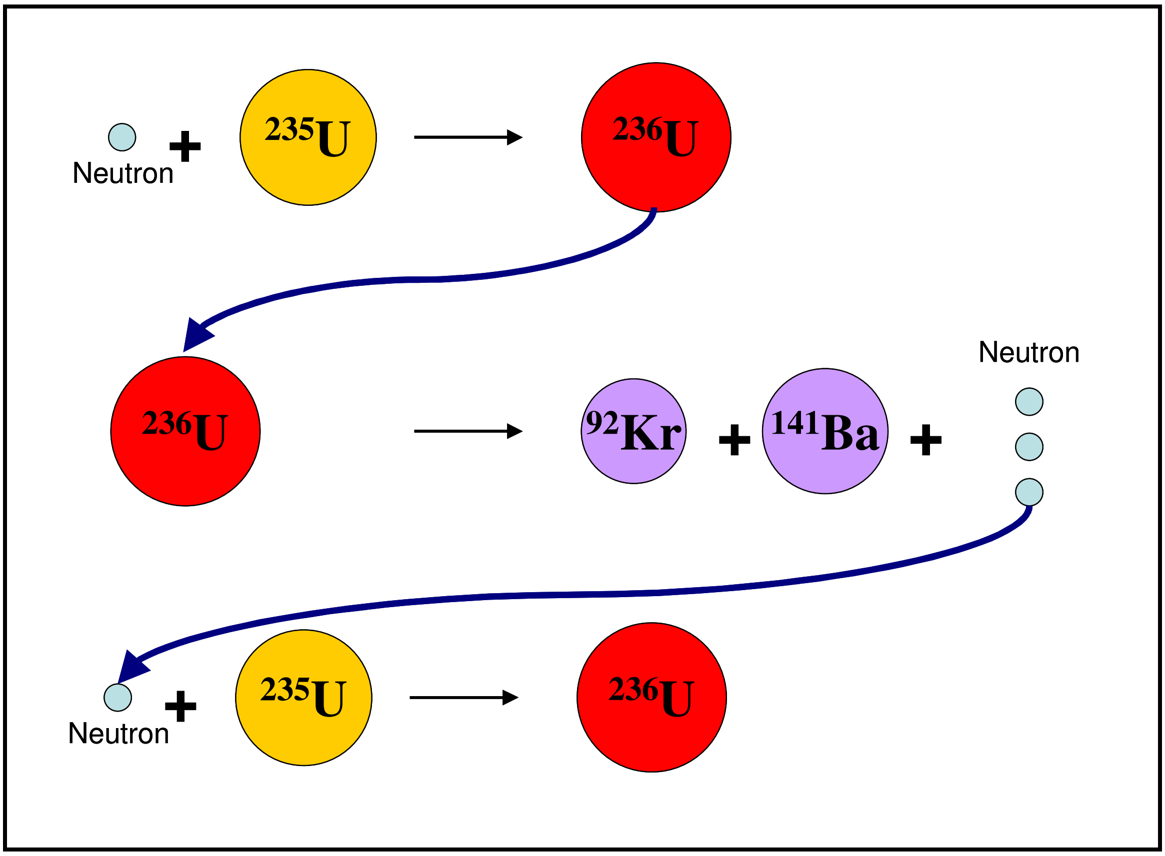


Figure 5-1: Fission Reaction

5.3.2 Nuclear Power Plant Control and Flexibility

The amount of thermal energy and electricity generated in a nuclear power plant can be adjusted by controlling the rate of fission reaction. This has to be carried out evenly, without disturbing the neutron flux distribution within the reactor. The usual approach, as shown in the process diagram in Figure 5-2, is to insert neutron absorbing control rods into the reactor. The amount of control rods inserted into the reactor will determine the amount of neutrons absorbed. When more neutrons are absorbed by the control rods, the amount of reaction will be reduced as fewer neutrons are available (CANTEACH, 1996). Hence, less thermal energy is available for electricity generation. Alternative to control rods, liquid with burnable poison, such as xenon-135 may be injected into the reactor cooling circuit to absorb the neutrons.

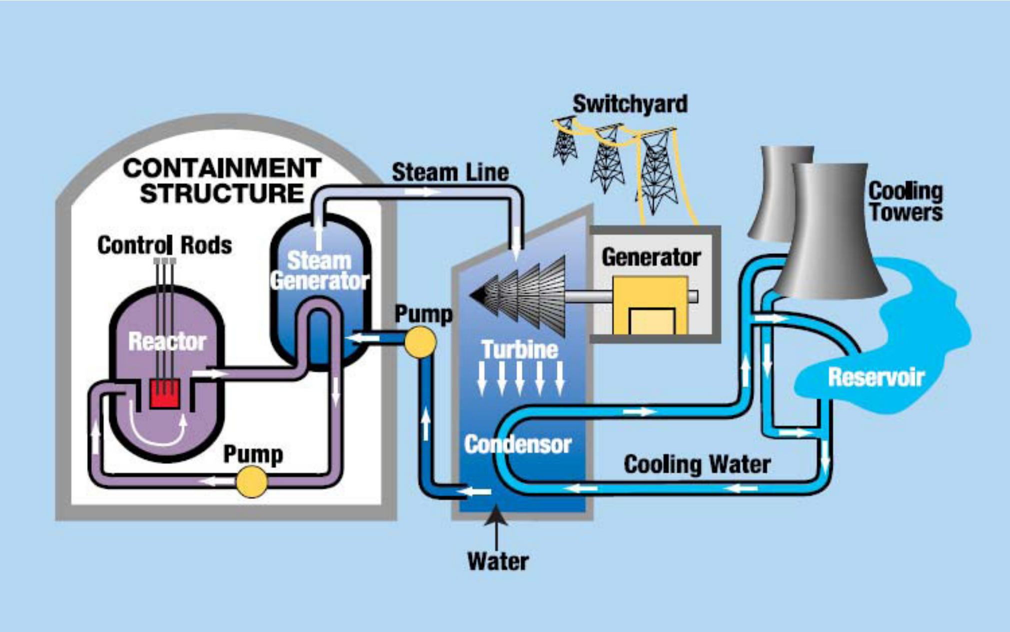


Figure 5-2: Nuclear Power Plant Process Diagram – Pressurised Water Reactor (Source: (Kaplan, 2008))

In nuclear power control, the key parameter is the reactivity ρ as defined in Equation 5-1 and Equation 5-2 below.

$$\rho = \frac{k-1}{k}$$ Equation 5-1

$$k = \frac{Rate\_of\_neutrons\_produced}{Rate\_of\_neutrons\_lost}$$ Equation 5-2

In a nuclear power plant, complex feedback mechanism is required to maintain the reactor in the 'critical' state, whereby k=1. This is because the neutrons are not only absorbed by the control rods; they are also absorbed by other by product from the fission process. One of the by products from the fission process is iodine-135. Iodine-135 will decay in a half-life of around seven hours into xenon-135. Xenon-135 is a neutron absorbing poison. Hence, the control process has to take into consideration the control rod, the poison from the fission process and the timing in order to maintain the critical state or to achieve the desire reactivity (Alam et al., 2011). As the control process is complicated, the nuclear power plants typically do not respond well to load changes. Traditionally, they are deployed to cater for the base load. Even though the control constraint may be overcome with the latest technology in nuclear power plant, it may not be financially attractive to operate the nuclear power plant at a lower plant factor. This is because the fuel cost is only a small portion of the total generation cost for a nuclear power plant. The average generation cost for a unit of electricity will increase if the plant factor is lowered to suit the load. Therefore, the nuclear power plants are most suitable for base load application. The financial aspect of the nuclear power plants was examined in more details in the following sections.

5.4 Financial Analysis

In Table 5-1, the various components of electricity generation cost are summarized based on data available from the generating companies, academic community and government agencies (Rafaj and Kypreos, 2007, Nuclear

Energy Institute, 2011, Kaplan, 2008, World Nuclear Association, 2011).

To analyse the effect of the nuclear power in terms of cost and GHG emission, the LEAP model created for Sabah is used. The reference scenario (**Scenario A - Reference**) as described in the previous chapter, whereby no effort is included to reduce the CO_2 emissions, was maintained. Generally, new gas, coal and hydro power plants are to be built, as per the SESB plant up plant shown in Figure 2-2, to meet the power demand of Sabah.

Table 5-1: Electricity Generation Cost of Nuclear Power Plants

Components	Cost
Capital Cost (RM/kWe)	15750 to 17500
Fuel Cost (RM/MWh)	26.25
Fixed O&M (RM/kW/year)	400
Variable O&M (RM/MWh)	33.25
Decommissioning Cost (RM/kW)	872 to 22750

A new scenario **(Scenario B - Nuclear)** is created. In this scenario, nuclear power plants will be adopted to meet the increased power demand, in conjunction with gas and hydro power plant. New nuclear power plants of 600 MW will be planned and built, together with gas and hydro power plants based on a capacity ratio of 4:1:1 respectively. The required plant capacity is computed dynamically by LEAP to maintain a minimum reserved margin of 30% (IDS, 2007). The life time of nuclear power plant is assumed to be 50 years (Kaplan, 2008).

The annual power generation costs from LEAP for the two scenarios are plotted in Figure 5-3. The costs considered include annualised capital costs, fixed O&M costs, variable O&M costs, fuel costs and decommissioning costs. It is observed that the cumulative costs of scenarios A-Ref and B-Nuclear are RM 56.424 and RM 66.718 billion respectively. The annual generation cost for scenario B is higher than that of scenario A throughout the period.

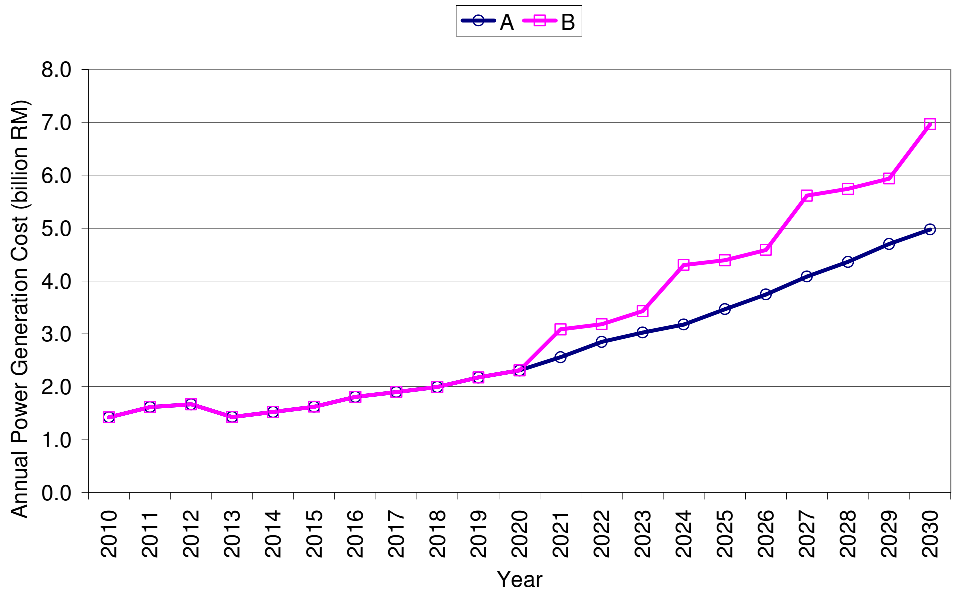


Figure 5-3: Annual Power Generation Costs for the 2 Scenarios

Figure 5-4 shows the computed average unit cost of electricity generation. It follows the previous trend whereby the generation cost of scenario B-Nuclear was higher. It is observed that the price of scenario B increased significantly in 2021, 2024, 2027 and 2030. This coincided with the year when a nuclear power plant is commissioned. Because of the large capacity of the nuclear plants, the reserve margin is increased significantly when a new plant was commissioned. This results in the higher average electricity generation cost because the power plant capacity is under-utilised. As the plant factor increases with the demand, the average price decreases. As a result, the average generation cost appears to be oscillating from 2020 to 2030. The average generation costs in scenarios A and B are RM 0.20 and RM 0.24 per kWh respectively.

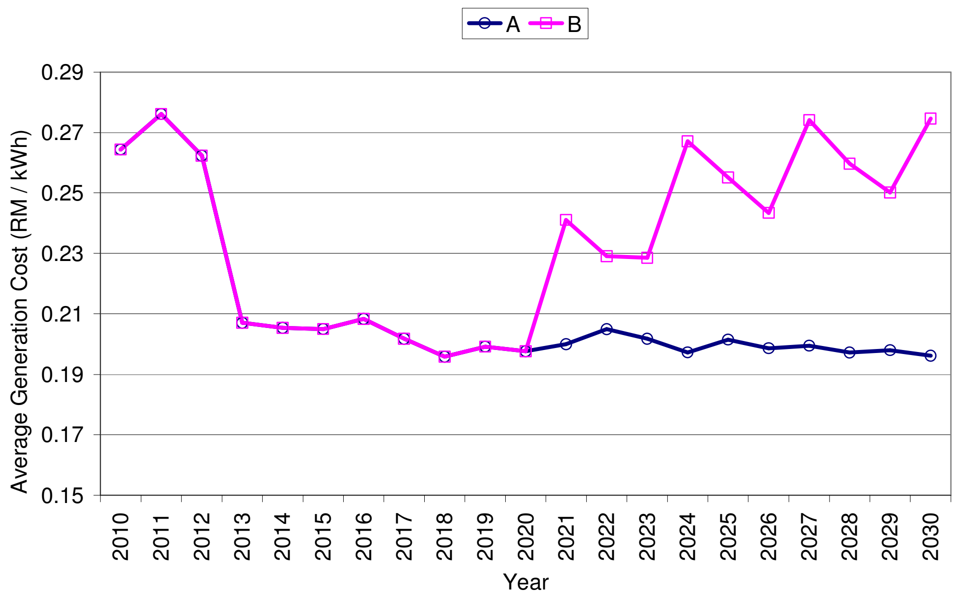
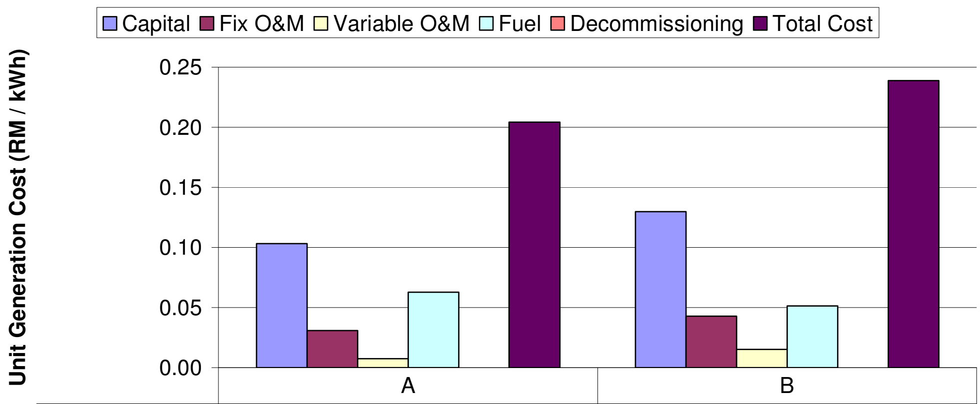


Figure 5-4: Average Unit Cost of Power Generation for the 2 Scenarios

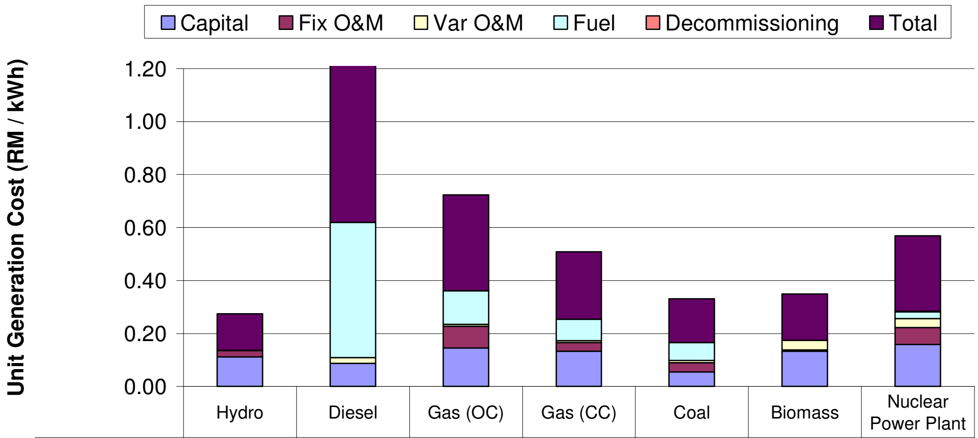
Figure 5-5 shows the average unit electricity cost encompassing annualised capital cost, fixed O&M cost, variable O&M cost, fuel cost and decommissioning cost for the two scenarios. The annualised capital cost for scenario B is higher because of the higher capital cost of nuclear power plants. The total annualised capital cost is RM 35.861 billion in scenario B, which is 26% higher than that of scenario A. The fixed and variable O&M costs in scenario B are higher than that of scenario A because of the higher maintenance cost for nuclear power plants. However, the fuel cost for nuclear power plants is lower, which is consistent with the lower fuel cost of scenario B. A decommissioning cost of RM872 per kW is adopted for nuclear power plant and this results in a very low average cost of RM0.003 per kWh in Scenario B. However, as found previously, the decommissioning cost can be as high as RM 22,750 per kW and this will have a significant impact on the average cost of scenario B.



	A	B
Capital	0.10	0.13
Fix O&M	0.03	0.04
Variable O&M	0.01	0.02
Fuel	0.06	0.05
Decommissioning	0.00	0.00
Total Cost	0.20	0.24

Figure 5-5: Accumulated (2010 to 2030) Cost for the 2 Scenarios Divided into Annualised Capital, Fixed O&M, Variable O&M and Fuel Costs

Based on the costs computed in LEAP, the unit costs of power generation using the various technologies are computed and presented in Figure 5-6. A plant factor of 80% is adopted in this calculation. It is found that the diesel power plants are the most expensive mainly because of the high fuel cost. This is followed by the nuclear power plants. The high cost of nuclear power plants is mainly due to the high capital cost. The fuel cost of nuclear power plants is among the lowest but the fixed and variable O&M costs are high.



	Hydro	Diesel	Gas (OC)	Gas (CC)	Coal	Biomass	Nuclear Power Plant
Total	0.14	0.62	0.36	0.25	0.17	0.17	0.28
Decommissioning	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel	0.00	0.51	0.13	0.08	0.07	0.00	0.03
Var O&M	0.00	0.02	0.01	0.01	0.01	0.04	0.03
Fix O&M	0.02	0.00	0.08	0.03	0.04	0.00	0.06
Capital	0.11	0.09	0.15	0.13	0.05	0.13	0.16

Figure 5-6: Average Cost of Electricity Generation Using Different Technologies

5.5 GHG Emission Assessment

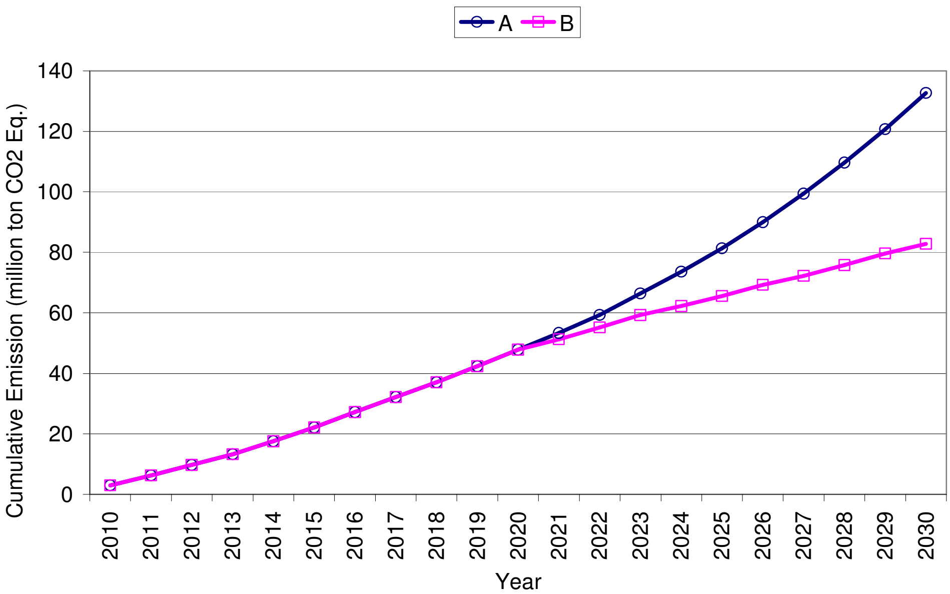


Figure 5-7: Cumulative GHG Emissions for the Power Generation Sector in Sabah from 2010 to 2030 for the 2 Scenarios

With the results from LEAP energy model, GHG emission analysis is carried out. The IPCC tier 1 emission factors within the LEAP database are applied for all the power generation process.

The results from the LEAP analysis are plotted in Figure 5-7. For scenario A, the cumulative GHG emission from the Sabah power generation sector over the 20 years period is 133 million tCO_2-eq. In scenario B, with the adoption of nuclear power plants, the cumulative emission is reduced to 83 million tCO_2-eq. This is equivalent to a 38% reduction in the GHG emission.

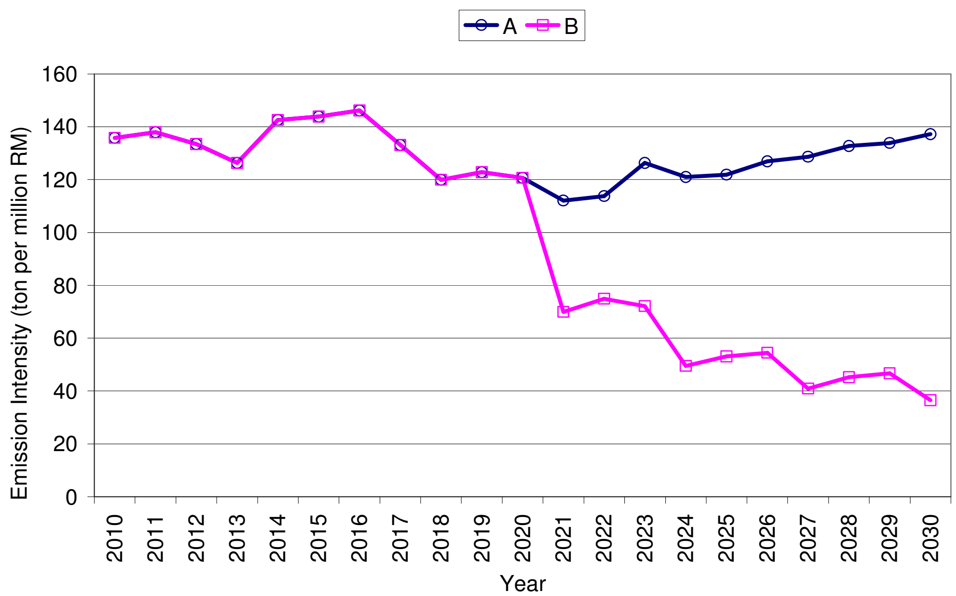


Figure 5-8: GHG Emission Intensities for Power Generation Sector in Sabah

The GHG emission intensity as shown in Figure 5-8 is computed using the projected GDP data. The GDP projection is based on data obtained from (IDS, 2007). The projection is interpolated from the data point (2010, RM 21.9 billion), (2015, RM 32.0 billion), (2020, RM 45.7 billion), (2025, RM 63.2

billion) and (2030, RM 87.4 billion). From the figure, the emission intensity of scenario A starts at 136 tCO_2-eq.per million RM and ends at 137 tCO_2-eq.per million RM. It varies over a small range over the 20 years period. The emission intensity reduces when hydro power plants are commissioned. The emission intensity increases with the increased utilization of fossil fuel power plants as a result of the growing power demands and reducing reserve margin. In scenarios B, the emission intensity is lowered with the adoption of nuclear power plants. It is reduced from 136 tCO_2-eq. per million RM in 2010 to 36 tCO_2-eq. per million RM in 2030. This is equivalent to a 73% reduction in 2030 compared to 2010 level.

The average emission factor for scenario A is 480 g per kWh. This is reduced to 300 g per kWh in scenario B.

The cost of GHG emission avoided is computed and summarised in Table 5-2. From the table, it is observed that the cost is RM 796.56 per ton of GHG emission avoided for using nuclear power plant in scenario B. This is significantly higher than that of the advanced combustion technologies found in the previous chapter, which costs RM 60.67 per tCO_2-eq. of GHG emission.

Table 5-2: Cost of GHG emission avoided

No	Description	Average electricity cost (RM / kWh)	Total GHG emission, CO_2 eq. (mil ton CO_2 eq.)	Total electricity output (GWh)	Average emission Factor, CO_2 eq. (g / kWh)	Cost of emission avoided[a] (RM / ton)
1	Scenario A - reference	0.2042	132.71	276,333	480.26	-
2	Scenario B - Nuclear	0.2388	82.84	276,333	299.78	796.56
3	Advance Gas and Coal Plant[b]	-	-	-	-	60.67
3	PV[b]	1.5612	-	-	0	3,250.74
4	Wind[b]	1.6064	-	-	0	3,344.85

Note:

a In computing the cost of emission avoided, the incremental cost of the option is first computed with respect to the reference scenario (scenario A). For example, the incremental cost for scenario B is RM 0.0071 per kWh. The average GHG emission factor is then computed by dividing the total emission by the total electricity output. The avoided emission is computed with reference to the reference scenario again. For scenario B, it is 117.034 g / kWh. The cost of emission avoided can be obtained by dividing the incremental cost (RM 0.0071 per kWh) by the emission avoided (117.034 g / kWh).

b The cost for Item 3, 4 and 5 were computed in the previous chapter.

5.6 Sensitivity Analysis

In this section, sensitivity analyses are carried out to study the impact of fuel price, capital cost and decommissioning cost on the electricity generation cost.

5.6.1 Impact of Increased Gas Price

The impact of the increase in natural gas price is first studied. As discussed in the previous chapter, the natural gas is heavily subsidized in the power generation sector in Malaysia. The price of natural gas for power sector is fixed at RM 10.70 per MMBTU, compared to the market price of RM 41.16 per MMBTU in December 2009 (Zuraimi, 2010). In the event that the subsidy is withdrawn, the fuel cost for gas power plants will increase by 285%. The variation in the natural gas price, with an increase of up to 300%, is applied to the fuel mixes in 2030 based on the four scenarios. The average unit electricity generation costs are computed for each scenario as shown in Figure 5-9. It is observed that the unit electricity cost in scenario A increases from RM 0.1961 per kWh to RM 0.2777 per kWh, when the gas price increases by 300%. This is corresponding to an increase of 42% in electricity cost. In scenario B, on the other hand, the electricity cost remains almost constant when the gas price increases, as the electricity demand is mainly supplied from the nuclear power plant. However, it is noted that, at a 300% increase in gas price, the average electricity cost for scenario A is still lower than that of scenario B. The generation cost for scenario A is RM 0.2777 per kWh, compared to that of scenario B at RM 0.2913 per kWh.

The above sensitivity analysis can also be used to assess the impact of carbon tax. With a carbon tax of 3.5% on fossil fuel as implemented in Costa Rica (Meyer, 2010), it will effectively increase the gas price by 3.5%. Similarly, the carbon tax of INR 50 (USD 1.11) (Pearson, 2010) per ton of coal in India will increase the coal price by 3.6%.

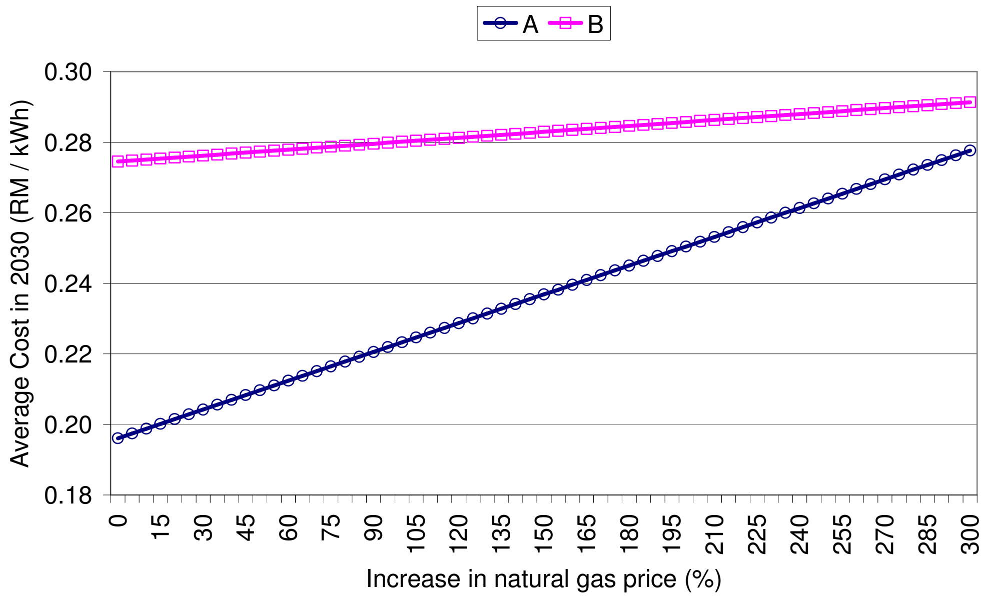


Figure 5-9: Impact of Increasing Natural Gas Price on the Electricity Generation Cost Based on the Fuel Mixes in the 2 Scenarios in 2030

5.6.2 Impact of Increased Nuclear Fuel Price

A sensitivity analysis is carried out on the nuclear fuel cost. When the nuclear fuel cost is increased by 300%, the average electricity cost in scenario B increases from RM 0.2745 per kWh to RM 0.3191 per kWh. This is equivalent to a mere 16% increase in the electricity cost. Therefore, the electricity cost of Scenario B with nuclear power plants is less susceptible to fluctuation in fuel price.

5.6.3 Impact of Increased Capital / Decommissioning Cost

In addition, based on the fuel mix of scenario B in 2030, sensitivity analysis is carried out on the impact of the nuclear power plant capital cost and decommissioning cost. As the construction of nuclear power plants take up to

10 years to plan, the capital cost may fluctuate and tends to increase beyond the original budget. Decommissioning, on the other hand, will be carried out only at the end of life of the nuclear power plant. Hence, the cost provision is normally based only on estimation and subject to changes in the future.

As shown in the result presented in Figure 5-10, the electricity cost will increase significantly with the increase of nuclear plant capital cost in scenario B. With an increase of 300%, the electricity cost will increase from RM 0.2745 per kWh to RM 0.5582 per kWh. This is equivalent to a 103% increase in the average electricity cost. The increase in the decommissioning cost has a lower impact on the electricity cost. A 300% increase in the decommissioning cost will result in a small increase of 6% in electricity cost. The electricity cost will increase from RM 0.2745 per kWh to RM 0.2903 per kWh.

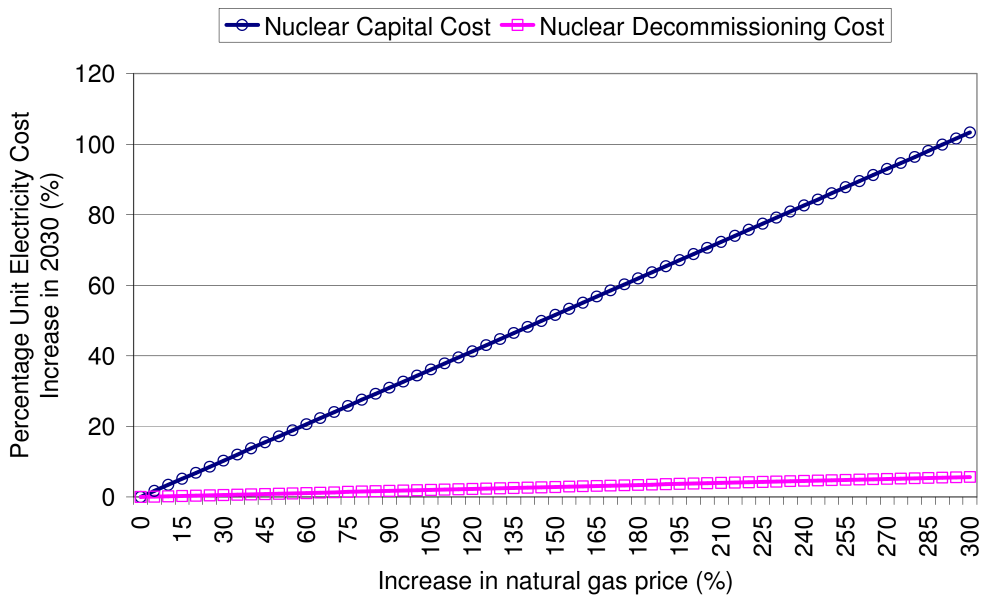


Figure 5-10: Impact of Increasing Nuclear Power Plant Capital Cost and Decommissioning Cost on the Electricity Generation Cost Based on the Fuel Mixes in Scenario B in 2030

5.7 Conclusion

From the above analysis, it is found that the nuclear power plants will be able to reduce the GHG emission. Cumulatively, the total emission is reduced by 38% in scenario B compared to the reference scenario. In terms of emission intensity, it is reduced by an even bigger margin, at 73%.

From the financial perspective, however, the nuclear option is not as attractive. Based on the projection, the average electricity cost in scenario B in 2030 will be increased to RM 0.2745 per kWh, compared to RM 0.1961 per kWh of the reference scenario. This represents a 40% increase in cost. This has offset the advantage of nuclear power plants for being less susceptible to fuel price fluctuation as found in the sensitivity analysis. It is found that at 300% increase of the gas price, the average electricity cost of the reference scenario is still cheaper that of the nuclear power plant option. With the possible capital cost overrun and expensive decommissioning cost in the future, the electricity cost of nuclear power plants will increase to even a higher level.

From the perspective of the cost effectiveness, it is found that the cost of emission reduction in scenario B was RM 797 per tCO_2-eq avoided. This is more than 10 times higher than the cost of RM 61 per tCO_2-eq avoided found in the previous chapter for the advanced combustion technology. With a similar budget, the GHG emission reduction achieved with the advanced combustion technologies will be 10 times of that of nuclear technology.

From the technological perspective, the limitation of the nuclear technology in addressing the nuclear waste and the potential disastrous consequences of a nuclear accident alone will have prevented its acceptance by the general public. Until a permanent and sustainable solution is found through the breakthrough in nuclear technology, it will always face substantial objection from the people.

Hence, it can be concluded from this study that the nuclear power plant option is not an attractive solution in emission reduction because of the high cost, poor reception from the general public and the limitation in the technologies.

CHAPTER 6

BIOMASS WASTE IN SABAH

6.1 Introduction

Biomass is one of the RE sources in Malaysia. Based on the statistics published by Malaysia Energy Commission (Malaysia Energy Commission, 2007), there were seven registered independent power producers in 2007 using biomass, with a total capacity of 70 MW. As per the study in (Shuit et al., 2009), power plants using biomass as feedstock are based on processes with proven technology that are currently being practiced commercially in Malaysia and elsewhere in the world. Malaysia is the second largest palm oil producer in the world. Forty three percent of the world palm oil is produced in Malaysia. A large amount of biomass waste is available from the harvesting of palm oil. Research result shows that 85.5% of the biomass available in Malaysia is from the palm oil industry (Hassan and Shirai, 2003). The other types of biomass available in Malaysia are: municipal solid waste (9.5%), waste from wood industry (3.7%), waste from rice industry (0.7%) and waste from sugarcane (0.5%)

Due to the relatively low energy density of the biomass, transportation cost of the biomass waste from plantations to power plant makes up a significant portion of the electricity generation cost for a biomass power plant. To minimise the transportation cost, biomass power plants can be built next to the existing palm oil processing plants so that the feedstock can be supplied directly from the processing plants. It is found that the processing plants with a minimum capacity of 60 ton per hour will be able to provide sufficient feedstock to the biomass power plants for efficient operation. It is computed that, in 2010, the total electricity that can be generated using the feedstock directly from these processing plant is 3,300 GWh per year in Sabah. This represents only 5% of the total energy available from the palm oil waste (Tyler et al., 2010). The remaining 95% of the biomass waste is distributed across the oil palm plantation. Therefore, it is important to derive a method to exploit the remaining 95% of biomass waste efficiently. A computer algorithm has been developed in this research and coded in Fortran programming language to find the optimized location of biomass power plants for minimum fuel and transportation cost and maximum utilization of the palm oil waste.

In the following sections of this chapter, the available palm biomass resources in Sabah are first evaluated. Then, the computer programme mentioned above is presented, with the relevant equations used in the programme derived and described in details. The computer programme, which is coded in Fortran programming language, is to determine the optimal location and capacity of the potential biomass power plant with the minimal operation cost. From the programme, the results are then presented. Based on the solution from the programme, the chapter is concluded with the findings on the potential, cost and emission reduction of palm oil biomass waste in Sabah.

6.2 Palm Oil Plantation and Biomass Waste

Malaysia is among the top palm oil producers in the world. Sabah is the highest palm oil producing state in Malaysia. There is about 1.36 million hectares of oil palm plantation (Malaysian Palm Oil Board, 2009). The distribution of palm oil area is shown in Figure 6-1. Therefore, it is envisaged that there is a great potential for biomass waste power in Sabah.

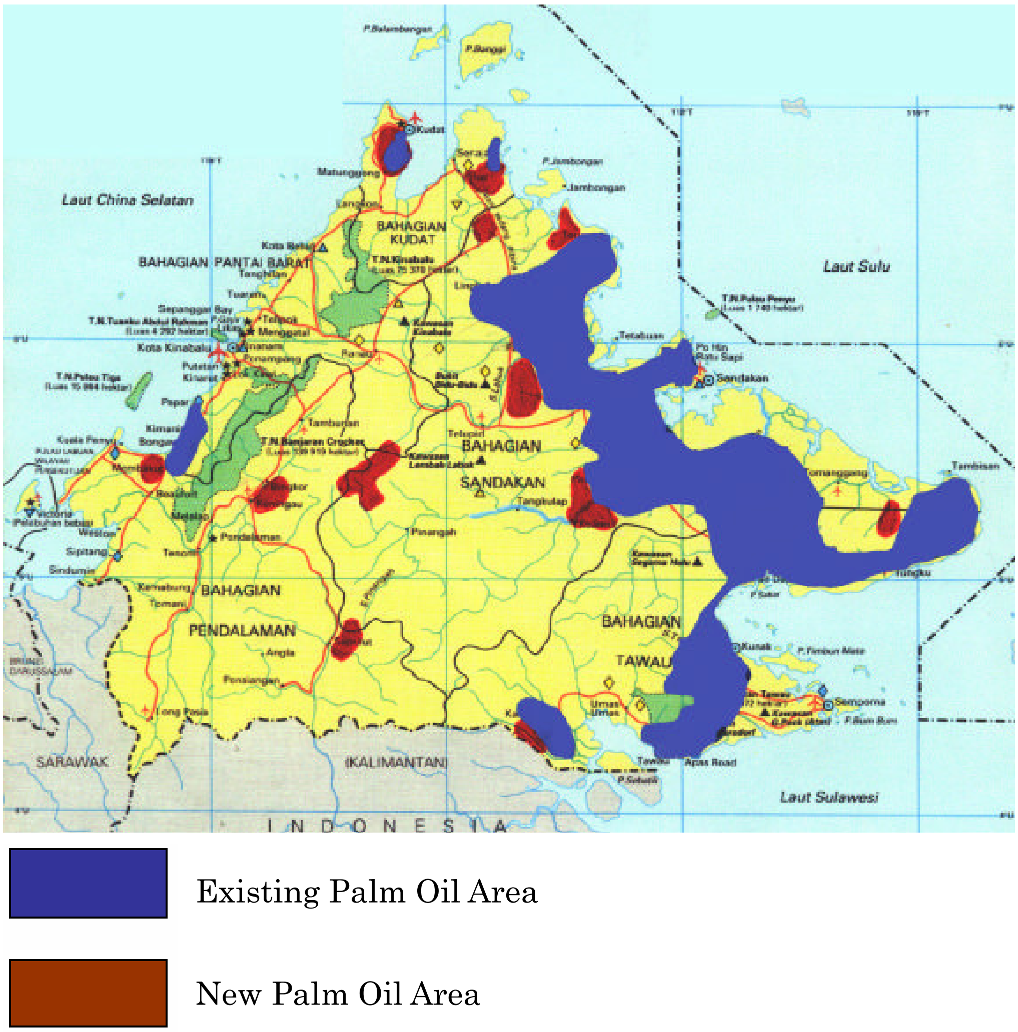


Figure 6-1: Existing and Potential New Palm Oil Area in Sabah [Source: (Teoh, 2010)

The types of biomass waste from the palm oil industry include: EFB, fiber, shell, fronds and trunks, and palm kernels. The average output of palm oil biomass and the energy density in Malaysia are tabulated in Table 6-1. The palm oil waste outputs in the table are based on statistics obtained for 2005. Based on the statistics, the average available energy from the palm oil waste is 311,866 MJ per hectare. For the 1.36 million hectares in Sabah, the total available energy is 424,165,070 TJ or 10.13 Mtoe. This is equivalent to 117,824 GWh.

Table 6-1: Palm Oil Biomass Components and Energy Density in Malaysia

Item	*Biomass Component*	*Output (million ton)[a]*	*Output (ton / hectare)[b]*	*Energy Density (MJ/ton)[c]*	*Available Energy (MJ/hectare)*
1	EFB	17.00	4.20	18,838	79,046.27
2	Fibre	9.60	2.37	19,068	45,182.89
3	Shell	5.92	1.46	20,108	29,382.47
4	Fronds and trunks	21.10	5.21	28,500	148,431.12
5	Palm kernel	2.11	0.52	18,900	9,843.33
	Total	**55.73**	**13.76**		**311,886.08**

Note: a Output in year 2005 (Sumathi et al., 2008, Hassan and Shirai, 2003, Shuit et al., 2009)

b Average value based on a total plantation area of 4,051,374 hectares (MPOB, 2011) throughout Malaysia

c Energy density as obtained in (Khor et al., 2010, Hassan and Shirai, 2003, Sumathi et al., 2008, Shuit et al., 2009)

6.3 Methodology

Due to the relatively low energy density of biomass, a large amount of biomass waste is required to be transported to the biomass power plant for power generation. Hence, transportation cost constitutes a significant portion of the total electricity production cost of a biomass power plant as found in the previous studies (Prasertsan and Krukanont, 2003, Krukanont and Prasertsan, 2004). The transportation cost is unique for biomass power plants and represents one of the key factors in determining the financial viability of the biomass power plant. In (Prasertsan and Krukanont, 2003, Krukanont and Prasertsan, 2004), the authors have devised a methodology to obtain the optimal location and capacity of biomass power plants based on the available rubber plantation waste in the southern Thailand. An approach is developed and presented in this chapter to determine the optimal location and capacity of biomass power plants. This approach is an enhanced version of the one in (Prasertsan and Krukanont, 2003, Krukanont and Prasertsan, 2004) because it has the following new features:

a. **Power Plant Location**: The methodology implements a two dimensional algorithm to identify the potential location of biomass power plants on any location in Sabah. In the study (Prasertsan and Krukanont, 2003, Krukanont and Prasertsan, 2004), a one dimensional algorithm is used, limiting the potential location of power plants along a major highway in the southern Thailand;

b. **Biomass Waste**: In addition to the fronds and trunks of oil palm during the replanting process, this study includes all other biomass waste from harvesting and the subsequent processing of palm oil. The other biomass includes EFB, fibre, shell and kernel. In the study (Prasertsan and Krukanont, 2003, Krukanont and Prasertsan, 2004) for the rubber plantation, only the wood waste from the replanting of rubber trees is considered;

c. **Operation Costs**: The fixed and variable O&M costs are included in this study. The study (Prasertsan and Krukanont, 2003, Krukanont and Prasertsan, 2004) adopts a fixed maintenance cost, which was based on a fixed percentage of the capital cost;

d. **Capital Cost**: Consistent with the methodology adopted in the other parts of this thesis, the capital cost is annualised and represented as one component in the production cost. In the study (Prasertsan and Krukanont, 2003, Krukanont and Prasertsan, 2004), a cash flow model with a target internal rate of return (IRR) based on NPV is used;

e. **Grid Connection**: The cost of connecting the power plant to the grid is included as one of the factor in determining the viability of the power plant in the model implemented in this thesis. The existing grid in Sabah is mapped in the algorithm to calculate the distance from the potential power plant to the grid. The previous study (Prasertsan and Krukanont, 2003, Krukanont and Prasertsan, 2004) does not consider the distance of the power plant from the grid and the connection cost to the grid.

6.3.1 Derivation of Equations

The main objective of this methodology is to determine the best locations and optimal capacities for biomass power plants with minimum total costs. In this methodology, the problem is treated as an optimization problem whereby, the capacity of the biomass power plant is optimised. At the optimal point, the operating cost of the biomass power plant is minimised. The lower operating cost will enable the power plant to afford a higher purchase price of biomass while maintaining the financial viability of the plant. This is critical in the event that the price of biomass waste increases.

The profit (P) is the difference between the revenue from the sales of electricity (I) and the total cost of electricity production (C), as expressed in Equation 6-1.

$$P = I - C \qquad \text{Equation 6-1}$$

The revenue consists of the selling of electricity energy (I_e) and electricity capacity (I_c) as shown in Equation 6-2.

$$I = I_e + I_c$$
$$I = tMP_e + 12MP_c \qquad \text{Equation 6-2}$$

where:

t is the annual operating hour of the biomass power plant;

M is the capacity of the biomass power plant (MW);

P_e is the selling price of electricity energy (RM/MWh); and

P_c is monthly charge for the maximum demand (RM/MW/month);

Based on the current FiT for biomass electricity generation in Malaysia, there is no provision for P_c (SEDA, 2011). Hence, Equation 6-2 can be further simplified to Equation 6-3.

$$I = tMP_e \qquad \text{Equation 6-3}$$

The total generation cost of the biomass power plant consists of the cost of biomass (C_b), cost of transportation of biomass (C_t), fixed O&M cost (C_f), variable O&M cost (C_v), labour cost (C_l), annualised capital cost (C_c) and annualised grid connection cost (C_x), as shown in Equation 6-4.

$$C = C_b + C_t + C_f + C_v + C_l + C_c + C_x \qquad \text{Equation 6-4}$$

The cost of biomass (C_b) is the annual cost of biomass waste (RM) purchased at the site of the source to sustain the operation of the biomass power plant. The biomass is assumed to be obtained from any point within the circular area with a radius of R (km). The biomass power plant is assumed to be at the centre of the circular area. Based on these assumptions, the biomass cost (C_b) can be obtained using Equation 6-5.

$$C_b = \int_0^R C_{bu}\psi(2\pi R)dR = C_{bu}\psi\pi R^2 \qquad \text{Equation 6-5}$$

where

C_{bu} is the unit biomass cost at source (RM / ton)

ψ is the annual average biomass availability (ton / km^2 / year)

The transportation cost (C_t) is defined as the annual transportation cost (RM) for the all the required biomass from the source to the biomass power plant. It can be computed using Equation 6-6.

$$C_t = \int_0^R C_{tu}\psi(2\pi R)RdR = \frac{2C_{tu}\psi\pi R^3}{3} \qquad \text{Equation 6-6}$$

where

C_{tu} is the unit transportation cost for biomass (RM / ton / km)

To calculate the fixed O&M cost (C_f), the biomass power plant capacity (M) need to be computed first as in Equation 6-7.

$$M = \eta_c Q_b$$

$$M = \eta_c \frac{\psi\pi R^2 H\eta_b}{3600t} \qquad \text{Equation 6-7}$$

where:

η_c is the power plant efficiency

Q_b is the boiler thermal load (MW)

H is the lower heating value of biomass (MJ / ton)

η_b is the boiler efficiency

t is the annual operating hour of the biomass power plant (h/year)

Hence, C_f can be computed from Equation 6-8.

$$C_f = MC_{fu} \qquad \text{Equation 6-8}$$

where

C_{fu} is the rate of fixed O&E cost (RM / MW / Year)

Substituting M from Equation 6-7 into Equation 6-8, the fixed O&M cost can then be calculated as in Equation 6-9.

$$C_f = C_{fu}\eta_c \frac{\psi\pi R^2 H\eta_b}{3600t} \qquad \text{Equation 6-9}$$

Similarly, the variable O&M cost can also be derived as in Equation 6=10.

$$C_v = C_{vu}Mt$$

$$C_v = \frac{C_{vu}\eta_c\psi\pi R^2 H\eta_b}{3600} \qquad \text{Equation 6-10}$$

Where

C_{vu} is the unit cost of variable O&M (RM/MWh)

C_l is the labour cost. It can be obtained by summing up the annual salary of all the employees required to operate the biomass power plant. The employees shall include plant manager, shift leader, O&M personnel, operator, fuel handling workers and administrative clerk.

To calculate the annualised capital cost, the total capital investment is derived first. Research result (Prasertsan and Krukanont, 2003, Krukanont and Prasertsan, 2004) shows that the unit capital cost of the biomass power plant is insensitive to the size of the biomass power plant around the optimal value. Hence, the total capital investment (C_{ct}) can be expressed in Equation 6-11, based on the unit capital investment cost C_{cu} (RM/MW)

$$C_{ct} = C_{cu} M$$

$$C_{ct} = C_{cu} \eta_c \frac{\psi \pi R^2 H \eta_b}{3600t} \qquad \text{Equation 6-11}$$

The annualised capital cost can then be obtained as in Equation 6-12.

$$C_c = C_{ct} \times CRF$$

$$C_c = C_{cu} \eta_c \frac{\psi \pi R^2 H \eta_b}{3600t} \times CRF \qquad \text{Equation 6-12}$$

where:

$$CRF\ (Capital\ Recovery\ Factor) = \frac{i \bullet k}{(k-1)}$$

$$k = (1+i)^n$$

$$i = \ annual\ interest\ rate$$

$n =$ *biomass power plant lifetime (years)*

Similarly, the annualised connection cost to grid can be obtained as in Equation 6-13.

$$C_x = C_{xu} R_g \times CRF \qquad \text{Equation 6-13}$$

where:

C_x is the unit cost for connection to grid (RM / km)

R_g is the distance of the biomass power plant to the nearest grid (km)

The revenue can be further derived by substituting the biomass power plant capacity in Equation 6-7 into Equation 6-3, as per Equation 6-14.

$$I = t\eta_c \frac{\psi\pi R^2 H\eta_b}{3600t} P_e$$

$$I = \frac{\eta_c \psi\pi R^2 H\eta_b P_e}{3600} \qquad \text{Equation 6-14}$$

Based on Equation 6-1 to Equation 6-14, Equation 6-15 can be derived to calculate the net profit of the biomass power plant per year.

$$P = \frac{\eta_c \psi \pi R^2 H \eta_b P_e}{3600} - C_{bu} \psi \pi R^2 - \frac{2C_{tu} \psi \pi R^3}{3}$$
$$- C_{fu} \eta_c \frac{\psi \pi R^2 H \eta_b}{3600t} - \frac{C_{vu} \eta_c \psi \pi R^2 H \eta_b}{3600} - C_l \qquad \text{Equation 6-15}$$
$$- C_{cu} \eta_c \frac{\psi \pi R^2 H \eta_b}{3600t} \times CRF - C_{xu} R_g \times CRF$$

At the breakeven point whereby $P = 0$, Equation 6-15 can be simplified into Equation 6-16 as shown below.

$$P = 0$$

$$\frac{\eta_c \psi \pi R^2 H \eta_b P_e}{3600} - C_{bu} \psi \pi R^2 - \frac{2C_{tu} \psi \pi R^3}{3} - C_{fu} \eta_c \frac{\psi \pi R^2 H \eta_b}{3600t}$$
$$- \frac{C_{vu} \eta_c \psi \pi R^2 H \eta_b}{3600} - C_l - C_{cu} \eta_c \frac{\psi \pi R^2 H \eta_b}{3600t} \times CRF - C_{xu} R_g \times CRF = 0$$

$$C_{bu} \psi \pi R^2 = \frac{\eta_c \psi \pi R^2 H \eta_b P_e}{3600} - \frac{2C_{tu} \psi \pi R^3}{3} - C_{fu} \eta_c \frac{\psi \pi R^2 H \eta_b}{3600t}$$
$$- \frac{C_{vu} \eta_c \psi \pi R^2 H \eta_b}{3600} - C_l - C_{cu} \eta_c \frac{\psi \pi R^2 H \eta_b}{3600t} \times CRF - C_{xu} R_g \times CRF$$

$$C_{bu} = \frac{\eta_c H \eta_b P_e}{3600} - \frac{2C_{tu} R}{3} - C_{fu} \eta_c \frac{H \eta_b}{3600t} - \frac{C_{vu} \eta_c H \eta_b}{3600} - \frac{C_l}{\psi \pi R^2}$$
$$- C_{cu} \eta_c \frac{H \eta_b}{3600t} \times CRF - \frac{C_{xu} R_g \times CRF}{\psi \pi R^2}$$

$$C_{bu} = (-\frac{C_l}{\psi \pi}) R^{-2} + (-\frac{2C_{tu}}{3}) R + \frac{\eta_c H \eta_b P_e}{3600} - C_{fu} \eta_c \frac{H \eta_b}{3600t}$$
$$- \frac{C_{vu} \eta_c H \eta_b}{3600} - C_{cu} \eta_c \frac{H \eta_b}{3600t} \times CRF - \frac{C_{xu} R_g \times CRF}{\psi \pi R^2} \qquad \text{Equation 6-16}$$

From Equation 6-16, the maximum affordable biomass cost can be determined by taking first derivative of the biomass cost with respect to the radius (R). At the maxima, the first derivative is equals to zero. Hence, the optimal radius can be determined from Equation 6-17. If the biomass power plant is sized up according to the optimal radius, then the overall power generation cost can be optimised. With a radius larger than the optimal radius, the additional distance to transport the biomass waste to the biomass power plant will result in higher overall operation cost. With a radius smaller than the optimal radius, the biomass power plant capacity is not optimised and the higher average overhead cost will also result in higher overall operation cost.

$$\frac{dC_{bu}}{dR} = (\frac{2C_l}{\psi\pi})R^{-3} + (-\frac{2C_{tu}}{3}) = 0$$

$$(\frac{2C_l}{\psi\pi})R^{-3} = \frac{2C_{tu}}{3}$$

$$R = (\frac{\psi\pi C_{tu}}{3C_l})^{-\frac{1}{3}}$$

$$R = (\frac{3C_l}{\psi\pi C_{tu}})^{\frac{1}{3}} \qquad \text{Equation 6-17}$$

With the optimal radius (R), the maximum allowable cost of biomass waste can be computed with Equation 6-16. The optimal biomass plant capacity (M) can be calculated using Equation 6-7.

6.3.2 Computer Algorithm

From Equation 6-17, R is inversely proportional to the average annual specific biomass waste availability from oil palm plantation (ψ). However, ψ is also dependent on the average density of the oil palm plantation within the circular area defined by R. A different value of R will result in a different value of ψ. Therefore, the value of R and ψ can be solved through an iterative process. A computer algorithm is developed using Fortran programming language for this purpose. The procedure of the algorithm is summarized in the following:

Step 1: Read the input data of the map and location of oil palm plantation from a two dimensional map.

Step 2: Assume an initial radius R_O of 1 km.

Step 3: Calculate the value of ψ for all locations within a country or region, based on the assumed value of R_O and oil palm location obtained in Step 1.

Step 4: Calculate the value of R using Equation 6-17 for all locations within the region, based on the values of ψ calculated in Step 3.

Step 5: Compare the computed value of R with the assumed value, R_O. If $R > R_O$, the value of R_O is increased by 0.1 km and repeat from Step 3. Otherwise, proceed to the next step.

Step 6: Calculate the maximum unit cost of biomass waste C_{bu} using Equation 6-16, based on the radius obtained in Step 5.

Step 7: Identify all the feasible biomass power plant locations on the region based on a defined maximum allowable cost of biomass waste. For example, the current biomass waste can be purchased at RM10 per ton (Shuit et al., 2009). To allow for possible increase in price, the allowable cost for biomass may be set at RM20 per ton. Based on this cost, all the potential locations which can afford a biomass waste cost of more than RM20 per ton are identified in the software. The surrounding oil palm plantation that will supply biomass waste to the biomass power plant is also identified. In the programme, the plantation area supplying to one biomass power plant is not allowed to overlap with that of another biomass power plant. A 1 km buffer zone is specified between the plantation areas that are supplying to two adjacent biomass power plants.

Step 8: Calculate the biomass power plant capacity for each identify location using Equation 6-7.

With the above algorithm, the total capacity of potential biomass power plant in a region can be obtained, as well as the optimal location for each biomass power plant.

6.4 Input Data

The algorithm is used to determine the distribution of biomass power plants in Sabah in order to achieve the minimum cost of expenditure. The geographical information and the oil palm plantation distribution (Teoh, 2010, Sabah Integrated Coastal Zone Management, 2011) in Sabah are digitised in a bitmap format as shown in Figure 6-2. Each pixel in the map represents an area of 100m X 100m.

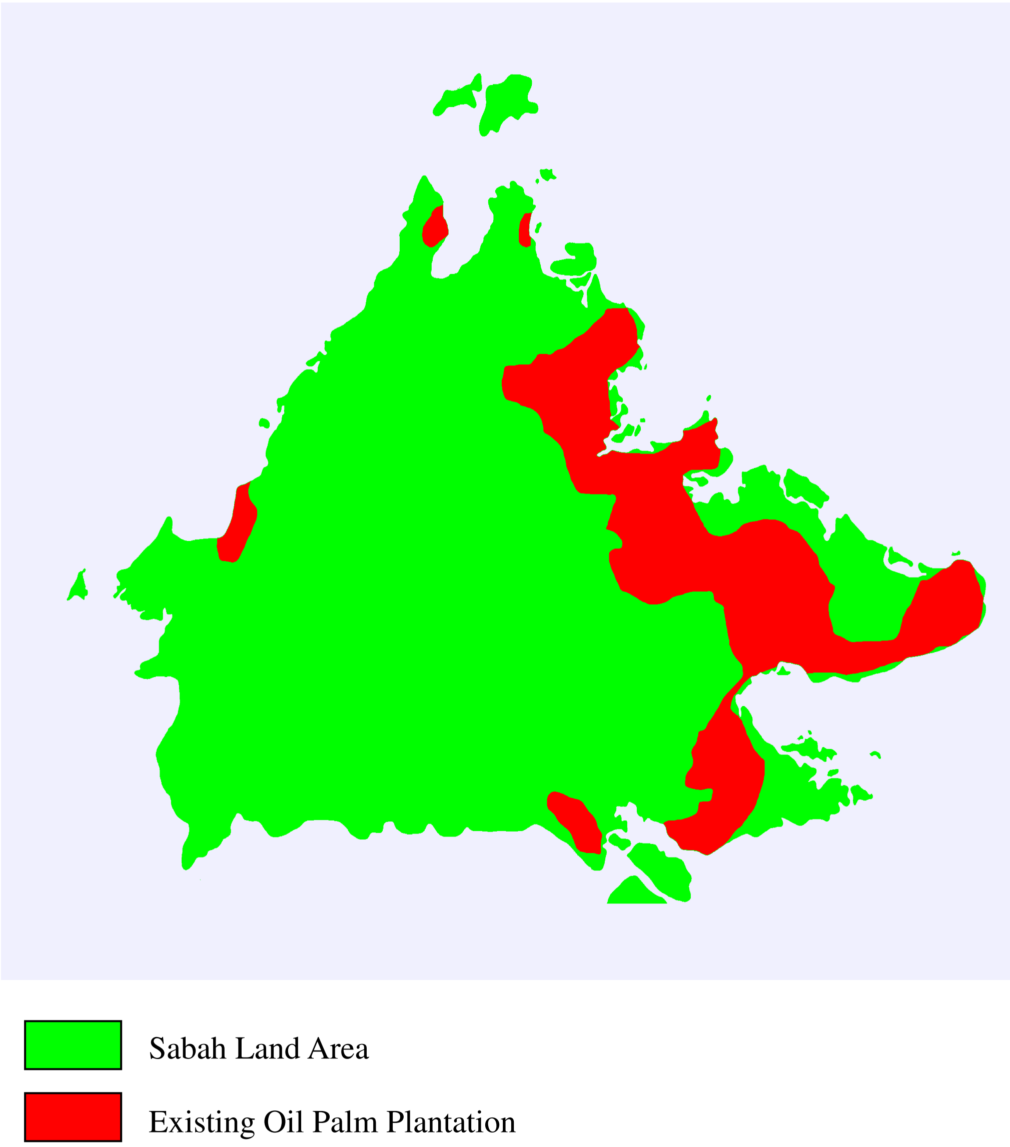


Figure 6-2: Digitised Map of Sabah and Existing Oil Palm Plantation Distribution

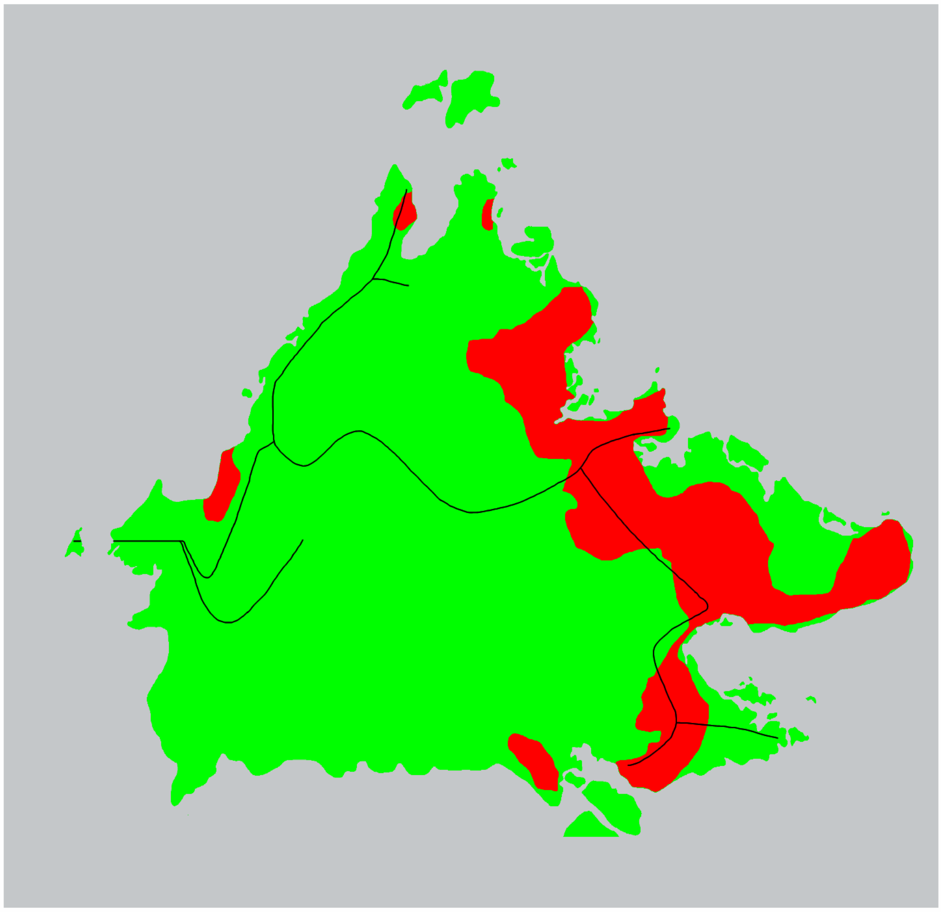
Table 6-2: Value of Parameters for the Equations

Item	Para-meters	Values	Remarks
1	η_c	60%	Cogeneration Efficiency (Prasertsan and Krukanont, 2003)
2	ψ	1376 ton/km^2/year	Average annual specific biomass waste availability from oil palm plantation as computed from Table 6-2. This value applies when the area investigated is fully planted with oil palm. If only a portion of the area is planted with oil palm, the value shall be proportionally reduced.
3	H	21083 MJ/ton	Average energy density of biomass waste as computed from Table 6-2.
4	η_b	80%	Boiler Efficiency (Prasertsan and Krukanont, 2003).
5	P_e	RM270 per MWh	FiT rate for biomass (SEDA, 2011).
6	C_{tu}	RM0.20 per ton per km	Transportation Cost (Malaysian Industrial Development Authority, 2005).
7	C_{fu}	RM27300 / MW / year	Fixed unit O&M cost (Rafaj and Kypreos, 2007)
8	t	7008 hours	Biomass power plant annual operation hour, based on plant factor of 0.80
9	C_{vu}	RM36.79 per MWh	Unit variable O&M cost (Rafaj and Kypreos, 2007)
10	C_l	RM1002000	Annual labour cost based on 1 plant manager (RM120,000), 4 shift leaders (RM60,000 each), 12 O&M staff (RM36,000 each), 4 operators (RM24,000 each), 1 clerical (RM24,000) and 5 general workers (RM18,000 each) (Prasertsan and Krukanont, 2003)
11	CRF	0.063158	Based on annual interest rate of 6% and plant lift of 20 years.
12	C_{cu}	RM10762000 per MW	Unit capital cost (Rafaj and Kypreos, 2007)
13	C_{xu}	RM1619433 / km	Unit cost of connection to grid (Bernama, 2009, MRCB, 2010)

The accuracy of the digitizing process is verified. First, the land area is measured to be 73242 km^2 from the digitised map. Compared to the actual land area of Sabah at 74398 km^2(Encyclopedia of the Nations, 2011) the error is less than 2%. The plantation area is also measured from the map as 1.38 million hectares. Compared to the published data of 1.36 million hectares (Malaysian Palm Oil Board, 2009), the error is also less than 2%.

The other input parameters required for the programme are summarized in Table 6-2.

The power grid in Sabah is also digitised based on SESB network map (Sabah Electricity Sdn Bhd, 2008) and superimposed on theplantation map as shown in Figure 6-4.



Sabah Land Area

Existing Oil Palm Plantation

Sabah Power Grid

Figure 6-3: Sabah Power Grid

6.5 Summary of Results From the Programme

The optimal radii as computed and generated by the Fortran programme in Step 5 is shown in Figure 6-4. The geographical distribution of the optimal radii is consistent with the location of existing oil palm plantation shown in Figure 6-2. The white area in Figure 6-4 represents the locations whereby no optimal radius can be found.

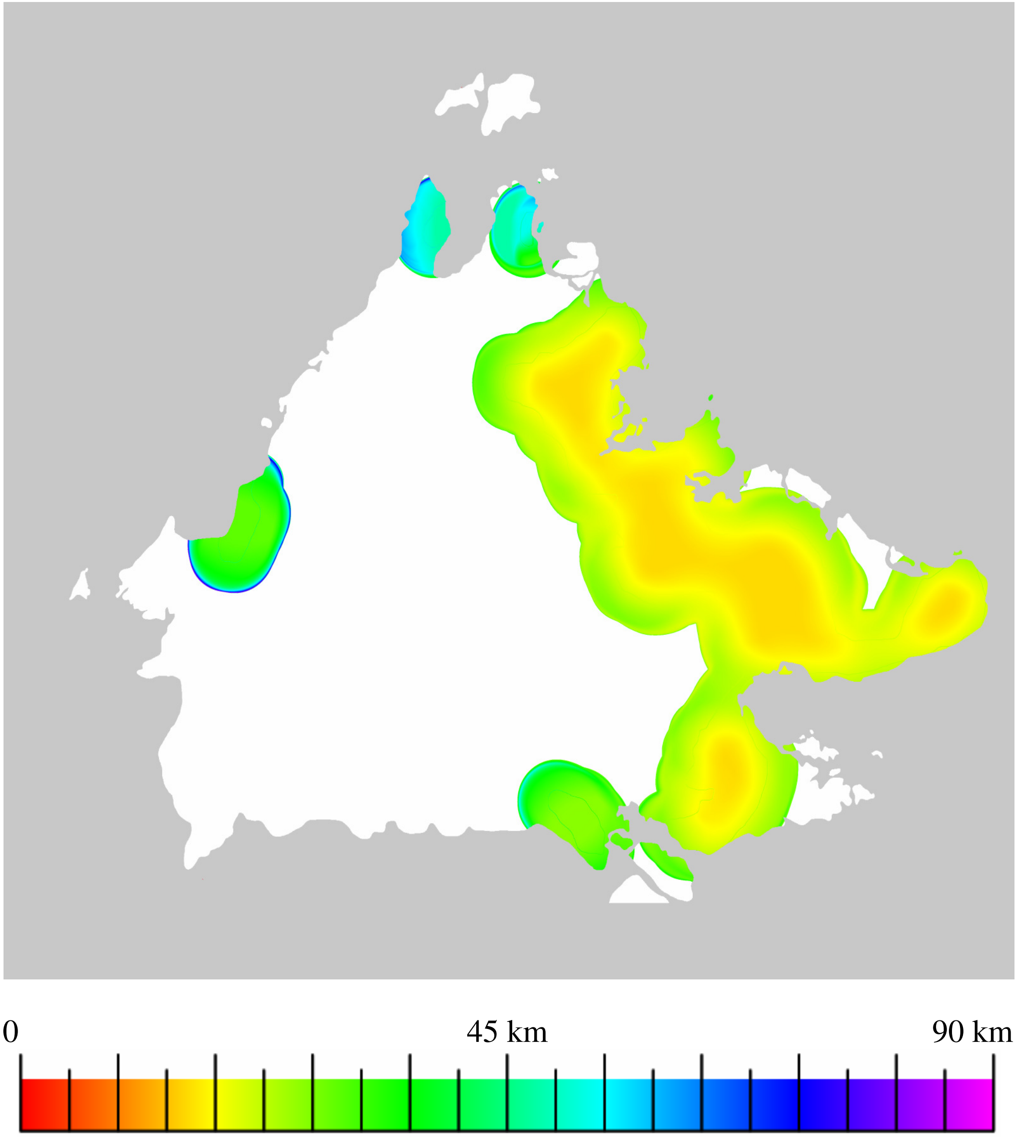


Figure 6-4: The Geographical Distribution of the Optimal Radii Generated by the Fortran Programme

The results for the optimal radii are further analysed to identify the range of value computed for the radii as shown in Figure 6-5. From the results, the optimal radii are all larger than 15 km. Most of the radii are between 15 and 20 km. There are a total of 1.4 million pixels on the map (each represent a location of an area of 100m X 100m on the map) found to have an optimal radii within this range. There are less locations with radii of more than 20 km.

No optimal radii are found to be greater than 90 km.

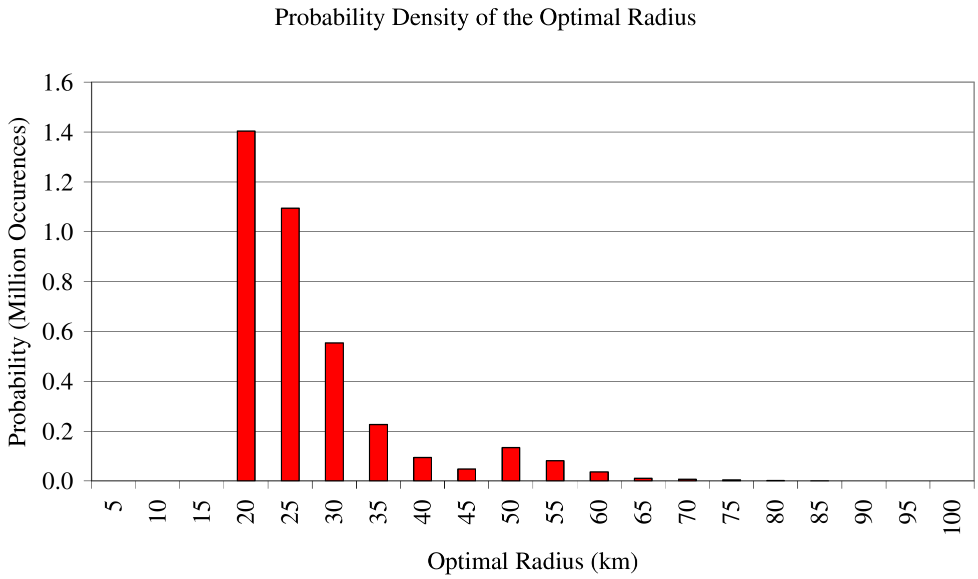


Figure 6-5: Probability Density of the Optimal Values by the Fortran Programme

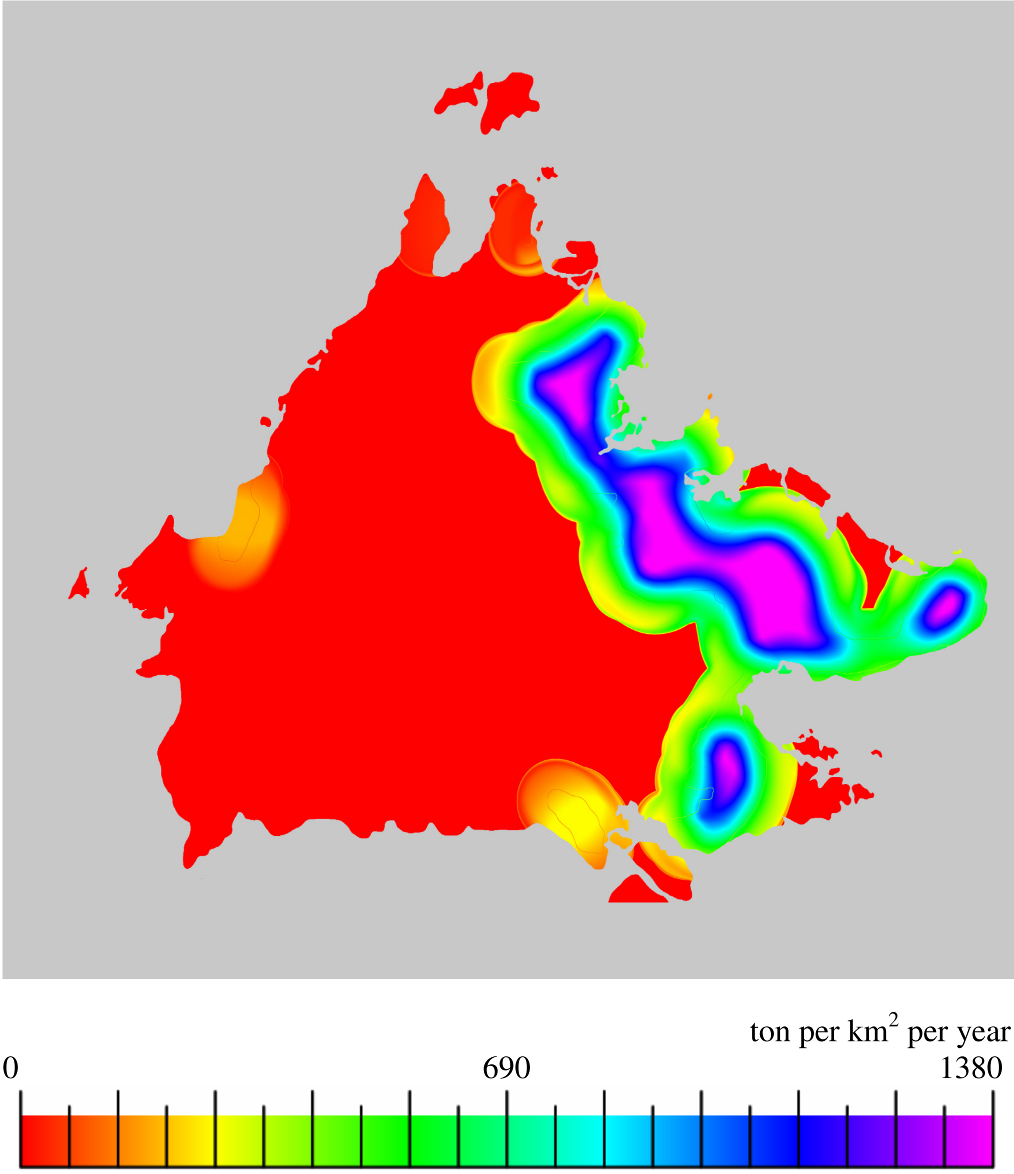


Figure 6-6: The Average Annual Specific Biomass Waste Availability Corresponding to the Optimal Radii as Computed by the Fortran Programme

For each of the optimal radii, the corresponding values for the annual biomass availability (ψ) are also computed and generated by the Fortran Programme as shown in Figure 6-6. Similarly, the results are further analysed as shown in Figure 6-7.

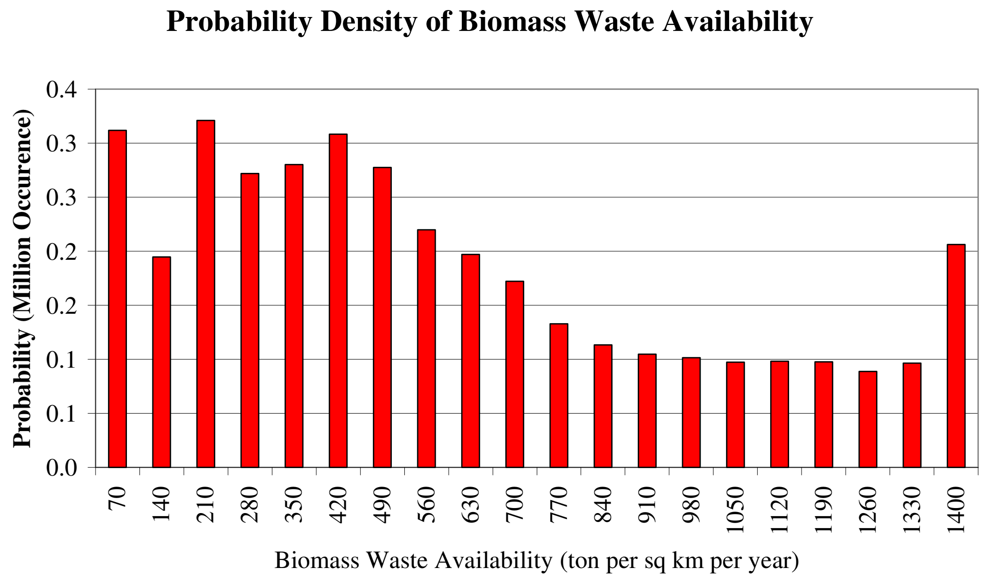


Figure 6-7: Probability Density of the Values Computed for the Average Annual Specific Biomass Waste Availability by the Fortran Programme

It is noted that the graph in Figure 6-7 of (ψ) is different from that of the optimal radii in Figure 6-5. This is expected as the optimal radius is not a linear function of (ψ), based on Equation 6-17. The relationship of the optimal radii and the average biomass availability is plotted as shown in Figure 6-8. From Figure 6-8, it is observed that the maximum average biomass availability is 1376 ton per km^2 per year and this is corresponding to the smallest optimal radius of about 15 km. With the biomass availability reduced to 50 ton per km^2 per year, the optimal radius is increased to 45 km. There is negligible energy available for power generation at any level of biomass availability below this level. Therefore, for practical reason, all optimal radii exceeding 45 km can be ignored in the computation. The Fortran Programme developed was set to ignore all optimal radii exceeding 100 km.

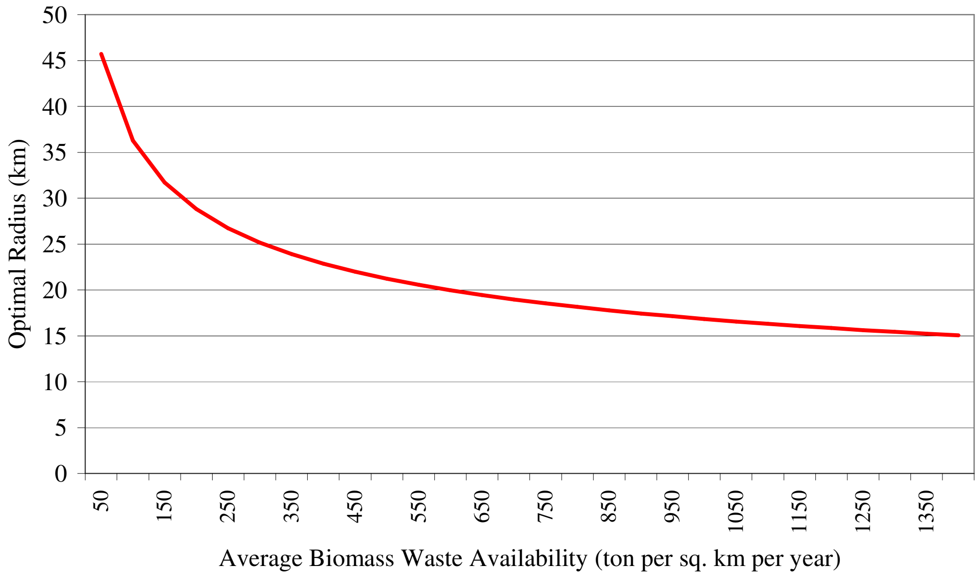


Figure 6-8: The Optimal Radius as a Function of the Average Biomass Availability (ψ)

With the optimal radius and ψ, the maximum cost of biomass waste that can be afforded by the plant (C_{bu}) is then computed by the Fortran Programme using Equation 6-16 as in Step 6. The results are presented in Figure 6-9 and Figure 6-10. From the results, it is found that the maximum allowable biomass waste cost can be as high as RM 380 per ton based on the optimal locations and radii. The white area in Figure 6-9 represents locations with no potential for biomass power generation.

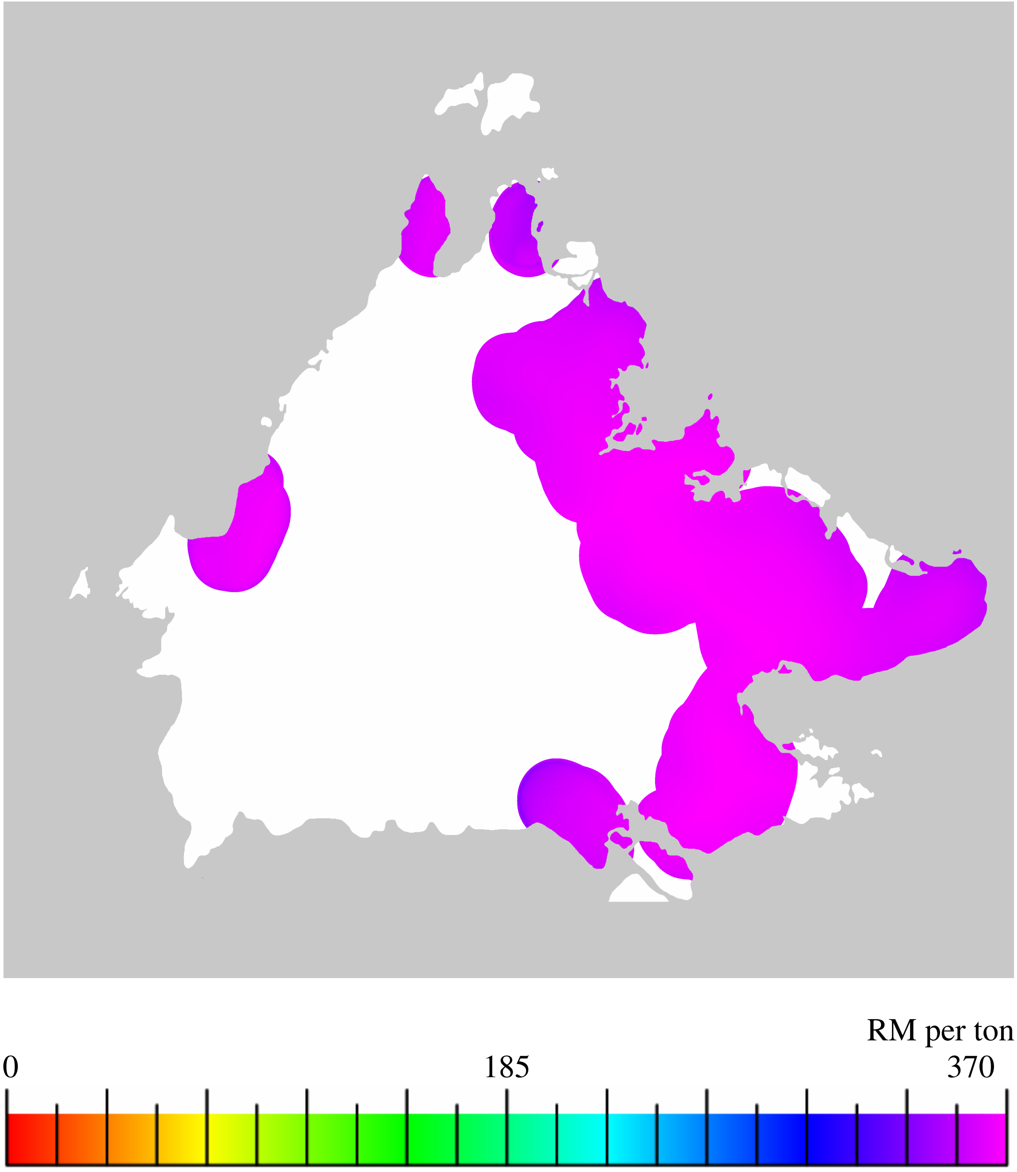


Figure 6-9: The Maximum Allowable Biomass Waste Cost as Computed by the Fortran Programme

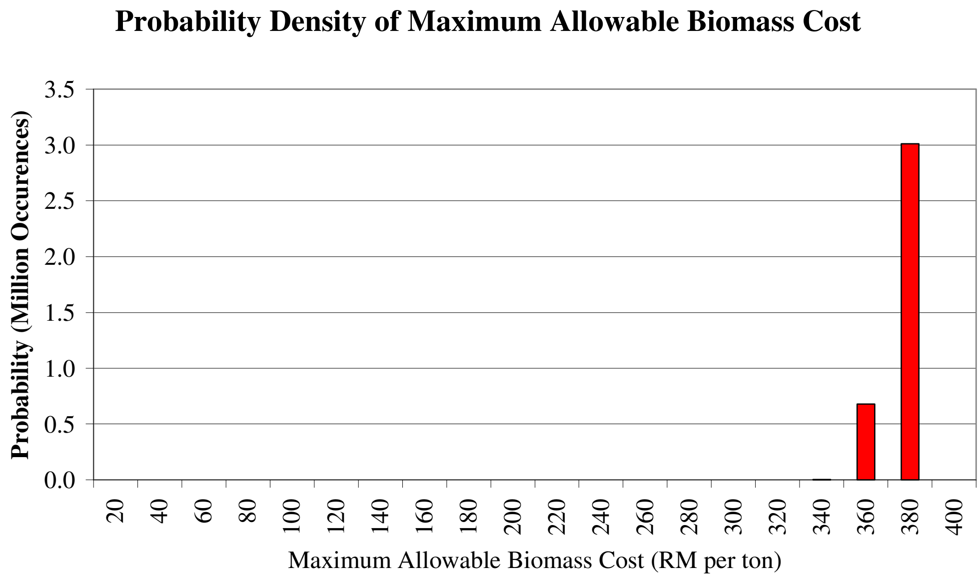


Figure 6-10: Probability Density of the Values Computed for the Maximum Allowable Biomass Waste Cost by the Fortran Programme

Following Step 7, all the feasible biomass power plant locations are identified with the Fortran Programme as shown in Figure 6-11. The centre of each circle in the figure represents the location of the biomass power plant. The biomass power plant will be fuelled by the biomass waste from the oil palm plantation within the circle.

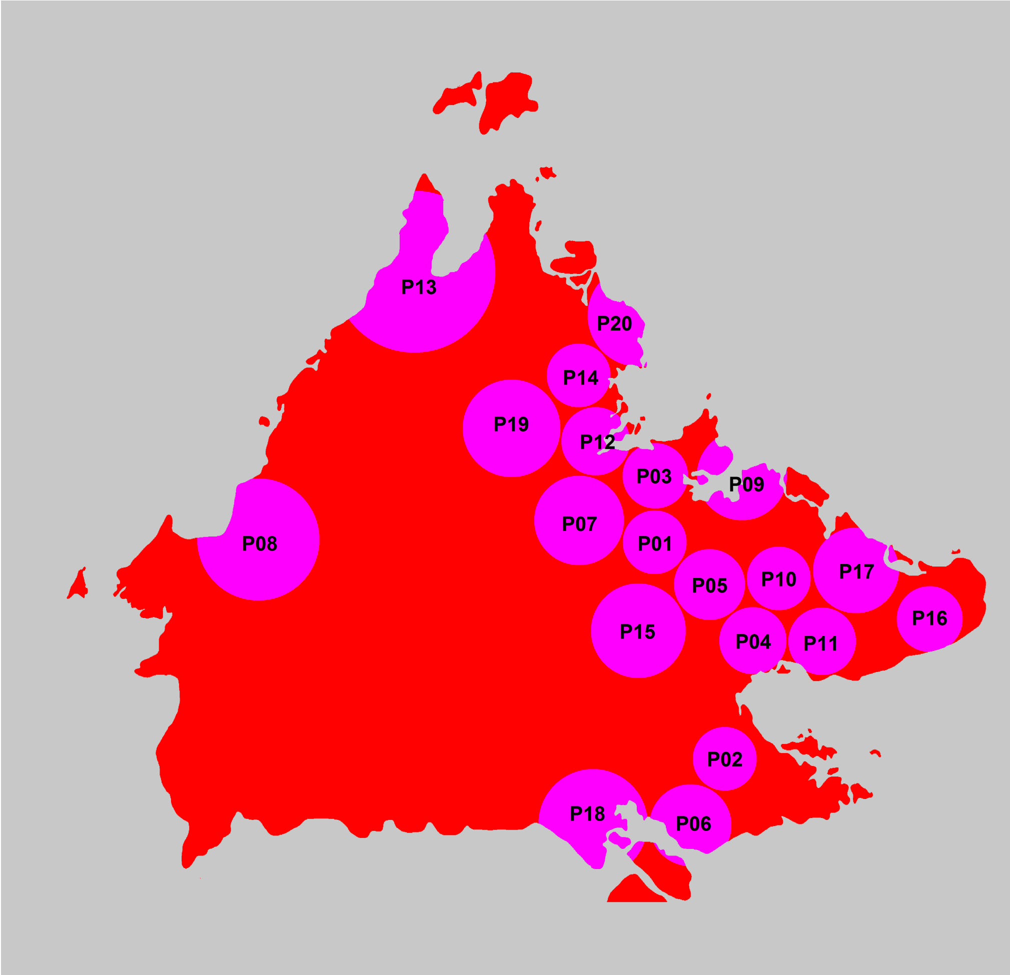


Figure 6-11: Potential Biomass Power Plant Locations as Identified by the Fortran Programme

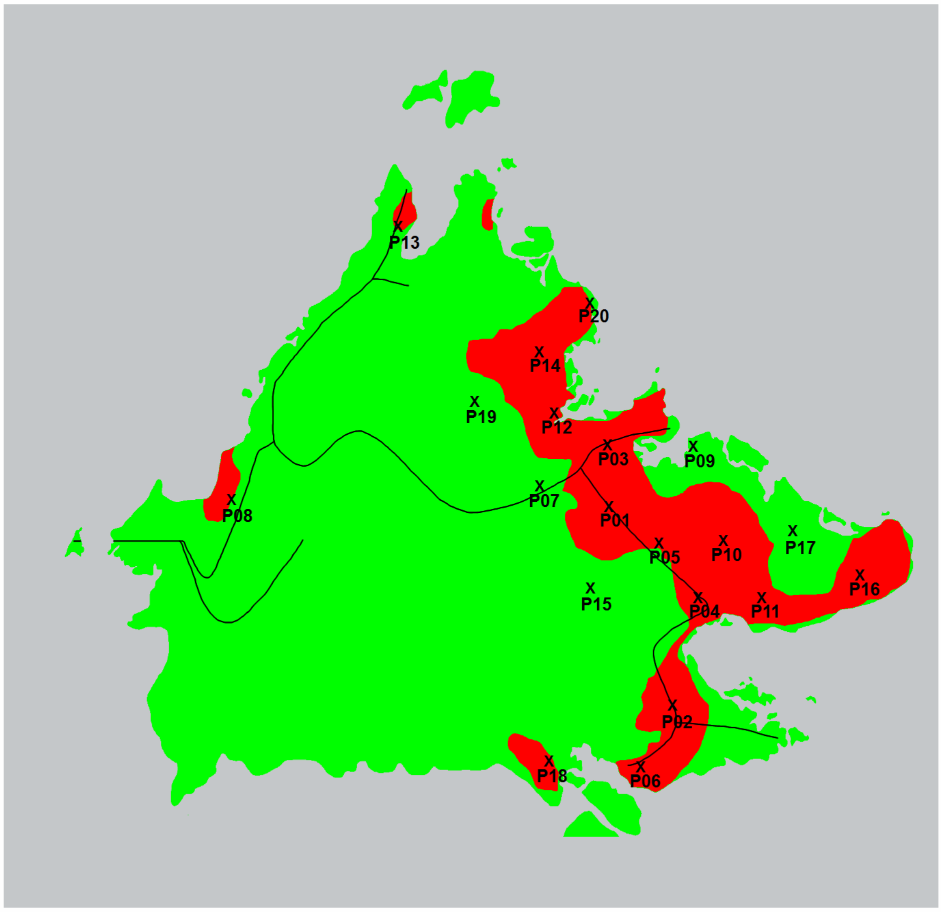
The biomass power plant sizes as calculated in Step 8 and other key parameters are tabulated in Table 6-3. As shown in the table, there are a total of 20 biomass power plants identified. The maximum allowable cost for biomass waste for these biomass power plants are between RM368.94 per ton and RM354.73 per ton. They are all above RM354 per ton. This means that these biomass power plants can afford to purchase the biomass waste at a cost of up to RM354 per ton and still operate at the break even point in terms of profit. For any point below this cost, the biomass power plant will be able to operate with additional profits.

Table 6-3: Capacity and Maximum Allowable Biomass Cost for the Identified Biomass Power Plant Location

Plant	C_{bu} *(RM per ton)*	*R* *(km)*	R_g *(km)*	*M* *(MW)*	*Pe* *(GWh)*
P01	368.94	15.14	0.00	397	2,785
P02	368.94	15.16	0.00	397	2,784
P03	368.86	15.58	0.00	387	2,709
P04	368.78	15.96	0.00	378	2,647
P05	367.97	16.80	5.60	358	2,511
P06	367.82	19.48	1.92	309	2,168
P07	367.09	21.28	4.33	283	1,983
P08	366.17	28.99	0.00	208	1,456
P09	366.00	21.30	11.82	283	1,983
P10	365.86	15.14	29.88	397	2,785
P11	365.72	16.07	27.78	375	2,628
P12	365.58	16.21	28.57	372	2,604
P13	364.31	38.30	0.00	157	1,103
P14	362.90	15.19	58.32	397	2,779
P15	362.32	22.43	33.79	269	1,882
P16	360.35	15.67	79.63	385	2,696
P17	359.99	20.31	57.24	297	2,078
P18	359.84	25.87	39.50	233	1,632
P19	359.56	23.18	49.30	260	1,822
P20	354.73	24.46	74.14	246	1,726
TOTAL				**6,387**	**44,764**

The capacity of these biomass power plants is between 157 MW and 397 MW. The total capacity is 6387 MW and the estimated annual output of electricity is 44764 GWh. This is more than 10 times of the estimate of 3300 GWh in the previous research (Tyler et al., 2010), based merely on biomass waste from the existing palm oil processing plants. In comparison, the projected total biomass power plant capacity required in Sabah by 2030 will be 5540 MW and the total electricity demand in the same year will be 25368 GWh. Therefore, the biomass power plant can potentially meet all the electricity demand of Sabah up to and beyond 2030. As the biomass waste is photosynthesized by the oil palm with CO_2 from the atmosphere, the biomass power generation is a net zero carbon emission process. This can transform the power industry in Sabah into a zero carbon emission industry.

To check the feasibility of the physical locations, the potential biomass power plant locations are overlaid over the plantation area and power grid map, as in Figure 6-12. It is found that most of the biomass power plant locations are within the oil palm plantation except P07, P09, P15, P17 and P19. The locations within the oil palm plantation are ideal for the plantation owners to build the biomass power plant as the supply of the biomass waste from their own plantation can be ensured. The locations at P09 and P17 are at the coastal area near Sandakan and Kinabatangan area and may not be suitable for biomass power plants. P09, P15 and P19 are at the internal hilly area with limited access. Therefore, if we are to discount these five locations, the biomass potential will be reduced to 4996 MW with an annual generation of 35013 GWh.



Sabah Land Area

Existing Oil Palm Plantation

Sabah Power Grid

X Proposed Biomass Power Plant Location

Figure 6-12: Potential Biomass Power Plant Locations with Respect to the Plantation Area

Based on the above findings, further analysis has been carried out in Chapter 8 on the GHG emission reduction potential using biomass waste. It was found that the emission factor of the power industry in Sabah could be reduced from 480 down to 349 CO_2-eq. per kWh, by using biomass waste.

6.6 Conclusion

With our large area of oil palm plantation, biomass is one of the more promising sources of RE in Malaysia. Malaysia is the second largest palm oil producer in the world. There is a lot of biomass waste available from the harvesting of palm oil. However, due to the relatively low energy density of the biomass, transportation cost of the biomass waste from the plantations to the biomass power plants for power generation may comprise a significant component of the electricity generation cost of the biomass power plant. This limitation due to the transportation cost is one of the key factors in preventing the biomass waste from being fully exploited for power generation.

In this chapter, a computer programme in Fortran has been developed to find the optimised location of biomass power plants for maximum utilization of the palm oil waste. With the programme, it is found that there are 20 feasible locations for biomass power plants, based on the existing oil palm plantation distribution in Sabah. The total capacity of these power plants are 4996 MW and the estimated output of electricity is 35013 GWh per year. This is sufficient to meet all the most of the electricity demand of Sabah up to 2030. Hence, the biomass power plants can potentially transform the power industry in Sabah into a zero carbon emission industry.

CHAPTER 7

GREEN BUILDING FEATURES

7.1 Introduction

Buildings have been identified as one of the key sectors in GHG emission reduction. Based on the study by the United Nations Environment Programme, buildings consume about 40% of the world energy (United Nations Environment Programme, 2007). In terms of GHG emission, the IPCC estimates that buildings contribute to about 25% of the world emission (Metz et al., 2007). The energy consumption of a building is dictated by the building design and a building is typically designed to last for more than 50 years. To reduce the GHG emission in the building sector, the design and construction of any buildings have to be planned in such a way that energy efficiency of the building is optimised.

To fulfil the objective of GHG emission, the building industry has started on the green building pursuit whereby buildings design with lower energy consumption and less environmental impact are promoted. As a result, many green building rating tools have been developed. Among the existing tools, the prominent ones are Building Research Establishment Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED). BREEAM was first introduced in the UK in 1990 (BREEAM, 2011) while LEED was introduced in the USA in 2000 (USGBC, 2011). The other tools include Building Environmental Performance Assessment Criteria (BEPAC, Canada), Green Building Tool (GBTool, more than 20 countries), Comprehensive Assessment System for Building Environmental Efficiency (CASBEE, Japan), Life Cycle Assessment/Life Cycle Cost (LCA/LCC Tool, Hong Kong), Green Building Evaluation System (EEWH, Taiwan), Green Star (Australia/New Zealand), and Green Mark (Singapore). Under the criteria of these tools, the indoor environmental quality is to be maintained or enhanced while lower energy consumption of the building is to be achieved. The comfort and well being of the building occupants cannot be compromised.

The rating tools enable buildings to be categorised systematically based on the environmental performance and occupant comfort. At the same time, the tools also assist the professionals to design better green buildings with optimal performance. The criteria in the tools serve as a guide to the designer in achieving the optimal building performance.

In Malaysia, the professionals in the construction industry have also embarked on the construction of green buildings. Before a local rating tool was available, they had to adopt the established ones from the foreign countries such as LEED and BREEAM. Green Mark is also a popular choice because of the similarity in weather condition between Singapore and Malaysia. However, the criteria in the imported tools do not totally match the local conditions. LEED and BREEAM, for example, are for countries with very different weather condition from Malaysia. While Green Mark is used in

Singapore which shares the tropical weather condition with Malaysia, its emphasis is tailored for the needs of the city state. Sixty two percent of the score is allocated for energy efficiency while only 5% for indoor environmental quality because of the extremely limited energy source in the city state. There is no criterion related to public transportation in Green Mark because the public transportation system in the city state is already among the most advanced in the world (BCA Green Mark, 2010). In addition, there are differences in the social and economical structure, national policies, local resources endowment and other factors between Malaysia and the other countries. These result in different emphasis and criteria in designing an optimal green building. Therefore, a rating tool tailored to meet the local requirements will be more effective and appropriate. Responding to this increasing demand, the Greenbuildingindex Sdn Bhd (GBISB) was set up in 2009 by the professionals in the construction industry to manage the rating, certification and accreditation process of green building in Malaysia. The first Green Building Index (GBI) rating tool was launched in 2009 (Tan, 2009).

Various studies on the energy saving and GHG reduction potential in the building sector have been conducted in Malaysia previously (Chwieduk, 2009, Mahlia et al., 2002, Mahlia et al., 2004, Mahlia et al., 2011). These studies have investigated the potential and effectiveness of various energy efficient measures for buildings in Malaysia, including insulation design of building envelops, implementing minimum energy efficient standards for air-conditioning units and refrigerators, and retrofitting of light fittings with energy efficient types. Other researchers have studied the potential GHG emission reduction that can be achieved through green building design (Oh and Chua, 2010), and the mechanism and criteria of GBI (Chua and Oh, 2011). However, these studies did not investigate the effectiveness of the green building rating tools and the associated mechanism, such as GBI, in reducing energy usage from the building sector.

In this chapter, the energy related aspects of GBI are studied in detail to establish its effectiveness in reducing energy demand from the building sector from the technical, environmental and cost effectiveness perspectives. First, the criteria of GBI are compared to other popular rating tools and the features related to energy efficiency are identified. Then, two case studies have been carried out to investigate the effectiveness of the tool in reducing energy consumption of buildings. In the case studies, the implemented technical features of the building, the resulted GHG emission reduction and the cost effectiveness of these features are investigated. The associated government incentives to encourage compliance with GBI criteria are also investigated and taken into consideration in the cost effectiveness analysis. Based on these, the potential of green buildings in Sabah are further analysed to ascertain the GHG emission reduction potential in the state.

7.2 Green Building Index and Building Energy Efficiency

GBI is a private sector driven initiative led by the professionals in the construction industry. The main objective is to provide opportunity for developers to design and construct green buildings based on the local conditions. It was designed to satisfy the following requirements (GBI, 2011a):

- Define green building by establishing a common language and standard of measurement;
- Promote integrated, holistic building design;
- Recognise and reward environmental leadership;
- Transform the built environment to reduce the environmental impact of development; and
- Ensure new buildings remain relevant in the future and existing buildings are refurbished and thereafter sustained properly to remain relevant.

Under the GBI framework, the certification mechanism is to be initiated by submission of an application form and payment of the requisite fee to Greenbuildingindex Sdn. Bhd. (GBISB) by the project owner or the appointed consultants. A GBI accredited facilitator may optionally be appointed by the applicant to advise on the design, submission and certification process. Within GBISB, accredited Certifiers will then access the project and produce a Certifier's report for each submission. Based on the report, the project will be presented to the GBI Accreditation Panel (GBIAP) to register and award the certification with the appropriate rating.

During design stage, the certification will lead to the award of a provisional GBI rating. Final award is given after the building is completed and occupied for one year. The award, however, has a validity of three years.

Re-assessment will be conducted every three years in order to ensure that the green building features are maintained throughout the building life.

GBI rating criteria are based on the basic principle of designing buildings with minimum environmental impact without compromising on the indoor environmental quality and occupant comfort. The criteria of the GBI tool are common to the prevailing rating tools. The criteria can be categorised into the following six categories:

- Energy Efficiency
- Indoor Environmental Quality (IEQ)
- Sustainable Site Planning & management
- material & Resources
- Water Efficiency
- Innovation

Based on the GBI tool for non-residential buildings, the weightage assigned to each category is compared with the other major tools (Leong, 2009a) as tabulated in Table 7-1. In terms of energy efficiency, the weightage allocated in GBI is 35%. This is the second highest among all the tools. It is only lower than the 62% allocated in Green Mark. The weightage is higher than that in LEED, BREEAM and Green Star. The weightage for water efficiency of GBI is 10%, marginally higher than that of the other tools. The weightages allocated for IEQ and Innovation are comparable to the others. The weightages for Sustainable Site and Material & Resources are lower than most of the tools, except Green Mark. Four categories of certification are awarded by GBI, according to the GBI points scored in the assessment, as per Table 7-2.

Table 7-1: Weightage of Criteria in GBI Compared to Other Tools

Rating Tools	Energy Efficiency	IEQ	Sustainable Site	Materials & Resources	Water Efficiency	Innovation
GBI	35%	21%	16%	11%	10%	7%
BREEAM	19%	13%	37%	17%	5%	9%
LEED	25%	22%	20%	19%	7%	7%
Green Mark	62%	5%	20%		9%	4%
Green Star	20%	19%	33%	16%	8%	4%

Table 7-2: GBI Building Classification

GBI points Scored	***GBI Classification***
Above 86	Platinum
76 to 85	Gold
66 to 75	Silver
50 to 65	Certified

Upon closer investigation, it is found that the criteria set out in all the 6 categories will affect the energy usage of a building either directly or indirectly. These criteria are evaluated and discussed in the following sections from the energy efficiency perspective.

7.2.1 *Criteria on Energy Efficiency*

GBI points are awarded directly for energy efficient features such as lighting zoning, which allows efficient control and minimises electricity consumption from artificial lighting. RE sources such as solar PV panel are also advocated. Installation of electric sub-metering is recommended to enable effective monitoring so that electricity consumption can be reduced. In addition, the building energy index (BEI) is used as a benchmark. GBI points are to be awarded if a lower BEI can be achieved for a building. Passive design features such as the overall thermal transfer value (OTTV) and roof thermal transfer value (RTTV) are also considered. GBI points are awarded if the OTTV is kept below 50 W/m^2 and RTTV below 25 W/m^2. The rest of the GBI points in this category are allocated to ensure that good maintenance practice is in place to preserve all the energy efficient features provided. All the 35 GBI points awarded in this category are directly related to energy efficiency.

In GBI tool, BEI is defined as in Equation 7-1.

$$BEI = \frac{(TBEC - CPEC - DCEC) \times \dfrac{52}{WOH}}{GFA_{ex.cp} - DCA - GLA \times FVR} \qquad \text{Equation 7-1}$$

where:

TBEC: Total Building Energy Consumption (kWh / year) for all landlord and tenancy areas;

CPEC: Carpark Energy Consumption (kWh / year) for carpark area (which is not air-conditioned) and typically covers artificial lighting, lifts, mechanical ventilation fans, sump pumps and plug loads (car washing facilities). Installations serving the whole building (such as hydraulic pumps and fire pumps) shall not be included;

DCEC: Data Centre Energy Consumption (kWh / year) for operation of the Data Centre equipment and for controlling its indoor environment (air-conditioning, mechanical ventilation, lighting and plug loads);

$GFA_{ex.cp}$: Gross Floor Area of buildings exclusive of car park area (m^2);

DCA: Gross area of Data Centre (m^2);

GLA: Gross Lettable Area (m^2) refers to the total functional use area for commercial purposes such as office, retail, cafeteria, restaurant, gymnasium and club house inside the building but excluding all common areas and service areas. The sum of GLA, common areas and service areas should equal the GFA excluding car park;

FVR: Floor Vacancy Rate is the weighted floor vacancy rate of office, retail and other functional spaces of GLA. The FVR (%) of GLA is equal to the non-occupied lettable area divided by the GLA.

52: Typical weekly operating hours of office buildings in KL / Malaysia (hours / week). This is equivalent to 2,700 hours / year.

WOH: Weighted Weekly Operating Hours of GLA exclusive of DCA (hours / week)

The *WOH* of the project can be computed using the Equation 7-2 below:

$$WOH = \frac{GLA_{retail} \times OH_{retail} + GLA_{office} \times OH_{office}}{GLA_{retail} + GLA_{office}}$$

Equation 7-2

where:

GLA_{retail}: GLA of the retail and F&B area;

GLA_{office}: GLA of the office area;

OH_{retail}: Operating hours of the retail and F&B area;

OH_{office}: Operating hours of the office area.

7.2.2 Criteria on Indoor Environment Quality (IEQ)

The criteria in this category are designed to maintain a minimal level of occupant's comfort. However, the following criteria in IEQ will also result in energy saving:

(a) Carbon dioxide monitoring and control: In addition to achieve better air quality, the carbon dioxide monitorifng will ensure that the ventilation fan is activated only when needed. Hence, it will avoid waste of energy in excessive running of the fan.

(b) Air change effectiveness: An air-conditioning design with effective air change will reduce the required fan capacity of the system.

(c) Daylighting: The increase daylight in the building will result in less energy use for electric lighting.

(d) Daylight glare control: Effective daylight glare control will reduce the need of closing the curtain and hence reduce the usage of electric lighting.

(e) Electric lighting levels: A design with optimal and non-excessive lighting level will reduce electricity consumption of the building.

(f) High frequency ballasts: In addition to reduce flickering effect of the fluorescent light, high frequency ballast is more efficient with lower ballast loss.

From the above, it is found that seven out of the total 21 GBI points in this category is related to energy efficiency.

7.2.3 Criteria on Sustainable Site

In this category, measures to control the pollutants and storm water run off from the site are specified. Brownfield sites and high density development are also encouraged to minimise the opening of greenfield site. Sites and building design which are conducive to public transportation are also rewarded with a total of 3 GBI points. This is to address the fact that 74% of the total energy consumption for a typical household in Malaysia is in the form of fuel for transportation (Singh, 2006). With increased usage of public transportation, the energy consumption can be reduced substantially. However, the proximity and access to public transportation is not within the control of a building developer most of the time. Rather, this has to be addressed in the master planning of the city transportation system. Therefore, this criterion is not analysed in the subsequent analysis.

The only other criterion within this category that results in lower building energy consumption is on the green roof requirement. A green roof with lower heat transfer value will result in a cooler building with less energy required for the air-conditioning and ventilation system. A total of one GBI

GBI point is allocated for this feature.

7.2.4 *Criteria on Material and Resources*

Sustainable timber is encouraged while environmentally harmful materials are to be avoided as specified in the criteria in this category. Regional, recycled and reused materials are also recommended. From the energy efficiency perspective, the recycled and reused materials normally required less energy to produce, while the use of regional material will reduce the energy consumption in transportation. However, from the life cycle analysis, building materials represent only 2% of total cost. The potential saving of energy from the criteria in this category is negligible over the lifetime of the building. The only criterion within this category of GBI criteria that results in lower building energy consumption is on the green roof requirement. Therefore, this is not considered in the subsequent analysis.

7.2.5 *Criteria on Water Efficiency*

In this category, water efficient fittings, water leakage detection and rain water harvesting are encouraged to reduce the consumption of potable water. It is found in the previous research that the water treatment and pumping of potable water on average consumes 0.44 kWh per cubic metre of water supply (Venkatesh and Brattebo, 2011). Therefore, reduction of water consumption will indirectly reduce the energy consumption of the building. A total of 10 GBI points are allocated in relation to water efficiency in GBI tool.

7.2.6 *Criteria on Innovation*

A total of six GBI points are awarded for innovative green building features. Energy efficient and energy saving features such as condensate water recovery, solar thermal technology, heat recovery system, heat pipe technology, cogeneration, and light pipes are qualified for the award of GBI points in this category.

From the above analysis, 62 GBI points out of the total 100 points are awarded for features that are either directly or indirectly related to energy efficiency.

In additional to non-residential buildings, GBI has also developed rating tools for residential buildings, industrial buildings and township. The basic principle presented above is maintained in these tools. However, the emphasis and weightage are different to suit the different requirements for these developments.

Although GBI was started as a private sector initiative, it has been endorsed by the Malaysian government. In the effort to reduce the country's GHG emission, the building sector has been identified as one of the key sectors. Subsequently, tax incentive has been announced in Budget 2010 for the investment in GBI rated buildings. Firstly, building owners obtaining GBI Certificates from 24th October 2009 until 31st December 2014 are given income tax exemption equivalent to the additional capital expenditure in obtaining such Certification. Secondly, buyers purchasing buildings with GBI Certificates from developers are given stamp duty exemption on instruments of transfer of ownership. The exemption amount is equivalent to the additional cost incurred in obtaining the GBI Certification. This exemption is given to buyers who execute sales and purchase agreements from 24th October 2009 until 31st December 2014 (Najib Tun Rajak, 2009). These incentives will enhance the financial attractiveness in green buildings as illustrated in the calculations given in the following sections.

7.3 Case Study 1 - Effectiveness of GBI Tool in Building Design

To study the effectiveness in the GBI tool in reducing building energy consumption, a green building design which targeted for GBI Platinum rating is investigated in detail in this section. The project consists of a 16-storey open plan office tower on 3 levels basement car park. The gross floor area of the building is 10,890 m^2, which is built on a land area of 4,028 m^2. A total of 164 car parks are provided in the basement car park. The construction cost of the base building without the green building features was RM80 millions. The perspective drawings indicating the design and location of the building is shown in Figure 7-1,

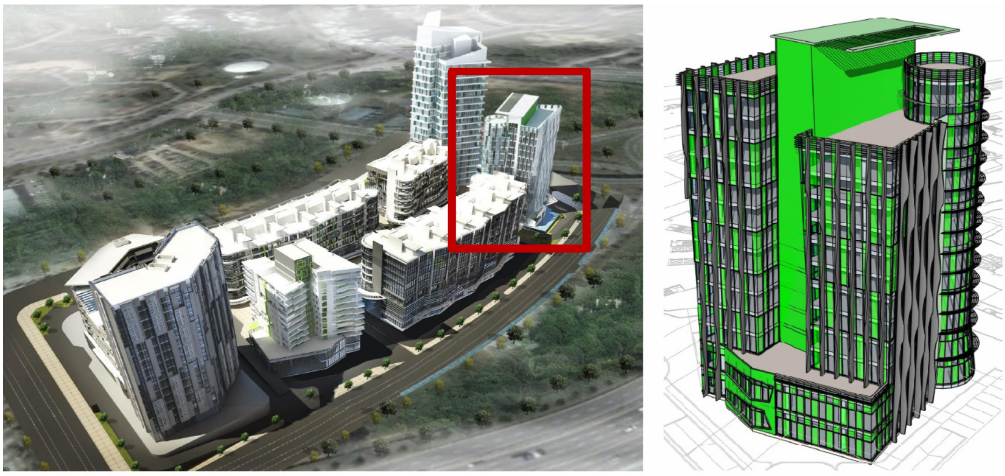


Figure 7-1: The Case Study – A GBI Platinum Design for a new Office Building at Mutiara Damansara

The green building features is designed to achieve the Platinum rating. A total of 88 GBI points were targeted. The additional cost for these green building features is RM7,467,044, with the break down provided in Table 7-3. Among the green building features implemented, most but not all are energy related. In the subsequent sub-sections, the technologies behind the energy related green building features are investigated in details.

Table 7-3: GBI Score and Cost for Project in Case Study 1

Item	*Description*	*GBI Score*	*Additional Cost (RM)*
1	Energy Efficiency	32	5,175,400
2	Indoor Environmental Quality	21	671,400
3	Sustainable Site Planning & Management	13	161,000
4	Material & Resources	8	94,200
5	Water Efficiency	7	145,044
6	Innovation	7	1,220,000
	TOTAL	88	7,467,044

7.3.1 OTTV

The OTTV is part of the Energy Efficiency in Category 1 of the GBI criteria. Although only 1 GBI point is allocated, it has a major impact on the energy consumption of the building. It determines the amount of heat that will be allowed into the building. The excess heat in a building will need to be removed using mechanical ventilation or air-conditioning system. Hence, a higher OTTV will result in high energy consumption of the mechanical ventilation and air-conditioning system. The OTTV calculation includes all forms of solar energy entering the building through the building envelope. The energy is transmitted through conduction and radiation and the OTTV can be computed using Equation 7-3 as defined in the Malaysian Standard (SIRIM, 2007).

$$OTTV = 15\alpha(1 - WWR)U_W + 6(WWR)U_f + (194 \times CF \times WWR \times SC) \qquad \text{Equation 7-3}$$

where:

WWR : Window to gross exterior wall ratio;

α : Solar absorptivity of the wall;

U_W : Thermal transmittance of the opaque wall (W/m^{2}K);

U_f : Thermal transmittance of the window (W/m^{2}K);

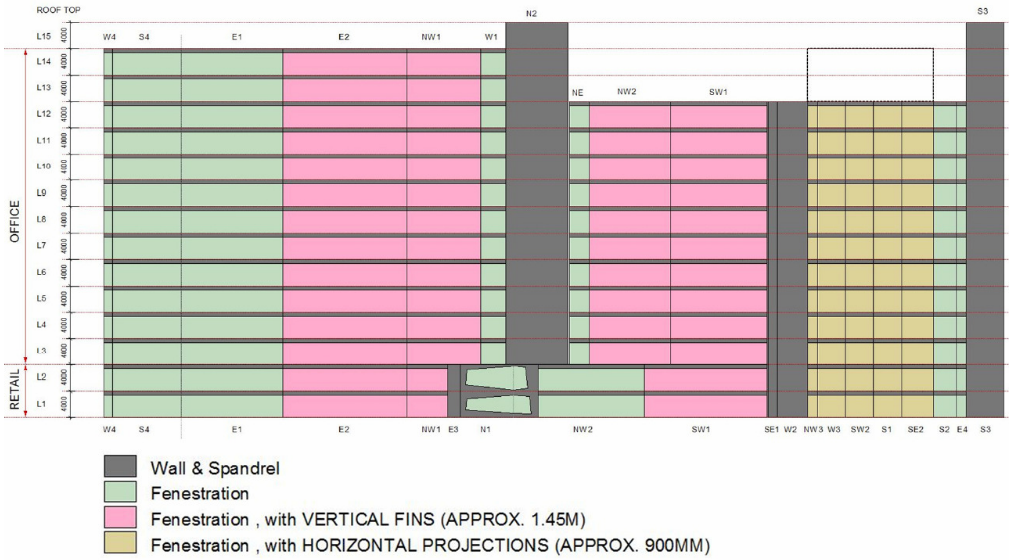
CF : Solar correction factor based on the orientation of the wall is facing as given in MS 1525 – Table 1 (SIRIM, 2007);

SC : Shading coefficient of the window;

The OTTV of the base building is first calculated. In order to calculate the OTTV, all external walls of different orientations are projected onto a single drawing as shown in Figure 7-2. Then, the solar radiation and conduction through each section of the external wall is calculated. Also, the wall surface areas are measured using the AutoCAD tool. The OTTV can then be computed and is found to be 143.31 W/m^2. The total heat load in the building from solar radiation and conduction is found to be 1,034 kW.

To reduce the OTTV and the heat load, the following measures have been implemented:

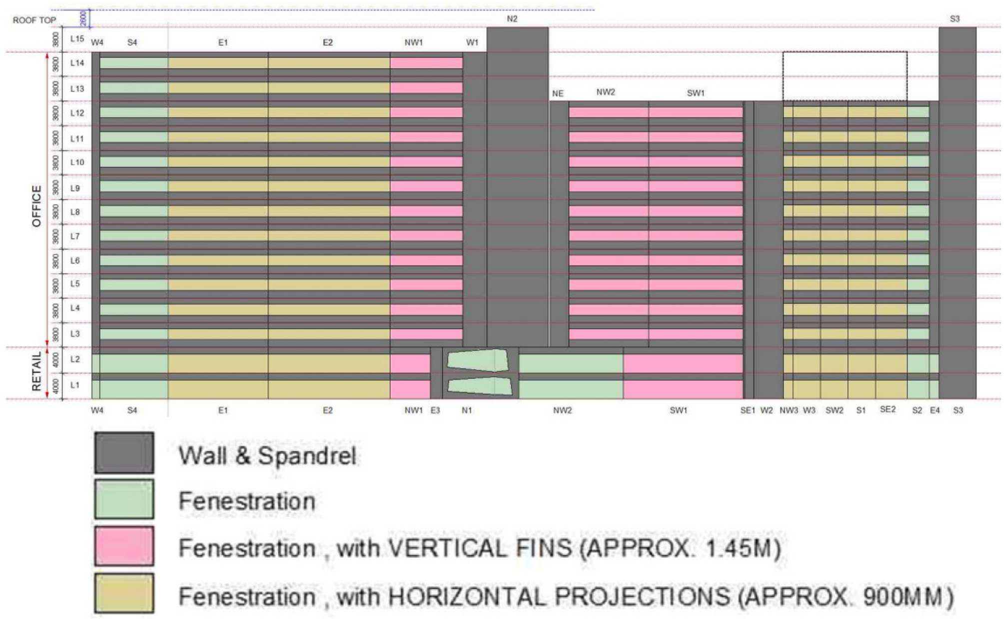
- Double glazing with low U_f was used for all window instead normal clear tempered glass
- Plenum was insulated
- The full height window was reduce to 1700mm high
- At the wall facing east, west and north east, all windows that were not critical in providing day lighting and view were removed and replaced with solid wall
- Horizontal sun shade was introduce on the east facing wall to improve the shading coefficient



Elevation	Facade Area [m^2]		OTTV [W/m^2]	A x OTTV
Heat Conduction Through Walls	2,088.08	$15\alpha A_W U_W$	11.58	24,196.04
Heat Conduction Through Windows	5,128.68	$6[A_f]U_f$	34.20	175,400.39
Solar Heat Gain Through Windows	5,128.68	[194 x CF x A_f x SC]	162.74	834,653.13
Total	**7,216.76**	$\frac{[A_1 \times OTTV_1 + A_2 \times OTTV_2 + \ldots + A_n \times OTTV_n]}{\text{Overall façade area}}$	**143.31**	**1,034,249.56**

Figure 7-2: OTTV Calculation of the Base Building

With the above measures, the OTTV is reduced to 33.22 W/m^2. The total heat load from solar heat gain has been reduced by 804 kW, down to 230 kW as shown in Figure 7-3. The resulted reduction in electricity consumption is taken into consideration in the calculation of BEI in the following section. A total of RM211,000 is spent on improving the building envelope to achieve the desired OTTV.



Elevation	Facade Area [m^2]		OTTV [W/m^2]	A x OTTV
Heat Conduction Through Walls	4,313.91	$15\alpha A_w U_w$	8.27	35,669.79
Heat Conduction Through Windows	2,596.64	$6[A_f]U_f$	13.20	34,275.62
Solar Heat Gain Through Windows	2,596.64	$[194 \times CF \times A_f \times SC]$	61.47	159,622.84
Total	**6,910.55**	$\frac{[A_1 \times OTTV_1 + A_2 \times OTTV_2 + ... + A_n \times OTTV_n]}{\text{Overall façade area}}$	**33.22**	**229,568.25**

Figure 7-3: OTTV Calculation of the Building with Additional Green Building Features

7.3.2 Other Energy Efficiency Features

In addition to the reduction in OTTV, the other energy efficiency features implemented are:

- Lighting Zoning (3 GBI points)
- Renewable Energy (5 GBI points)
- Reduction on BEI (12 GBI points)

ZONE	AREA	TYPE OF LIGHTING CONTROL TO BE USED
	Area with Daylight Support	Lux Sensor to be used and lighting will only turn "ON" when lux level is insufficient
	Office without Daylight Support	Proper labelled lighting swithes with zoning map and lighting zone control shall be within 100sq.meter
	Lobby without Daylight Support	Time Delay Motion Sensor to be used to switch "OFF" lighting when no sense of motion pulse.
	Staircase with Daylight Support	Lux Sensor to be used and lighting will only turn "ON" when lux level is insufficient
	Toilet without Daylight Support	Time Delay Motion Sensor to be used to switch off lighting when no sense of motion pulse.
	AHU Room without Daylight Support	Time Delay Motion Sensor to be used to switch off lighting when no sense of motion pulse.
	Riser Room without Daylight Support	Independent switch control at every riser

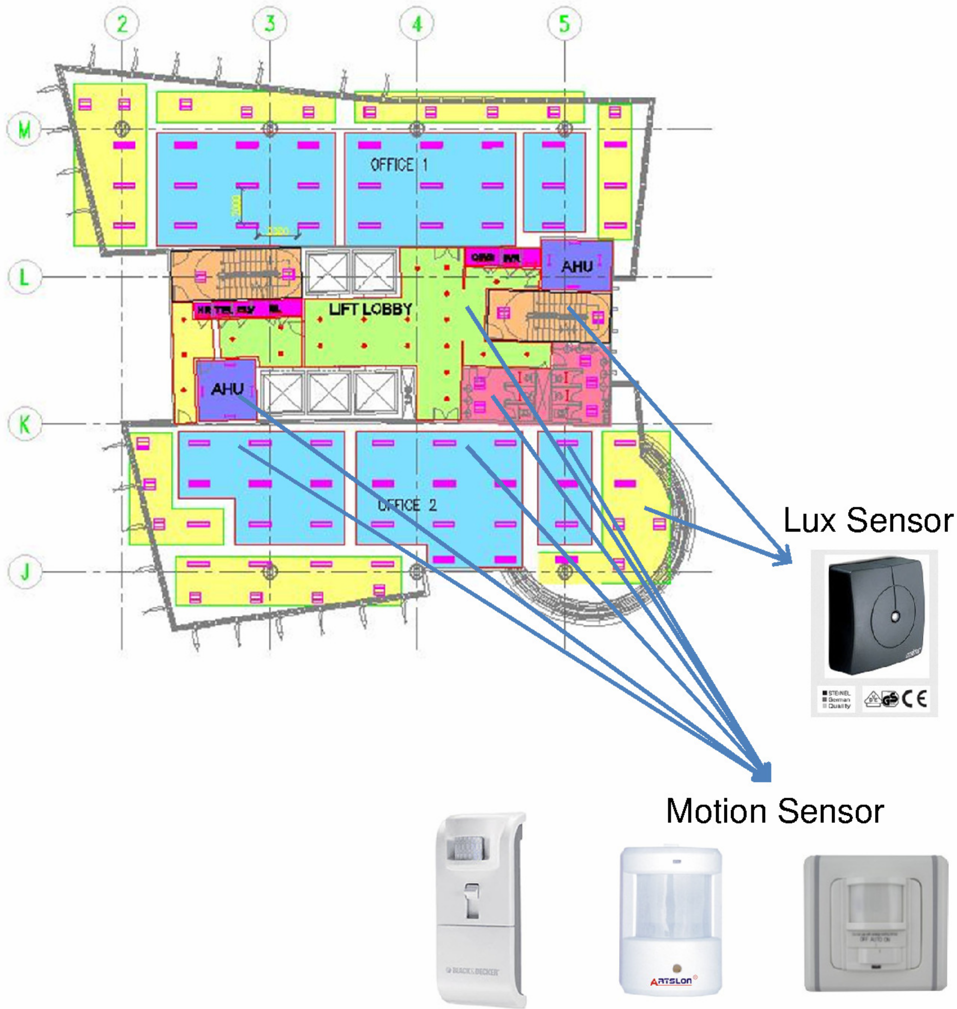


Figure 7-4: Lighting Design for a Typical Floor Incorporated Appropriate Zoning, Motion Sensors and Lux Sensors

First, optimal lighting zoning is incorporated into the circuit design to enable the occupants to turn on only the required zone of lighting when needed. Each lighting zone is to be less than 100 m^2. In addition, motion sensors at the common circulation area have been included in the design such that the light can be turned off automatically when there is no one in the zone. For area with day lighting, light sensors have been incorporated to automatically turn off the electrical light fittings when there is sufficient day light to maintain a minimal lighting level of 300 lux. The lighting design for a typical floor is shown in Figure 7-4. With the design, the lighting energy consumption has been reduced from 713,042 kWh per year to 94,004 kWh per year. This is equivalent to an 87% saving in energy. The total additional cost incurred for the design was RM89,600.

For RE, a PV system of 40 kWp is installed in order to qualify for the 5 maximum GBI points in the GBI tool. Based on thin film (amorphous silicon) system, the annual energy generated is 47,200 kWh. The total cost for the system is RM720,000.

The BEI of the project has been reduced substantially from 268 kWh/m^2 to 99 kWh/m^2. This is achieved by reducing the energy consumption from lighting, small power point and air-conditioning system. The addition cost incurred for the features implemented is RM3,920,000. The reduction in lighting energy consumption is achieved with the design described in Figure 7-4. In addition, electronic ballast and T5 fluorescent lamps with high energy efficiency are used for all fluorescent light fittings. For small power points, the occupants are required to use only energy efficient equipment such as notebook computer instead of desktop computer to achieve the energy reduction. For the air-conditioning system, the following advanced energy efficient features have been incorporated:

- Energy efficient water cooled chiller system
- Ultra high efficiency centrifugal chiller
- High differential chilled water temperature difference to reduce the pumping energy
- Low noise plug fan for the air handling unit (AHU) to eliminate the need of a silencer and hence avoiding the energy loss due to the static pressure of the silencer
- High efficiency AHU cooling coil with low pressure drop to reduce the pumping energy
- High energy efficiency motor for all pumps
- Oversized cooling tower for higher chiller efficiency
- Adopting the underfloor air distribution (UFAD) method to reduce the effective cooling load as illustrated in Figure 7-5
- The condensate water collected from the building AHU are channelled to the condenser side of the chiller to provide a lower water temperature entering the chiller which results in lower chiller energy consumption
- Auto condenser tube cleaning system for the chiller to eliminate scale formation and fouling so that maximum efficiency of the chiller can be maintained

- Advance air filtration system to reduce the static pressure of filter at the AHU and reduce energy consumption of the fan
- Lower OTTV as described above

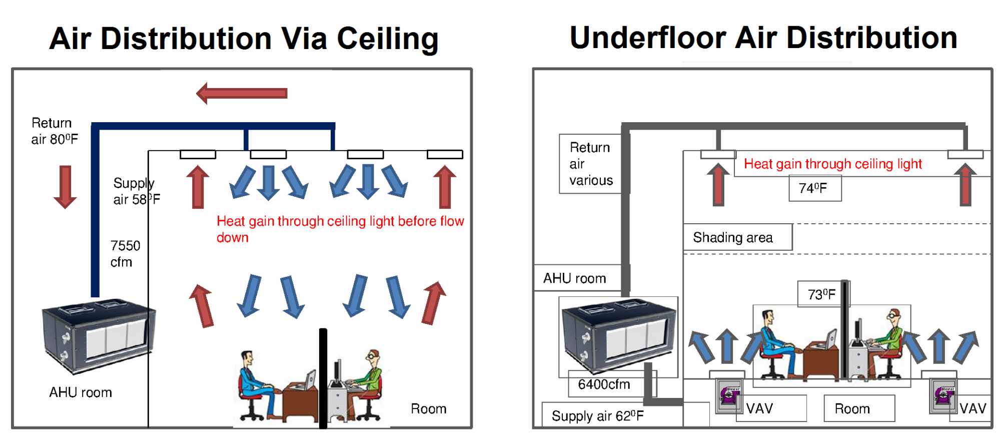


Figure 7-5: Effective Cooling Load is Reduced with UFAD

7.3.3 Features for Indoor Environmental Quality

The following green building features implemented for indoor environmental quality also contribute to the reduction the energy consumption of the building:

- Carbon Dioxide Monitoring and Control (1 GBI point)
- Air Change Effectiveness (1 GBI point)
- Day Lighting (2 GBI points)
- Daylight Glare Control (1 GBI point)
- Electric Lighting Level (1 GBI point)
- High Frequency Ballasts (1 GBI point)

Carbon dioxide sensors are installed at all AHU to ensure that sufficient fresh air is introduced to keep the carbon dioxide level below 1,000 ppm. At the same time, this also reduced the fresh air intake during low occupancy of the building. The fresh air drawn from outside the building need to be cooled down to the desired temperature and excessive fresh air intake will consume additional energy. Hence, with less fresh air intake during low building occupancy, less energy is consumed. The cost for all the carbon dioxide sensors is RM5,000 and the energy reduction has been taken into consideration in the above BEI calculation.

The air change effectiveness is designed to achieve above 95% efficiency. With more effective air change, the occupants will be kept comfortable without having to set the temperature lower than the optimal level. This will reduce the energy consumption of the air conditioning system. A total of RM30,000 is allocated for computer fluid dynamic (CFD) modelling to ensure the air change effectiveness was achieve.

The building is design to achieve the optimal daylight factor with glare control. Based on the design, the daylight factor of between 1% and 3.5% has been achieved at 52% of the total net floor area. This abovementioned range of daylight factor is the optimal level whereby the occupant can work comfortably without the need of electric lighting. A total of RM483,000 is spent on the glare control features.

The electric lighting level is designed according to MS1525 (SIRIM, 2007) such that the optimal lighting level is achieved without excessive lighting being provided. There is no additional cost incurred for this compliance. In addition, high frequency ballast with T5 fluorescent lamps is used to reduce the flickering effect of the lighting and improve the comfort level of the occupants. At the same time, this reduces the energy consumption of the light fittings. A total of RM86,000 is spent on upgrading the light fitting to comply for this requirement.

7.3.4 Features for Sustainable Site Planning & Management

The only criterion within this category of GBI criteria that results in lower building energy consumption is on the green roof requirement. One GBI point is scored for this criterion by having a green roof for at least 50% of the total roof area, or having 75% of the roof area installed with high solar reflective index (SRI) material. A combination of green roof and roof with high SRI material is also acceptable. For this project, 30% of the roof area is green roof and the remaining 70% is covered with high SRI material. The total cost is RM65,000. The energy reduction has been taken into consideration in the computation for the BEI

7.3.5 Innovative Features

The following innovative features are implemented, which also resulted in reducing the energy consumption of the building:

- Condensate water recovery system (1 GBI point)
- Auto condensate tube cleaning system (1 GBI point)
- Advanced air filtration technology (1 GBI point)

These features result in the lower energy consumption of the air conditioning system and have been described and discussed in details in the previous section on BEI. The total cost for these innovative features is RM730,000.

7.3.6 Summary for Case Study 1

In summary, out of the total 88 GBI points scored, 32 points were related to reducing the energy consumption of the building, as shown in Table 7-4. The total additional cost incurred is RM6,433,800.

Table 7-4: Summary of Energy Related Features Based on GBI Criteria

Item	*Description*	*GBI Score*	*Additional Cost (RM)*
1	Energy Efficiency	21	4,940,600
2	Indoor Environmental Quality	7	604,000
3	Sustainable Site Planning & Management	1	65,000
4	Material & Resources	0	94,200
5	Water Efficiency	0	0
6	Innovation	3	730,000
	TOTAL	32	6,433,800

With the features implemented, the BEI of the building has been reduced from 268 kWh/m^2 to 99 kWh/m^2. The total energy consumed by the building has been reduced from 3,017,942 kWh per year to 1,164,859 kWh per year. This represents a 61% reduction in the building energy consumption.

Table 7-5: NPV and ROI Calculation for Investment for Case Study 1

Item	*Description*	*Unit*	*Without PV*	*With PV*
A	BUILDING & COST			
	Base Building BEI	kWh / year / m^2	268	
	BEI with EE Features	kWh / year / m^2	103	99
	Base Building Energy Consumption	kWh / year	3,017,942	
	Green Building Energy Consumption	kWh / year	1,164,859	1,117,859
	Energy Saved	kWh / year	1,853,083	1,900,283
	Base Building Cost	RM	80,000,000	

Table 7-5: NPV and ROI Calculation for Investment for Case Study 1

Item	*Description*	*Unit*	*Without PV*	*With PV*
	Building Cost include EE Features	RM	85,713,800	86,433,800
	Cost of EE Features	RM	5,713,800	6,433,800
	Electricity Price	RM / kWh	0.43	
	Cost saved per year	RM / year	796,912	817,122
	Annual Discount Rate	%	6	6
B	NPV WITHOUT TAX INCENTIVE			
	NPV (20 years)	RM	3,426,714	2,938,521
	Break Even Period	Years	10	12
C	NPV WITH TAX INCENTIVE			
	Total Saving From Tax Exemption (25% of Additional Capital Expenditure)	RM	1,428,450	1,608,450
	NPV (20 years)	RM	4,774,309	4,455,927
	Break Even Period	Years	7	8
D	NPV WITH TAX INCENTIVE AND FiT			
	FiT rate for PV	RM / kWh	NA	1.2
	Total Saving From Tax Exemption (25% of Additional Capital Expenditure)	RM	NA	1,608,450
	NPV (20 years)	RM	NA	4,871,023
	Break Even Period	Years	NA	8

The return on investment is calculated as shown in Table 7-6. From the calculation, it is found that the break even period is 10 years if considering the PV system is not considered. With the PV system included, the period is increased to 12 years. When the tax incentive is taken into consideration, the period is reduced to 7 years and 8 years for the option without and with PV respectively. When the FiT at RM1.20 per kWh is also taken into consideration, the period remains at 8 years for the option with PV due to the relatively small size of the PV system installed. However, the NPV at 20 years is higher, at RM4,871,023, when FiT has been taken into consideration. Without FiT, the NPV is RM4,455,927.

7.4 Case Study 2 – Measured Data from Green Energy Office Building

The second case study is carried out on a building that has been completed and occupied with real life measured data. The Green Energy Office Building (GEO) which houses the Malaysia Green Technology Corporation (MGTC) is the first building certified under GBI. It was certified on 24th September 2009. The gross floor area of the building is 4,152 m^2 and the net air-conditioned area is 3,175 m^2. The total construction cost is about RM 18 million, which is about 45% higher than the average construction cost. The cost is inclusive of the 92 kWp of PV panels (Shafii, 2007). In this case study, the energy data collected by the energy consultant after the building has been commissioned are analysed.

7.4.1 Energy Efficiency Features of GEO Building

The GEO building is designed with many energy efficiency features. On the passive energy efficiency features, the building is oriented such that there are minimum windows and door openings on the east and west facing façade. In addition, the windows are equipped with double glazing and low-E coating and the wall is insulated with 100 mm mineral wools to achieve a u-value of 0.56 W/m^2/K. The façade adopted a step-in design as shown in Figure 7-6. Self shading is achieved in this facade design whereby the upper floor is able to provide shading for the floor below.

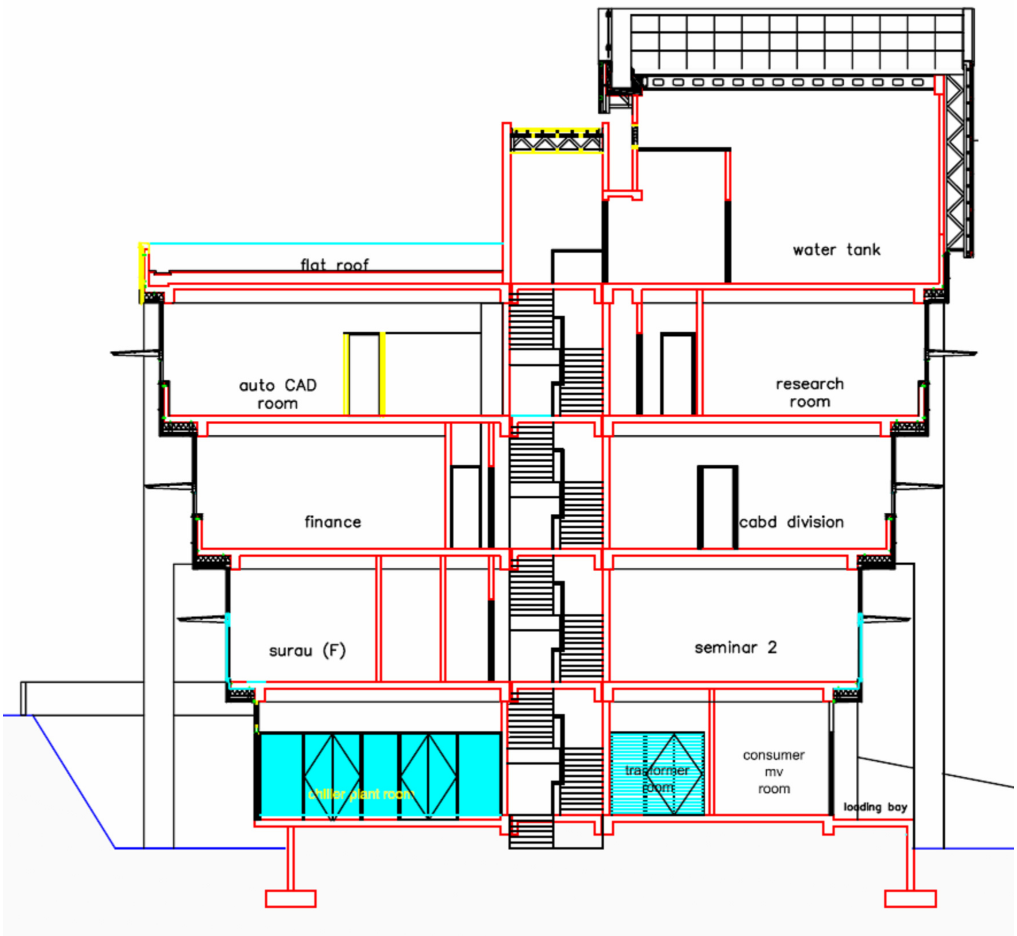


Figure 7-6: GEO Building with Step-in Façade (Source: (Reimann, 2010))

Based on measurement, the lighting power has been reduced to 0.56 W/m^2. This is achieved with almost 100% day light. The building is also equipped with light shelf, sky light, integrated blind, task light, and automatic lighting control using occupancy sensors and light sensors. An office equipment policy is also put in place to ensure that only energy efficient equipments such as notebook computers are to be selected.

The energy efficiency components selected for the air-conditioning include chiller with high coefficient of performance, energy recovery, reduced chilled water pumping, energy efficient pumps, energy efficient fans and variable speed drives. Floor slab cooling is also incorporated as an innovative feature.

In addition, 92 kWp of PV solar panels and a rain water harvesting system with 16,820 litres capacity are installed. The rain water harvesting system is able to meet 60% of the building water demand.

The electricity consumption has been measured for a 15 month period after the building was commissioned and presented in Figure 7-7. The numbers have been normalized to 30 days for each month for easier comparison. There is a major reduction in energy consumption after April 2009 when the air-conditioning system is calibrated and updated using a cooling tower with higher energy efficiency. The average net electricity of the building is lowered to about 9,000 kWh per month.

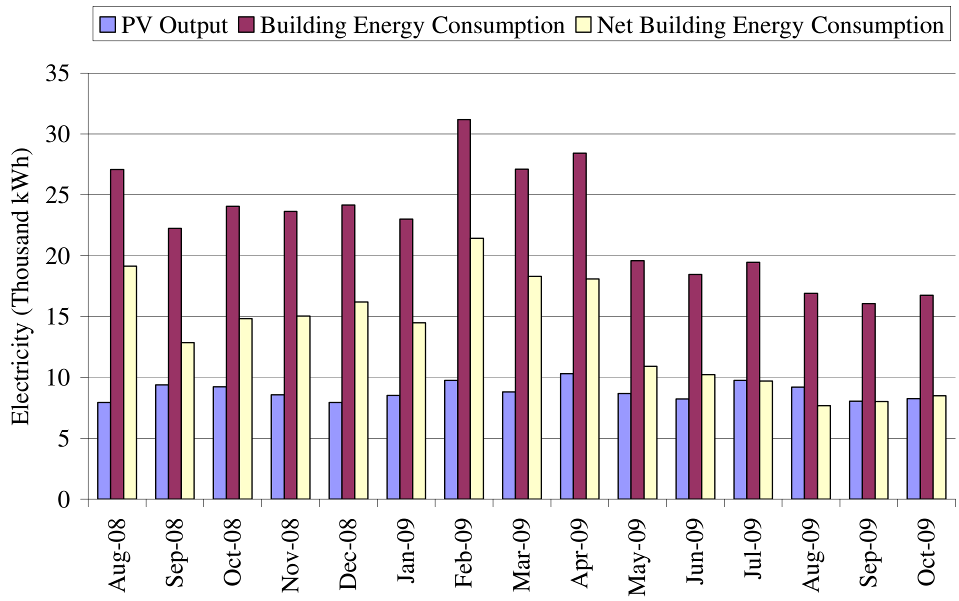


Figure 7-7: Measured Electricity Consumption and PV Generation at GEO Building

Using Equation 7-1, the BEI of the building is computed based on a net floor area of 3,175 m^2. The average BEI is found to be around 68 kWh / m^2 per year, without considering the contribution of electricity generated by the PV panels. Including the PV contribution, the BEI is lowered further to 35 kWh / m^2 per year. This is substantially lower compared to the average BEI of 275 kWh / m^2 per year in Malaysia (Lau et al., 2009).

7.4.2 Summary of Case Study 2

During the cost analysis of the project, it is found that the construction cost based on conventional design is RM 2,900 per m^2 of gross floor area. With all the energy efficiency features, the cost increases to RM 3,499 per m^2. With the cost of the solar PV system included, the cost further increases to RM 4,210 per m^2 (Shafii, 2007). Based on these cost data, the return on investment analysis was computed and presented in Table 7-6. Without the PV, the NPV is RM 422 per m^2 over a 20 year period and the break even period is 9 year. This is based on the initial investment of RM599 per m^2 and a 6% discount rate. No tax incentive is included in this calculation. With the tax incentive included, the NPV increases significantly to RM 921 per m^2 and the break even period is reduced to 3 years.

Table 7-6: Calculation on the NPV and ROI for Investment on Green Building Features

Item	*Description*	*Unit*	*Without PV*	*With PV*
A	BUILDING & COST			
	Base Building BEI	kWh / year / m^2	275.00	
	BEI with EE Features	kWh / year / m^2	68.00	35.00
	Energy Saved	kWh / year / m^2	207.00	240.00
	Base Building Cost	RM / m^2	2,900.00	
	Building Cost include EE Features	RM / m^2	3499.00	4210.00
	Cost of EE Features	RM / m^2	599.00	1,310.00
	Electricity Price	RM / kWh	0.43	
	Cost saved per year	RM / year / m^2	89.01	103.20
	Annual Discount Rate	%	6	6
B	NPV WITHOUT TAX INCENTIVE			
	NPV (20 years)	RM / m^2	421.94	-126.30
	Break Even Period	Years	9	> 20
C	NPV WITH TAX INCENTIVE			

Table 7-6: Calculation on the NPV and ROI for Investment on Green Building Features

Item	*Description*	*Unit*	*Without PV*	*With PV*
	Total Saving From Tax Exemption (25% of Additional Capital Expenditure)	RM / m^2	149.75	327.50
	NPV (20 years)	RM / m^2	921.28	174.78
	Break Even Period	Years	3	16
D	NPV WITH TAX INCENTIVE AND FiT			
	FiT rate for PV	RM / kWh	NA	1.2
	Total Saving From Tax Exemption (25% of Additional Capital Expenditure)	RM / m^2	NA	327.50
	NPV (20 years)	RM / m^2	NA	466.23
	Break Even Period	Years	NA	11

When the PV panels are included, the NPV is –RM126,30 per m2 without tax incentive. With tax incentive, the NPV is improved to RM174.79 per m2. The investment is found to be viable when the incentive is included and the break even period is 16 years. With FiT of RM 1.20 per kWh included, the NPV is RM 466 per m^2. The break even period is 11 years.

7.5 GHG Emission Reduction Analysis

Based on the statistics (Malaysia Energy Commission, 2007), the commercial buildings consumed 34% of electricity in Malaysia in 2009. With the projected power demand in Sabah as presented in Figure 4-1, the total energy demand by the commercial building can be computed. Assuming that 80% of the new buildings to be constructed will adopt the energy efficiency features without installing the PV panels, the electricity that is to be saved from the commercial buildings in Sabah is calculated and plotted against the business as usual scenario for a 20 year period as shown in Figure 7-8. The PV system is not taken into consideration in this analysis as it is investigated in a separate scenario in this thesis. From the above case study, the energy reduction in case study 1 is 61% whereas that in case study 2 is 75%. A lower figure of 61% is adopted in the subsequent analysis.

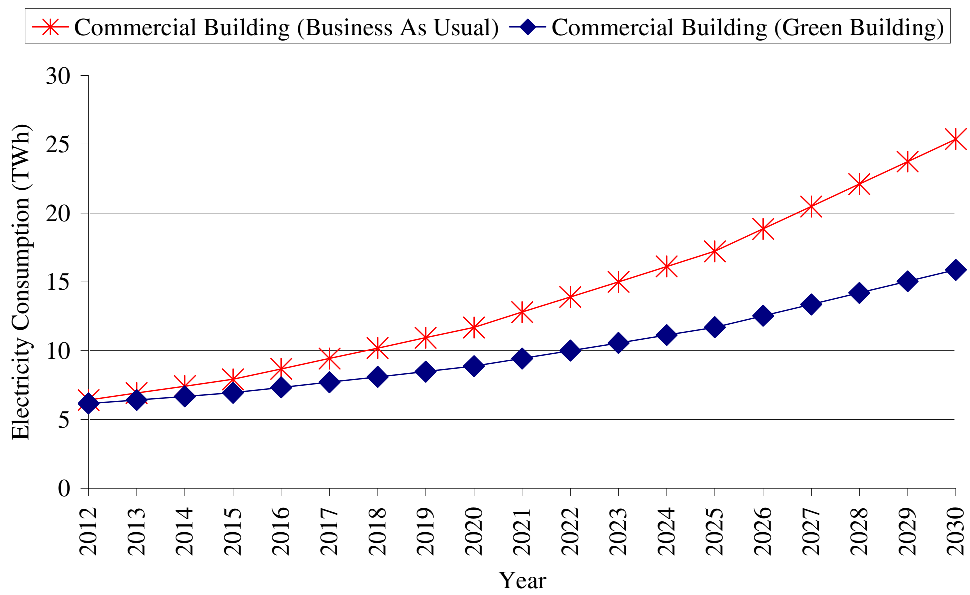


Figure 7-8: Electricity Consumption of Commercial Buildings in Sabah

Based on the electricity demand projection by UNDP, the total electricity consumed is calculated to be 265 TWh in the business as usual scenario. With the energy efficiency features, it is reduced by 28% to 190 TWh. Based on the average emission factor of 480 ton CO_2 per GWh for electricity generation in Sabah, the total amount of GHG emission avoided is 36 million ton CO_2 over the period. This represents a 28% reduction.

7.6 Discussion of Results

In the case study on the first GBI certified building (Case Study 2), it is found that the energy efficiency features implemented have been proven to be effective and technically feasible.

To assess the cost effectiveness of this option in reducing GHG emission, the cost per unit of GHG emission avoided is computed using the method as outlined in (Koh et al., 2011). A plant life time of 20 years and an annual interest rate of 6% are applied in the calculation. It is found that the cost of emission avoided for the energy efficiency features, without the PV panels, is RM 131 per tCO_2 in Case Study 1 and RM 96 per tCO_2 in Case Study 2.

In comparison, 1 kWp PV system costs RM18,000 and generates on average 1,180 kWh of electricity per year. Applying the same method, the cost of emission avoided using PV panel is about RM 2,342 per tCO_2. Therefore, the energy efficiency option is found to be much more cost effective in reducing GHG emission.

On the GHG emission potential, the study shows that green building features in the commercial building sector in Sabah can potentially reduce the GHG emission by 36 million tCO_2. This is a significant amount of GHG emission avoided that can be capitalised through carbon trading scheme such as the Programmatic CDM (Figueres and Philips, 2007). Based on a conservative estimation of RM 50 per tCO2, a total of RM 1.8 billion could be generated.

7.7 Conclusion

The GBI rating tool has been analysed in this study on the relevant components for energy efficiency in buildings. It is found that 62% of the criteria will influence the building design for lower energy consumption, either directly or indirectly. Therefore, the adoption of the tool in building design can reduce the electricity consumption and hence GHG emission from the building sectors.

The first GBI certified building is examined by studying the measured data on energy consumption. It is found that the energy efficiency features implemented have managed to reduce the electricity consumption by 75%. If the PV panels are taken into consideration, a further 12% reduction is achieved. From the financial analysis, the energy efficiency features are viable investments, with a payback period of 11 years. With the tax incentive taken into consideration, the payback period is reduced to 3 years. The PV panels, however, are found to be a less attractive investment. It is found to be viable only with the tax incentive and FiT taken into consideration. Therefore, the GBI tool can be an effective catalyst to drive the GHG emission reduction in the building sector.

Despite the attractive value proposition, the GBI has yet to receive wide acceptance in the industry. Based on the published information by GBI (GBI, 2011b), there are only two commercial buildings certified. So far, including all projects in the design and construction stage, there are only 15 buildings certified. Based on the findings from a survey conducted on the practitioners from the industry (Ang, 2010), the low take up rate is mainly due to lack of knowledge and skilled workers in green building technology. Therefore, additional efforts should be carried out to improve the public awareness on the GBI initiatives and to train more experts in designing green buildings. The potential financial income from carbon trading of RM 1.8 billion can be utilised in the required training programme, as well as other measures to reduce the cost and hurdles of constructing green buildings.

Instead of benchmarking buildings based on fixed BEI, future research can also be carried out to study the benefit of benchmarking based on the average BEI of new buildings, as described in (González et al., 2011). The average BEI will decrease as new technologies in energy efficiency are developed. As a result, the benchmark criteria for building design based on the average BEI will become more stringent as well. Following this method, the maximum reduction in electricity consumption can be achieved.

CHAPTER 8

METHODOLOGY FOR LOW CARBON ENERGY PLANNING

8.1 Introduction

In this chapter, a methodology to systematically identify the most cost effective scenario for long term planning in GHG emission reduction is developed and presented. The methodology is applied to find a solution for the energy sector in Sabah to meet the increasing power demand at an affordable cost while achieving the environmental objective of maximum GHG emission reduction.

In the following sections of this chapter, the developed methodology is first described in detail. Then, alternative scenarios are created. In each alternative scenario, a potential GHG emission reduction technology as found in the previous chapters is selected. The selected technologies must be matured and do not require advanced level of technical expertise to implement so that they can be successfully implemented in developing economies. Through the iterative process as defined in the methodology, an optimal combination of the technologies can be found to meet the power demand in Sabah. In the optimal solution, the maximum GHG emission reduction is achieved with the lowest cost.

8.2 Methodology

The methodology is summarised in the flow chart as shown in Figure 8-1. Each process in the flow chart is explained in detail in this section.

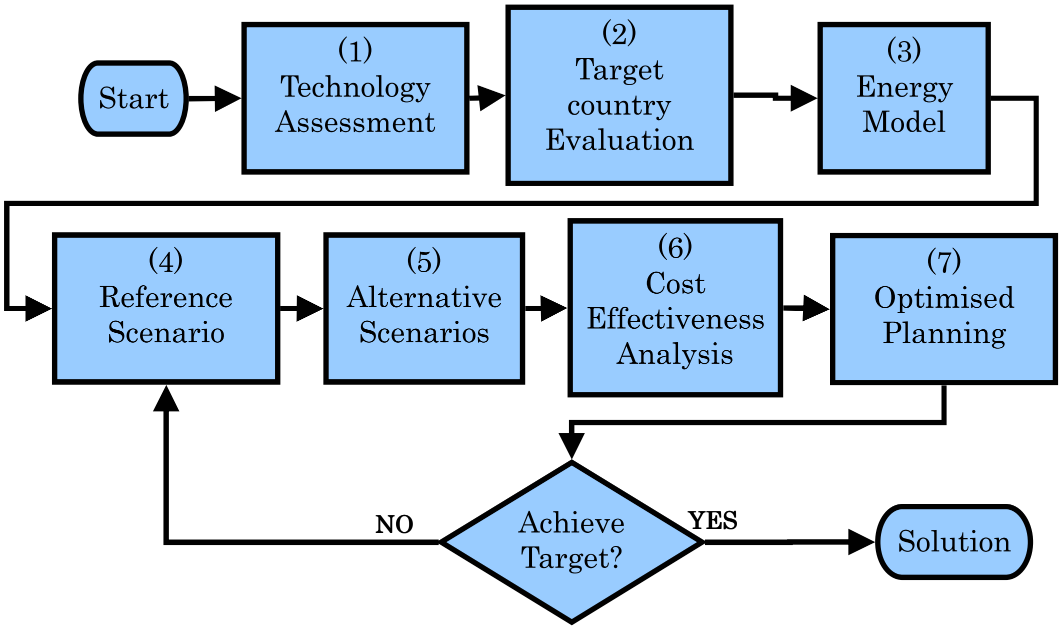


Figure 8-1: Flow Chart of the Methodology

8.2.1 Step 1 - Technology Assessment

In this methodology, all potential technologies for GHG emission reduction in power sector such as RE, Energy Efficiency, advanced combustion technologies are first evaluated. This detailed study had been carried out as described in the previous chapters. To ensure successful implementation in a developing country, only technologies that meet the following criteria are selected:

Proven Technology: Only technologies that are matured with proven application are to be adopted. All the technologies selected must be commercially available with technical support provided by vendors. New technologies that are in the developing stage or pilot testing stage are not considered.

Level of Technical Expertise Required: Technologies that require high level of technical expertise to implement are avoided as there may not be sufficient expertise within a developing economy for successful implementation.

Compatibility: Compatibility of the technology with the existing power grid in the developing economy is to be taken into consideration as well. Technology that requires advanced infrastructure such as smart grid features is to be avoided as the implementation of such technology will require extremely high capital investment initially. Also, migrating to advance smart grid system will be a technical challenge with wide spreading effect to the power system.

8.2.2 Step 2 - Target Country Evaluation

All relevant data and facts of the target developing country are to be collected with sufficient details for constructing an energy model. The required information includes existing power plant capacity, fuel mix, thermal efficiency, emission factors, transmission and distribution system, demand and supply requirements, projected economy growth and demand growth, plant-up plan, existing national energy policies, subsidies, energy prices, technologies prices and power market structure.

8.2.3 Step 3 - Energy Model

With the information collected in step 2, an energy model of the power system is to be constructed using the energy modelling software, LEAP.

8.2.4 Step 4 - Reference Scenario

A reference scenario (S0) is to be created for a projection period appropriate to the technologies investigated. A 20 year period is chosen in this analysis because the typical lifetime of most power plants is 20 years.. S0 is to be projected based on existing projection data and policies, without any additional technologies implemented for sustainable development and emission reduction. From the energy model, the aggregated cost, GHG emissions and electricity output can be calculated using the following equations:

$$C0 = \sum_i \sum_j c0^i_j \qquad \text{Equation 8-1}$$

$$G0 = \sum_i \sum_j g0^i_j \qquad \text{Equation 8-2}$$

$$E0 = \sum_i \sum_j e0^i_j \qquad \text{Equation 8-3}$$

Where: $C0$: Aggregated cost of all electricity generated over the projection period in S0. The cost includes annualised capital cost, variable O&M cost, fixed O&M cost, fuel cost and decommissioning cost. (RM)

$c0_j^i$	:	Generation cost using technology i in year j in S0. The cost includes annualised capital cost, variable O&M cost, fixed O&M cost, fuel cost and decommissioning cost. (RM)
i	:	Index for type of power generation technology in the simulated scenario
j	:	Index for year in the simulation period
$G0$	:	Aggregated GHG emissions of all electricity generated over the projection period in S0. (ton CO_2-eq)
$g0_j^i$	:	GHG emissions using technology i in year j in S0. (ton CO_2-eq)
$E0$	:	Aggregated electricity output over the projection period in S0. (kWh)
$e0_j^i$	:	Electricity output using technology i in year j in S0. (kWh)

Using Equation 8-1, Equation 8-2 and Equation 8-3, the following values can be calculated:

Unit electricity cost (RM per kWh): $$CE0 = \frac{C0}{E0} \qquad \text{Equation 8-4}$$

GHG emission factor (ton per kWh): $$GF0 = \frac{G0}{E0} \qquad \text{Equation 8-5}$$

8.2.5 Step 5 - Alternative Scenarios

Based on technology assessment in step 1, technologies with potential are selected according to the local conditions in the target developing economies as found in step 2. For each selected technology, a scenario SX is created in the energy model, where X represents the scenario number. For each SX, the corresponding parameters CX, GX, EX, CEX and GFX are to be computed using Equation 8-1, Equation 8-2, Equation 8-3, Equation 8-4 and

Equation 8-5.

8.2.6 Step 6 - Cost Effectiveness

Using the results in step 5 above, the cost per unit emission avoided (RM per ton CO_2-eq) and incremental electricity cost (RM per kWh) can be calculated for each scenario SX by applying Equation 8-6 and Equation 8-7 below:

Incremental electricity cost: $CIX = CEX - CE0$ Equation 8-6

Cost per unit emission avoided: $CGX = \dfrac{CIX}{GF0 - GFX}$ Equation 8-7

8.2.7 Step 7 - Optimised Planning

Based on the computed CGX, the scenario with the lowest CGX is to be selected for implementation. This selected scenario is then used as the reference scenario (S0). The process repeats from step 4 until the total GHG emission (G0) is reduced to the planned target.

8.2.8 Final Step - Solution

Using the above methodology, the combination of technologies adopted in the iterative process will form the solution for the target developing economy to achieve its emission reduction target.

The LEAP software had been fully utilised to automate the process as far as possible. However, as LEAP is a commercial software and the software development tool kit (SDK) is not available to the public, the following steps have to be carried out manually:

a. Export of simulation results to spreadsheet for cost effectively analysis; and

b. Configuration of scenarios at the start of each iteration.

8.3 Energy System Modelling

The methodology described above is applied in the power sector of Sabah.

To construct the energy model, key input parameters on the selected technology options and the power system of the target economies must be obtained. Based on these parameters, the energy model can be constructed in LEAP.

8.3.1 Sabah Energy Model in LEAP

The demand and supply model of the power system in Sabah is first modelled in LEAP. The model is constructed using the following data:

- Sabah electricity demand projection over the next 20 years from 2010 to 2030.
- The power plant-up plan over the next 20 years.

- Hourly load demand profile.
- Life-span, capital cost and other essential operating and maintaining expenditures for all electricity generation options.

A detailed description of the energy model construction and the source of data have been described in Section 4.3 of Chapter 4.

8.3.2 GHG Emission Reduction Scenarios

Eleven scenarios are created in this study. The reference scenario (S0) is first created in LEAP. In this scenario, there will be no additional effort to reduce the CO_2 emissions. The fuel mix will be similar to that of the existing combination, mainly constitute of gas, coal and hydro. All new gas and coal power plants to be procured after 2010 are assumed to be the type with efficiency of 33.15% and 45.2% respectively (Malaysia Energy Commission, 2007). This is based on the current average efficiency of power plants in Malaysia. Gas power plants are assumed to be combined cycle type, as the gas power plants installed in the recent years are of this type. Based on S0, other scenarios with GHG emission reduction options as discussed above are created to study the financial and environmental implications. All the scenarios are summarised in Table 8-1.

Table 8-1: Key technologies applied in the scenarios

Scenario	Technologies
S0	Business as usual
S1	Solar PV cell
S2	Hydropower
S3	Biomass from palm oil waste
S4	Supply side energy efficiency–advanced combustion technology
S5	Carbon capture technology
S6	Demand side energy efficiency–Industrial Sector
S7	Demand side energy efficiency–Building Sector
S8	Energy efficient device–Energy saving bulbs
S9	Energy import from Bakun
S10	Nuclear Power

Scenario S1–PV: Based on S0, PV panel is added to the fuel mix in this scenario. Based on the Renewable Energy Policy (Badriyah, 2010), the RE penetration target in 2030 will reach 17%. Out of the total RE, PV shall contribute 3.63% in 2030. Based on this target, the PV panel capacity is ramped up from 0% to the targeted penetration in 2030 in this scenario. The other power plant capacities are maintained as per S0 so that the peak demand can be met even if there is no power output from the PV panels due to unavailability of sun light. In the LEAP model, this is achieved by increasing the reserve capacity. In 2030, the reserve margin is increased from 30% to 33.63%.

Scenario S2–Hydropower: In this scenario, hydropower is prioritised in the plant up plan. The potential of hydropower is exploited to the maximum to meet the power demand. In the previous studies carried out on hydropower in Sabah, 68 sites have been identified to be suitable for hydropower projects, with a combined capacity of 1,900 MW (Tyler et al., 2010). Hence, in this scenario the hydropower capacity is ramped up to the maximum 1,900 MW. The other fuel types are increased based on the prevailing ratio to meet the projected power demand.

Scenario S3–Palm Oil Waste: In this scenario, the biomass power plants using palm oil waste is maximised to meet the projected power demand. There were 1.36 million hectares of oil palm plantations in Sabah in 2009 (Malaysian Palm Oil Board, 2009). The area is growing at the annual rate of 2.1%. The growth rate is expected to decrease and reach zero in 2020. As discussed in Chapter 6, due to the relatively low energy density of the biomass, the location and size of biomass power plant need to be optimised in order to achieve the financial viability of the power plant. As per Table 6-3, the total capacity of biomass power plants which are financially viable has been found to be 6,387 MW. The total output from these plants will be 44,764 GWh per year. This is more than sufficient to meet the total demand for electricity in Sabah in 2030. However, for better energy security and diversity, the power industry shall not be dependent on a single fuel source. Therefore, in this scenario, the capacity of new biomass power plant is limited to 50% of the total new power plant capacity to be built. The other 50% of the new plants are distributed evenly between hydro, gas and coal power plant.

Scenario S4–Efficient Power Plant: In this scenario, all the new gas and coal power plants to be procured after 2010 are assumed to be of the most efficient types available. The coal power plants will be of ultra-supercritical PCC type with the thermal efficiency of 50% (Alicia, 2008). The gas power plants will be based on the most advanced Class H turbine in the combined cycle configuration to achieve the plant thermal efficiency of 60%. In addition, all the gas power plants commissioned before 2010 are to be upgraded in 2016 and 2020 to increase their thermal efficiencies to 60%. The timing of their upgrades is chosen to coincide with the time for major refurbishments. Generally, a power plant requires a major refurbishment once every 10 years (Alicia, 2008). The refurbishment exercise does not include coal power plants as all the coal power plants are to be commissioned after 2010.

Scenario S5–Efficient Power Plant and CCS: In this scenario, the advanced combined cycle gas turbine power plants with the thermal efficiency of 60% as per S4 are adopted for the all new gas plants. In addition, CCS technology is to be adopted for the new coal power plants. The IGCC technology is adopted because the CCS technology has been found to be more effective when applied to the IGCC plants. The overall thermal efficiency of the resulted IGCC-CCS plants is 33.9% (Othman et al., 2009).

Scenario S6–Industrial Energy Efficiency: In this scenario, the recommendations from the Malaysian Industrial Energy Efficiency Improvement Project (MIEEIP) are implemented (Akker, 2008). It has been found that, on average, the electricity use of the industrial sector can be reduced by 5.6% following the recommendations of MIEEIP (Faridah, 2005).

Therefore, a 5.6% reduction of the electricity demand from the industrial sector is assumed in this scenario. Based on the data obtained from the MIEEIP project (Oh et al., 2010, Oh and Chua, 2010, Akker, 2008), an upgrade of RM 100.4 million can result in annual energy saving of 2.583 million GJ, or 717.5 GWh. This amount of electricity saved will be equal to the electricity produced by an 81.9 MW power plant running at 100% plant factor. Based on this assumption, the equivalent capital cost can be calculated to be RM1,226 per kW. The cost of this option is calculated based on this equivalent capital cost in LEAP.

Scenario S7–Energy Efficient Buildings: In this scenario, energy efficient buildings are to be promoted to achieve maximum reduction in electricity demand. As discussed in Chapter 7, in promoting energy efficiency, Malaysia will amend the UBBL to incorporate requirements for energy efficient features in new buildings (Oh and Chua, 2010). The UBBL will likely to adopt Malaysian Standard MS 1525:2001 “Code of Practice on Energy Efficiency and use of RE for Non-residential Buildings” and the design criteria as defined in the GBI tool. Based on the case study investigated in Chapter 7, the annual energy use of commercial buildings can be reduced by 61% by adopting the green building features. From Table 7-5, a total investment of RM5,713,800 will result in an annual electricity saving of 1,853,083 kWh. This amount of electricity saved will equal to the electricity produced by a 211.5 kW power plant running at 100% plant factor. Hence, the equivalent capital cost can be calculated to be RM27,010 per kW. The cost of this option is calculated based on this equivalent capital cost in LEAP.

Scenario S8–Energy Saving Light Bulbs: In this scenario, the energy saving light bulbs are adopted to maximise the reduction in electricity demand. As part of the Malaysian government's efforts in EE, the country will stop the production, import and sale of incandescent light bulbs by 2014. It is found that the measures will reduce the overall electricity use by 1% (Bernama, 2010). For cost analysis, the additional cost of purchasing compact fluorescent bulbs instead of incandescent lamp is first calculated. The market price of a 14W compact fluorescent bulb is RM20. Typically, the bulb will last for 8000 hour with an average output of 760 lumen (Philips, 2010a). The market price of a 60W incandescent lamp is RM2. Typically, the bulb will last for 1000 hour with an average output of 630 lumen (Philips, 2010b) Based on the above information, the additional cost of the compact fluorescent bulb is normalised to the amount of energy saved over the lifetime (RM / kWh). This amount is then input as the variable O&M cost in the LEAP energy model.

Scenario S9–Import Electricity from Bakun Hydropower Plant: In this scenario, electricity is imported from the Bakun hydropower plant to meet the demand. The Bakun hydropower plant in Sarawak is scheduled to start generating electricity in 2011. The capacity of the plant will reach 2,400 MW when fully commissioned. With the submarine cable project to transfer power to West Malaysia aborted, there will be a surplus of capacity in Sarawak. Up to 400 MW of the excess capacity can be fed to meet the demand in Sabah via a 275 kV HVAC line. It has been estimated that the transmission line will incur a 7.5% transmission loss (Razavi, 1990b). The unit capital cost is computed based on the construction of the 500 km 275 kV HVAC transmission line (Koh and Lim, 2010), normalised to the 400 MW power that it will transmit. The electricity purchased cost of RM 0.11 per kWh from Bakun hydropower plant (Koh and Lim, 2010) plus the 7.5% transmission loss is input as the flexible O&M cost for LEAP modelling purpose.

Scenario S10–Nuclear Power Plant: In this scenario, nuclear power plants are adopted to meet the increased power demand, in conjunction with gas and hydro power plant. New nuclear power plants of 600 MW will be planned and built, together with gas and hydro power plants based on a capacity ratio of 4:1:1. The required plant capacity is to be computed dynamically by LEAP to maintain a minimum reserved margin of 30% (IDS, 2007). The life time of nuclear power plant is assumed to be 50 years (Kaplan, 2008).

Table 8-2: Key parameters for cost analysis in LEAP

No	Technology (Scenario)	Plant Life Time [Years]	Effi-ciency [%]	Capital Cost [RM (US$) / kW]	Fuel cost [RM (US$) / kWh output] [a]	Fixed O&M cost [RM (US$) / kW / year]	Variable O&M cost [RM (US$) / GJ]
1	Hydro (S0, S2)	50 [b]	47 [b]	12270 [c] (3506)	0	173.25 [b] (49.50)	0.4200 [b] (0.1200)
2	Diesel (S0)	20	31 [b]	1200 [c] (343)	0.5100 [d] (0.1457)	0 [e]	6.0278 [f] (1.7222)
3	Biomass (S0,S3)	20 [b]	48 [v]	10762 [b] (3075)	0.1323 [w]	27.30 [b] (7.80)	10.2200 [b] (2.9200)
4	Open Cycle Gas (S0)	20 [b]	28.7 [b]	3600 [c] (1029)	0.1272 [h] (0.0363)	177.21 [b] (50.63)	1.9600 [b] (0.5600)
5	Combined Cycle Gas (S0)	20 [b]	45.2 [b]	6000 [c] (1714)	0.0808 [h] (0.0231)	128.10 [b] (36.60)	2.2050 [b] (0.6300)
6	Conventional PCC Coal (S0)	30 [b]	33.15 [b]	5167 [c] (1476)	0.0664 [j] (0.0190)	241.50 [b] (69.00)	2.5200 [b] (0.7200)
7	PV (S1)	20 [b]	NA	28000 [k] (8000)	0	31.50 [b] (9.00)	4.3750 [b] (1.2500)
8	Advanced Combined Cycle Gas – Class H (S4,S5)	20 [b]	60	7820 [i] (2234)	0.0608 [h] (0.0174)	128.10 [b] (36.60)	2.2050 [b] (0.6300)
9	Advanced Ultra-supercritical PCC Coal (S4)	30 [b]	50	8877 [l] (2536)	0.0440 [j] (0.0126)	235.25 [b] (67.21)	2.6250 [b] (0.7500)
10	IGCC with CCS (S5)	20 [b]	33.9	9983 [m] (2852)	0.0649 [j] (0.0185)	315.00 [b] (90.00)	13.6500 [b] (3.900)
11	Industrial Energy Efficient Project (S6)	10 [n]	NA	1226 [o] (350)	0	0	0
12	Energy Efficient Buildings (S7)	10 [n]	NA	27010 [p] (7717)	0	0	0
13	Energy Saving Bulbs (S8)	Not Appli-cable	NA	0 [q]	0	0	3.0193 [q] (0.8627)
14	Import from Bakun (S9)	50	NA	2025 [r] (579)	0	0	33.0330 [s] (9.4380)
15	Nuclear Power Plant (S10) [x]	50	80	15740 (4500)	0.02625 (0.0075)	400 (114.29)	9.2361 (2.6389)

Note:

[a] Fuel cost was computed separately and added to the LEAP analysis

[b] Data based on findings in (Rafaj and Kypreos, 2007)

[c] Cost computed based on SESB press release (SESB, 2009b, SESB, 2009a)

[d] Based on current subsidised diesel price of RM 1.70 per litre and average generator consumption of 0.3 litre per kWh output

[e] All O&M costs for diesel plant are lumped in the variable O&M cost

[f] Cost obtained from (Tyler et al., 2010)

[g] Zero fuel cost was assumed for the biomass plant as all the plants are to be built at the existing palm oil processing factories

[h] The fuel price is computed using subsidised gas price of RM 10.70 per mmbtu (Zuraimi, 2010) in Malaysia and the corresponding plant efficiency for the respective technology

[i] Additional USD 520 per kW based on previous research (Alicia, 2008) is added to the capital cost of a standard combined cycle gas plant of RM 6000 per kW

[j] The fuel cost is computed based on 2009 Indonesian coal price of USD30.72 per ton for the coal grade of 4200 kCal/kg (PT. Coalindo Energy, 2009) and the corresponding plant efficiency of the technology

[k] Capital cost of PV includes installation of complete system (Lim et al., 2008) and assumed to reduce annually by 3.6% (Key and Peterson, 2009)

[l] Additional USD 1060 per kW based on previous research (Alicia, 2008) is added to the capital cost of a conventional PCC coal plant of RM 6000 per kW

[m] Additional USD 316 per kW based on previous research (Rafaj and Kypreos, 2007) is added to the capital cost of a conventional PCC coal plant of RM 6000 per kW

[n] Conservative assumption of 10 years for mechanical and electrical equipments

[o] Additional capital cost invested to achieve the energy savings computed based on the MIEEIP findings (Oh et al., 2010, Oh and Chua, 2010, Akker, 2008), whereby an upgrade of RM 100.4 million resulting in annual energy saving of 2.583 million GJ

[p] From Table 7-5, a total investment of RM5,713,800 would result in an annual electricity saving of 1,853,083 kWh. This amount of electricity saved would equal to the electricity produced by a 211.5 kW power plant running at 100% plant factor. Hence, the unit capital cost could be obtained as RM27,010 per kW

[q] The additional cost of purchasing compact fluorescent bulbs (14W, 8000 hours lifetime, 760 lumen, RM 20) (Philips, 2010a) instead of incandescent lamp (60W, 1000 hours lifetime, 630 lumen, RM 2) (Philips, 2010b) is normalised to amount of energy saved over the lifetime (RM / kWh) and input as variable O&M cost for LEAP modelling purpose

[r] Capital cost of the 500 km 275 kV HVAC transmission line (Koh and Lim, 2010)

[s] The electricity purchased cost of RM 0.11 per kWh from Bakun hydropower plant (Koh and Lim, 2010) is input as the flexible O&M cost for LEAP modelling purpose, including 7.5% of transmission loss in the 500 km transmission line

[t] A foreign currency exchange rate of USD 1 = RM 3.50 applied for all above calculation

[u] All costs used in this thesis are nominal current price.

[v] Based on 80% boiler efficiency and 60% cogeneration efficiency as discussed in Chapter 6

[w] Based on maximum biomass cost of RM369 per ton, energy intensity of 21083 MJ per ton (5856.4 kWh per ton), average transportation distance of 15km and transporation cost of RM0.20 per ton per km

[x] Key input parameters for nuclear power as discussed in Chapter 5 and shown in Table 5-1; Decommissioning cost of RM872 per kW was adopted

8.4 Source Data

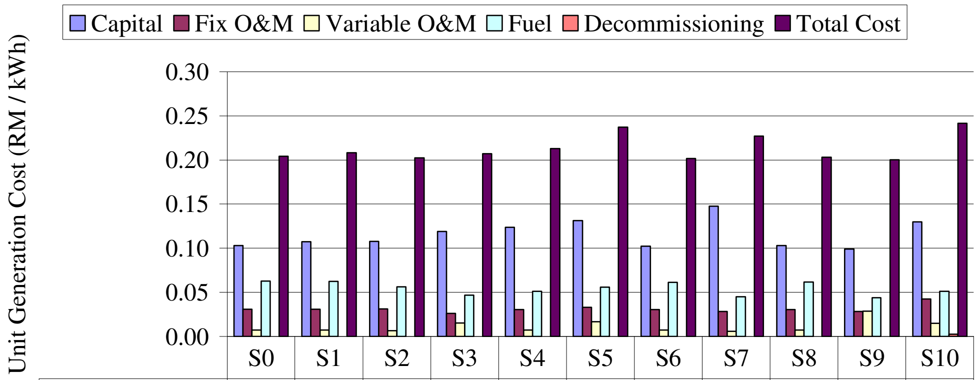
The required input source data for financial computation are summarised in Table 8-2. Items 11, 12 and 13 of the table are the measures to reduce electricity use. These options, including industrial energy efficiency measures, energy efficient building and energy saving light bulbs, do not involve power generating technologies.

8.5 First Iteration Results

In the first iteration, the output from LEAP are analysed and further processed to assess the electricity cost, GHG emissions and sensitivity to fuel price increase as shown in the followings.

8.5.1 Cost

The unit electricity costs, the annualised capital costs, fixed O&M costs, variable O&M costs, decommissioning costs and fuel costs are plotted in Figure 8-2. As discussed in the previous chapters, only the annualised capital costs for capacity added during the simulation period are taken into consideration in the LEAP programme. The capital cost of the existing power plant at the start of the simulation is not included in the calculation. In order to maintain the consistency during the analysis of the unit generation cost for the all the technologies, the annualised capital costs are computed and included in the graph for all existing power plants.

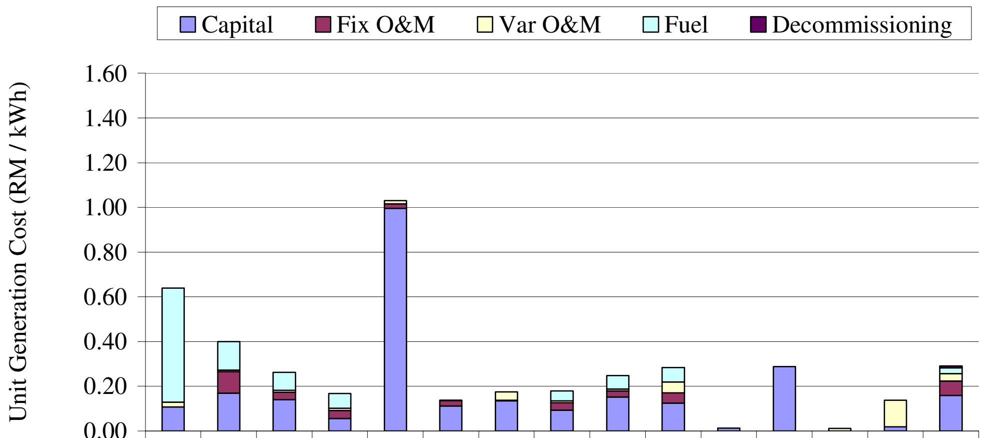


	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Capital	0.10	0.11	0.11	0.12	0.12	0.13	0.10	0.15	0.10	0.10	0.13
Fix O&M	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04
Variable O&M	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.03	0.02
Fuel	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.05	0.06	0.04	0.05
Decommissioning	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.002
Total Cost	0.20	0.21	0.20	0.21	0.21	0.24	0.20	0.23	0.20	0.20	0.24

Figure 8-2: Unit Electricity Cost for All the Scenarios Investigated

From Figure 8-2, it is found that the electricity cost of RM 0.20 per kWh in S6 is similar to that of S0. It shows that the energy efficiency measures recommended in MIEEIP will be very cost effective in achieving a significant saving in electricity usages with similar capital investment. The electricity cost in S2, S8 and S9 are also similar to that of S0, at RM 0.20 per kWh. The costs in S1, S3 and S4 are marginally higher, at RM 0.21 per kWh or 5% higher than S0 cost. The cost of RM 0.24 per kWh in S5 and S10 is the highest. It is 20% higher than that of S0.This is because of the higher capital cost and variable O&M cost of the CCS technology and nuclear power technology. The decommissioning cost is applicable to S10 only, for the nuclear power plant.

The average unit cost of electricity generation for all the technologies in this scenario is computed as shown in Figure 8-3. The costs are obtained by computing the average generation cost for each technology in all the scenarios. Among the technologies currently used in S0, the electricity cost from diesel power plants is found to be the highest at RM 0.64 per kWh. This is followed by that of the open cycle gas turbine power plants at RM 0.40 per kWh. These plants are used only to meet the peak demands. The electricity costs of the other technologies in S0 are between RM 0.17 and RM 0.26 per kWh.



	Diesel (S0)	OC Gas (S0)	CC Gas (S0)	Coal (S0)	PV (S1)	Hydro (S2)	Biomass (S3)	Coal (S4)	Gas (S4, S5)	IGCC-CSS (S5)	MIEEIP (S6)	Building (S7)	Light (S8)	Bakun (S9)	Nuclear (S10)
Decommissioning	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Fuel	0.51	0.13	0.08	0.07	0.00	0.00	0.00	0.04	0.06	0.06	0.00	0.00	0.00	0.00	0.03
Var O&M	0.02	0.01	0.01	0.01	0.02	0.00	0.04	0.01	0.01	0.05	0.00	0.00	0.01	0.12	0.03
Fix O&M	0.00	0.10	0.03	0.04	0.02	0.02	0.00	0.03	0.03	0.05	0.00	0.00	0.00	0.00	0.06
Capital	0.11	0.17	0.14	0.06	1.00	0.11	0.13	0.09	0.15	0.12	0.01	0.29	0.00	0.02	0.16

Figure 8-3: Average Unit Cost of Power Generation for all Technologies

Among the other technologies, the electricity cost by the PV panel in S1 is found to be the highest at RM 1.03 per kWh as shown in Figure 8-3. It is 415% above the average cost of RM 0.20 per kWh in the reference scenario. This is followed by that from nuclear plants and building energy efficiency measures at RM 0.29 per kWh, or 46% higher than the S0 average cost. The electricity costs from the other technologies in the alternative scenarios (S2, S3, S4, S5 and S9) are between RM 0.14 and RM 0.28 per kWh.

The energy efficiency measures in S6 and S8 are found to be very cost effective. The cost to achieve the energy saving in S6 and S8 is merely RM 0.01 per kWh of electricity saved.

8.5.2 GHG Emission Reduction

The computed unit emission factors for all the scenarios are plotted in Figure 8-4.

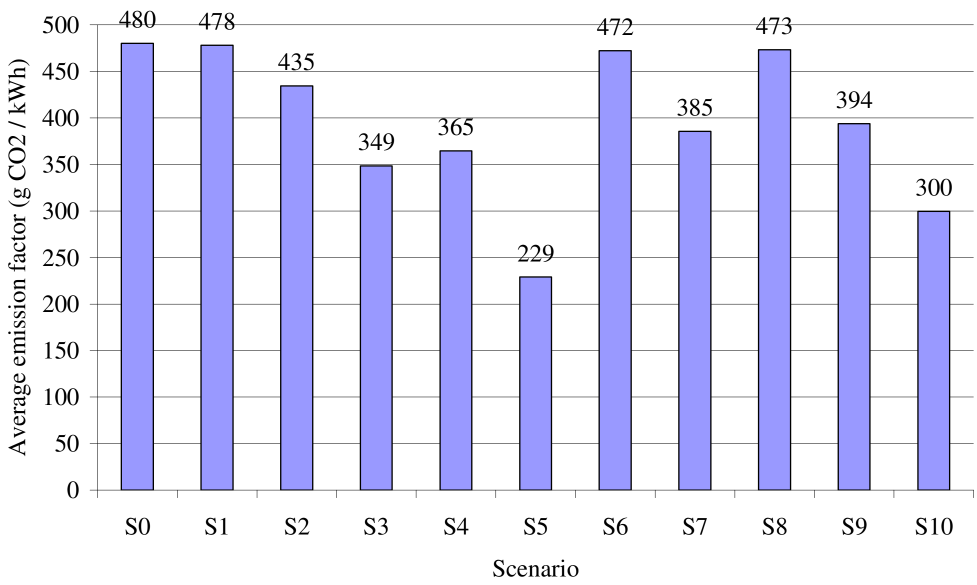


Figure 8-4: Average GHG Emission Factor for all Scenarios

From Figure 8-4, it is found that the emission factor for S0 is 480 g CO_2-eq per kWh. The emission factors of all the alternative scenarios are lower, ranging from 229 to 478 g CO_2-eq per kWh. The highest reduction is achieved in S5, using IGCC-CCS technology to reduce the emission factor by 52% to 229 gCO_2/kWh. Only marginal reduction of the emission factor is achieved in S1, S6 and S8, by 0.5%, 1.7% and 1.4% respectively.

8.5.3 Cost Effectiveness

The cost of GHG emission avoided is computed as summarised in Table 8-3. From the table, it is found that the cost in S1 is the highest, at RM 1,804.12 per tCO_2–eq. avoided. In comparison, the CO_2 is traded at around RM 50.80 (12.70 Euro) per ton at European Climate Exchange (European Climate Exchange, 2010), based on the current spot price retrieved on 7 July 2010 for CER (Certified Emission Restrictions) for the CDM scheme from the European Climate Exchange. Therefore, the cost of using PV panels for emission reduction is much higher than the prevailing market price.

The negative values for S2, S6, S8 and S9 indicated that the costs of electricity in these scenarios are lower than that of S0. Therefore, by implementing these measures, GHG emission is reduced while cost of electricity is also reduced. For S3, S4 and S5, the costs are in between RM 23.40 and RM 131.78 per tCO_2–eq. avoided. These numbers are close to the prevailing price of CER at RM 50.80 per ton. Therefore, most, if not all, of the cost can be paid back through the CDM by implementing these measures. The cost of RM 206.89 per tCO_2–eq. for the nuclear option in S10 is the second highest.

Table 8-3: Cost of GHG Emission Avoided in First Iteration

Scenario	*[A] Emission Factor (g CO2/ kWh)*	*[B] Unit Cost (RM / kWh)*	*[C]=([B]-[B0])/([A0]-[A]) Emission Avoided (RM / ton CO2)*
S0	A0=480.2602	B0=0.2042	-
S1	478.0636	0.2082	1,804.12
S2	434.5556	0.2023	-40.54
S3	348.5010	0.2073	23.40
S4	364.8384	0.2128	74.16
S5	229.1246	0.2373	131.78
S6	**472.1452**	**0.2016**	**-321.44**
S7	385.4756	0.2271	241.47
S8	473.4183	0.2029	-188.67
S9	393.9737	0.2001	-47.20
S10	299.7809	0.2415	206.89

8.5.4 Sensitivity to Fuel Prices

In Malaysia, natural gas is heavily subsidized in the power generation sector. The price of natural gas for power sector is fixed at RM 10.70 per MMBTU, compared to the market price of RM 41.16 per MMBTU in December 2009 (Zuraimi, 2010). By removing the subsidy on natural gas, the impact on the electricity costs for all the scenario is investigated as shown in Table 8-4.

Table 8-4: The Impact on Electricity Generation Cost by Removing Subsidy on Natural Gas

Scenario	*[A] Unit Electricity Cost (RM / kWh) at Current Gas Price*	*[B] Unit Electricity Cost (RM / kWh) at Unsubsidised Gas Price*	*[C]=([B]-[A])/[A]*100% Percentage Price Increase*
S0	0.20	0.31	51%
S1	0.21	0.31	50%
S2	0.20	0.29	45%
S3	**0.21**	**0.28**	**34%**
S4	0.21	0.30	40%
S5	**0.24**	**0.32**	**36%**
S6	0.20	0.30	51%
S7	**0.23**	**0.30**	**34%**
S8	0.20	0.31	51%
S9	**0.20**	**0.27**	**37%**
S10	0.24	0.31	28%

From Table 8-4, it is found that the cost increase of 51% in S0, S6 and S8 is the highest. A similar impact was observed in S1, with a cost increase of 50%. Lesser impacts are found in S3, S5, S7 and S9 as the cost increases are in the range of 34 % to 37%. In S10 whereby nuclear power plants are deployed, the price increase is found to be much lower, at 28%. It is expected that increases in other fossil fuel prices will have a similar impact on the electricity price.

8.5.5 *Solution from First Iteration*

In the first iteration, Industrial EE (S6) is the most cost effective scenario. This is because the unit cost of GHG emission avoided is –RM321.44 per tCO_2–eq. The average electricity cost is reduced from RM0.2042 per kWh in S0 to RM0.2016 per kWh. The total emission avoided over the simulation period of 20 years is 2.23 million tCO_2-eq. The average emission factor is reduced from 480 g CO_2–eq. per kWh to 472 g CO_2–eq. per kWh. Therefore, S6 is the solution for the first iteration and will be adopted as the reference scenario in the second iteration.

8.6 Second Iteration

Referring to the flow chart in Figure 8-1, S6 in the previous iteration is adopted as the reference scenario (S0) in the second iteration and the iterative process continued at step 4 of the flow chart. The following scenarios are created in the LEAP model in this second iteration as shown in Table 8-5.

Applying the same methodology as per the first iteration, the cost of emission avoided for each scenario is computed as shown in Table 8-6. The cost of emission avoided for S8 is the lowest, at –RM214.58 per tCO_2–eq. Therefore, it is selected as the based scenario for the third iteration. It should be noted that S8 is selected even though the emission factor is the highest among all the other alternative scenarios, except S0 and S1. The other scenarios are not selected because the lower emission factors are achieved at a much higher cost.

Table 8-5: Scenarios in LEAP Model for Second Iteration

Scenario	Description
S0	Demand side energy efficiency for the industrial sector from the first iteration adopted as the base scenario
S1	Solar PV cell: PV added to the base scenario based according to the target penetration rate of energy policy
S2	Hydropower: Modified S0 to explore hydropower power up to the maximum potential
S3	Biomass from palm oil waste: Modified S0 to explore biomass energy up to the maximum potential
S4	Supply side energy efficiency: Modified S0 with advanced combustion technology adopted for new gas and coal power plant
S5	CCS technology: Modified S4 with CSS technology adopted for new coal power plant
S6	Not used
S7	Demand side energy efficiency–Building: Modified S0 with energy saving from green building design taken into consideration
S8	Energy efficient device–Energy saving bulbs: Modified S0 with energy saving from efficient lighting taken into consideration
S9	Energy import from Bakun: Modified S0 to include electricity imported from Bakun hydropower plant
S10	Nuclear Power: Modified S0 with nuclear power plant taken into consideration

Table 8-6: Cost of GHG Emission Avoided In Second Iteration

Scenario	*[A] Emission Factor (g CO2/ kWh)*	*[B] Unit Cost (RM / kWh)*	*[C]=([B]-[B0])/([A0]-[A]) Emission Avoided (RM / ton CO2)*
S0	A0=472.1452	B0=0.2016	-
S1	468.8716	0.2060	1,394.40
S2	426.6080	0.1983	-70.55
S3	348.2610	0.2036	17.06
S4	358.2387	0.2100	74.90
S5	224.8194	0.2341	132.04
S6	NA	NA	NA
S7	225.2544	0.1911	-42.13
S8	**467.4672**	**0.2005**	**-214.58**
S9	386.6904	0.1985	-34.98
S10	293.5998	0.2390	210.34

8.7 Subsequent Iterations and Solution

The process is continued following the flow chart as per Figure 8-1, until all GHG emission options are completely used up. The results from all iterations are summarised in Table 8-7, Table 8-8, Table 8-9, Table 8-10, Table 8-11 and Table 8-12.

Table 8-7: Cost of GHG Emission Avoided In 3rd Iteration

Scenario	*[A] Emission Factor (g CO2/ kWh)*	*[B] Unit Cost (RM / kWh)*	*[C]=([B]-[B0])/([A0]-[A]) Emission Avoided (RM / ton CO2)*
S0	A0=467.4672	B0=0.2005	-
S1	464.1577	0.2051	1,386.75
S2	**419.7423**	**0.1970**	**-72.76**
S3	344.2152	0.2025	16.60
S4	354.2949	0.2091	76.50
S5	220.9914	0.2332	132.96
S6	NA	NA	NA
S7	220.3841	0.1905	-40.36
S8	NA	NA	NA
S9	381.9578	0.1978	-31.62
S10	294.6567	0.2355	202.44

Table 8-8: Cost of GHG Emission Avoided In 4th Iteration

Scenario	*[A] Emission Factor (g CO2/ kWh)*	*[B] Unit Cost (RM / kWh)*	*[C]=([B]-[B0])/([A0]-[A]) Emission Avoided (RM / ton CO2)*
S0	A0=419.7423	B0=0.1970	-
S1	417.5694	0.2033	2,886.53
S2	NA	NA	NA
S3	344.2152	0.2025	73.07
S4	323.2350	0.2050	83.17
S5	208.4988	0.2260	137.42
S6	NA	NA	NA
S7	330.4251	0.2214	272.77
S8	NA	NA	NA
S9	**340.4601**	**0.1950**	**-24.90**
S10	298.2239	0.2264	242.26

Table 8-9: Cost of GHG Emission Avoided In 5th Iteration

Scenario	*[A] Emission Factor (g CO2/ kWh)*	*[B] Unit Cost (RM / kWh)*	*[C]=([B]-[B0])/([A0]-[A]) Emission Avoided (RM / ton CO2)*
S0	A=340.4601	B=0.1950	-
S1	337.9422	0.1991	1,601.98
S2	NA	NA	NA
S3	**282.6194**	**0.1977**	**47.13**
S4	260.4544	0.2038	109.27
S5	160.5668	0.2225	152.99
S6	NA	NA	NA
S7	250.8085	0.2231	312.68
S8	NA	NA	NA
S9	NA	NA	NA
S10	251.4896	0.2173	250.24

Table 8-10: Cost of GHG Emission Avoided In 6th Iteration

Scenario	*[A] Emission Factor (g CO2/ kWh)*	*[B] Unit Cost (RM / kWh)*	*[C]=([B]-[B0])/([A0]-[A]) Emission Avoided (RM / ton CO2)*
S0	A0=282.6194	B0=0.1977	-
S1	281.8404	0.2024	5,968.00
S2	NA	NA	NA
S3	NA	NA	NA
S4	**216.8173**	**0.2060**	**124.98**
S5	127.6131	0.2246	173.37
S6	NA	NA	NA
S7	207.3968	0.2262	378.52
S8	NA	NA	NA
S9	NA	NA	NA
S10	282.6194	0.1977	-

From Table 8-10, it is noted from the results of the 6th iteration that no nuclear power plant is selected in S10. This is because the options adopted in the previous iterations have been able to meet most of the electricity demand in Sabah. The remaining demand is small. The large plant capacity typical for nuclear power plant is not suitable for the incremental demand for Sabah. Hence, the nuclear option in S10 is not considered in the subsequent iteration.

Also, it is found that S4 in 6th Iteration is the most cost effective. As described previously, S5 is an enhanced version of S4, with additional CCS implemented. Therefore, S4 and S5 cannot be adopted at the same time. With the adoption of S4 after the 7th iteration, S5 is not considered in the subsequent iteration.

It can be observed from the above that, at the end of each iteration, one option will be adopted and this reduces the number of available options by one in the subsequent iteration. In addition, certain option may become not feasible after a few iterations. This is illustrated by the CCS option (S5) and nuclear option (S10) in the above example. Therefore, it can be concluded that the number of iterations in this methodology is always less than the number of options.

Table 8-11: Cost of GHG Emission Avoided In 7th Iteration

Scenario	*[A] Emission Factor (g CO2/ kWh)*	*[B] Unit Cost (RM / kWh)*	*[C]=([B]-[B0])/([A0]-[A]) Emission Avoided (RM / ton CO2)*
S0	A0=216.8173	B0=0.2060	-
S1	210.7246	0.2117	942.05
S2	NA	NA	NA
S3	NA	NA	NA
S4	NA	NA	NA
S5	NA	NA	NA
S6	NA	NA	NA
S7	**165.3357**	**0.2347**	**559.00**
S8	NA	NA	NA
S9	NA	NA	NA
S10	NA	NA	NA

Table 8-12: Cost of GHG Emission Avoided In 8th Iteration

Scenario	*[A] Emission Factor (g CO2/ kWh)*	*[B] Unit Cost (RM / kWh)*	*[C]=([B]-[B0])/([A0]-[A]) Emission Avoided (RM / ton CO2)*
S0	A0=165.3357	B0=0.2347	-
S1	163.7139	0.2389	2,570.39
S2	NA	NA	NA
S3	NA	NA	NA
S4	NA	NA	NA
S5	NA	NA	NA
S6	NA	NA	NA
S7	NA	NA	NA
S8	NA	NA	NA
S9	NA	NA	NA
S10	NA	NA	NA

Hence, after eight iterations, S1 is selected as the solution. With the solution implemented, the emission factor was reduced from 480 g CO_2–eq. per kWh to 164 g CO_2–eq. per kWh. The average electricity cost is increased from RM0.2042 per kWh to RM0.2389 per kWh.

In the resulted optimised scenario, all the options investigated are adopted at an optimal proportion to achieve the maximum GHG emission reduction with a minimal cost using Equation 8-7. As discussed above, the nuclear option is not adopted because the other options are more cost effective in meeting the electricity demand and GHG emission reduction requirements. In Figure 8-5, the optimal plant capacity for each option based on the optimised solution is presented. At the start of the simulation period in 2010, the electricity demand in Sabah is mainly supplied from the Natural Gas and Diesel Power Plant, with a combined contribution of 83%. Biomass and hydro power contributes to 7% and 10% respectively out of the total electricity generated. By 2030, the fuel mix is diversified and it includes advanced coal and gas power plants, hydro power plants, electricity import from Bakun Dam, Biomass power plants, EE measures and Solar PV.

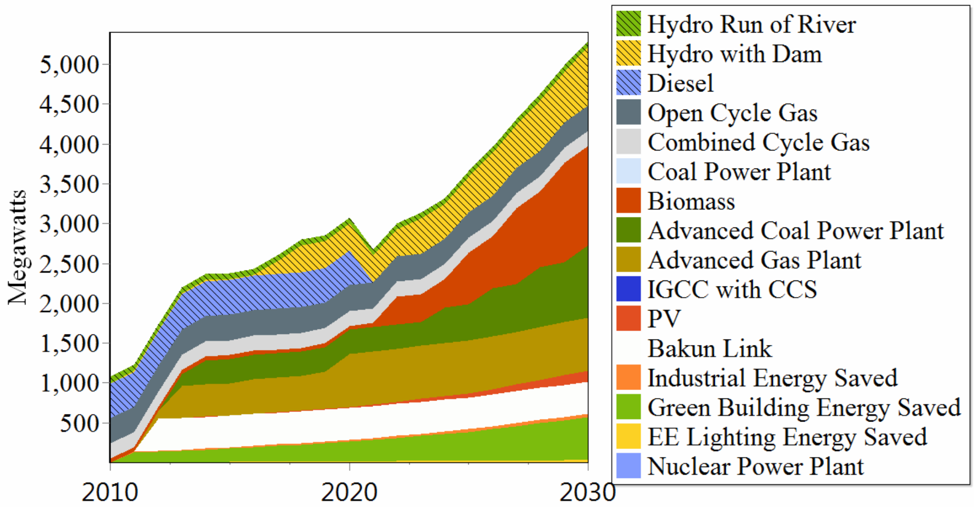


Figure 8-5: Resulted Plant Capacity in the Optimised Solution

From Table 8-13, biomass contributes to the biggest share in the fuel mix in 2030, at 33%. This is followed by the hydro power, at 21%. In addition, the electricity imports from Bakun Dam contributes another 10%. The share of fossil fuel has been reduced to 14%. The share of natural gas and coal are 3% and 11% respectively. Solar PV contributes 1% of the fuel mix. The remaining 21% is from the various EE measures. Among these measures, green building contributes 18% while the industrial EE and efficient light bulbs contributes 2% and 1% respectively.

Table 8-13: Fuel Mix in 2030 for the Optimised Solution

Item	*Fuel Type*	*Output (GWh)*	*Percentage*
1	Biomass	8,321	33%
2	Hydro	5,399	21%
4	Building EE	4,461	18%
5	Coal	2,890	11%
7	Bakun Import	2,659	10%
8	Gas	774	3%
9	Industry EE	412	2%
10	Light EE	241	1%
11	PV	212	1%
	TOTAL	25,368	100%

Table 8-14: Effectiveness in GHG Emission Reduction Compared to Base Scenario and Renewable Policy Scenario from 2010 to 2030

Item	*Parameters*	*Optimised Solution*	*Base Scenario*	*Renewable Policy*
1	Total Emission (mil tCO_2-eq.)	45.25	132.71	110.15
2	Average Emission Factor (g/kWh)	164	480	398
4	Average Electricity Cost (RM/kWh)	0.2389	0.2042	0.2422
5	Cost of Emission Reduction (RM/tCO_2-eq. Avoided)	110	0.00	465

The optimised solution is benchmarked against the following two scenarios in Table 8-14:

a. **Base Scenario** whereby no additional efforts are spent to reduce the GHG emission;

b. Scenario based on RE policy whereby the RE penetration rates as stipulated in the RE policy are achieved, as discussed in Chapter 2 and 4.

Compared to the base scenario, the optimised solution has reduced the total emission from 132.71 million tCO_2-eq. to 45.25 million tCO_2-eq. This is equivalent to a GHG reduction of 66%. To achieve the emission reduction, the electricity cost is increased by a mere 17%, from RM 0.2042 per kWh to RM 0.2389 per kWh. The cost of emission reduction is RM 110 per tCO_2-eq. avoided.

The scenario based on RE policy, on the other hand, has managed to reduce the GHG emission by only 17% from 132.71 million tCO_2-eq. to 110.15 million tCO_2-eq. The electricity cost is higher at RM 0.2422 per kWh, or 19% higher than that of the base scenario. This result in a much higher cost of emission reduction at RM 465 per tCO_2-eq. avoided.

Compared to the optimised scenario from the methodology, the current Malaysian energy policy of RE depends solely on RE to achieve the desired GHG emission reduction, without considering the other lower cost option of energy efficiency, advanced combustion technology and CCS. In addition, the target proportions for each RE are not optimized. For example, the target penetration rate PV, which is more expensive, is 3%. This is much higher than the 1% found in the optimized scenario from the methodology. At the same time, the target penetration rates for the cheaper RE options, such as biomass and hydro power are lower than the optimized scenarios. Hence, compared to the optimized scenario, less GHG emission reduction is achieved at a higher generation cost with the RE energy policy.

8.8 Sensitivity Analysis

The methodology is further checked for its robustness. As biomass contributes to the biggest share in the fuel mix of the optimised result, its share is varied to test the response of the methodology. The share is reduced by 10%, 20% and 30% respectively and a new optimised solution is found for each variation by following the methodology, with the results summarised in Table 8-15. It is found that the reduced biomass in the fuel mix is replaced by coal and gas power plants. The other components in the fuel mix remain unchanged as they have been utilised to the fullest in the optimised solution.

Table 8-15: Variation of Fuel Mix in 2030 with Reducing Biomass Component

		Output (GWh)			
Item	*Fuel Type*	*Optimised Solution*	*-10% Biomass*	*-20% Biomass*	*-30% Biomass*
1	Biomass	33%	30%	27%	24%
2	Hydro	21%	21%	21%	21%
4	Building EE	18%	18%	18%	18%
5	Coal	11%	13%	15%	16%
7	Bakun Import	10%	10%	10%	10%
8	Gas	3%	4%	6%	7%
9	Industry EE	2%	2%	2%	2%
10	Light EE	1%	1%	1%	1%
11	PV	1%	1%	1%	1%
	TOTAL	100%	100%	100%	100%

The impact on emission reduction from the variation is evaluated in Table 8-16. When the share of biomass is reduced by 30%, the emission factor is increased slightly from 164 g/kWh to 177 g/kWh. The electricity cost reduces slightly from RM 0.2389 per kWh to RM 0.2374 per kWh. As a result, the cost of emission avoided reduces from RM 110 per tCO_2-eq. to 109 per tCO_2-eq. Therefore, it can be concluded that the methodology remains robust and effective in reducing GHG emission while maintaining the minimum electricity cost.

Table 8-16: Effectiveness in GHG Emission Reduction with Reducing Biomass Component

Item	***Parameters***	***Optimised Solution***	***-10% Biomass***	***-20% Biomass***	***-30% Biomass***
1	Total Emission Reduction (mil tCO_2-eq.)	87.46	87.24	85.53	83.81
2	Average Emission Factor (g/kWh)	164	165	171	177
4	Average Electricity Cost (RM/kWh)	0.2389	0.2396	0.2382	0.2374
5	Cost of Emission Reduction (RM/tCO_2-eq. Avoided)	110	112	110	109

8.9 Analysis of Key Results

Through the iterative process carried out, a solution for a scenario with an optimal combination of the potential GHG reduction options has been successfully derived. The optimal solution has been derived by adopting the various options at the optimal proportion to achieve maximum GHG emission reduction at a minimal cost. The options adopted in the solution include fossil fuel with high efficient combustion technology, hydro power, imported power from Bakun Dam, Biomass, Solar PV, and the various EE measures in green building, industrial energy reduction and energy efficient light bulbs. The adopted proportion of these options is shown in Table 8-13.

In the solution, the emission factor was reduced from 480 g CO_2–eq. per kWh to 164 g CO_2–eq. per kWh. The average electricity cost was increased from RM0.2024 per kWh to RM0.2389 per kWh. The GHG reduction achieved is much higher than that can be achieved in any single option. The total reduction is 87.459 million tCO_2-eq. over the 20 year period. This significant reduction has been achieved with a minimal increase of 18% in electricity generation cost.

An optimal solution can be found after 8 iterations, as shown in

Table 8-17. The cell highlighted in red is the option adopted after the respective iteration. It is interesting to note that the adopted option is not always the option with the highest GHG emission reduction. For example, during iteration 1, S6 is adopted although the emission reduction of 2.24 million tCO_2-eq. is the second lowest. The criteria for an option to be adopted is based on the lowest cost of emission avoided as shown in Table 8-18. It is noted that the costs of emission avoided are different among the different iterations. This is because, at each iteration, the base scenario is different and the costs of emission avoided are computed with reference to this base scenario. Therefore, all the parameters have to be re-calculated for each iteration, instead of adopting the same parameters from the first iteration.

Table 8-17: Emission Reduction Achieved Over 8 Iterations

	Technology	Total Emission Reduced with Respect to S0 (Million tCO_2-eq.)							
		I1	***I2***	***I3***	***I4***	***I5***	***I6***	***I7***	***I8***
1	S0-BAU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	S1-PV	0.61	0.90	0.91	0.60	0.70	0.22	1.68	**0.45**
3	S2-Hydro	12.63	12.59	**13.19**	-	-	-	-	-
4	S3-Biomass	36.41	34.24	34.07	20.88	**15.99**	-	-	-
5	S4-EE Supply	31.89	31.48	31.28	26.68	22.11	**18.19**	-	-
6	S5-CCS	69.40	68.36	68.13	58.39	49.72	42.85	-	-
7	S6-Industrial EE	**2.24**	-	-	-	-	-	-	-
8	S7-Green Building	26.19	68.24	68.30	24.69	24.78	20.79	**14.23**	-
9	S8-EE Light	1.89	**1.29**	-	-	-	-	-	-
10	S9-Bakun Import	23.84	23.62	23.64	**21.91**	-	-	-	-
11	S10-Nuclear	49.87	49.35	47.77	33.59	24.59	0.00	-	-
	% Reduction	1.69%	0.97%	9.94%	16.51%	12.04%	13.70%	10.72%	0.34%
	Cumulative	1.69%	2.66%	12.60%	29.11%	41.15%	54.85%	65.57%	65.91%

As shown in Table 8-19, the average generation cost also changes from one iteration to the next one. Again, the adopted option is not always the one with the lowest generation cost.

Table 8-18: Cost of Emission Avoided Over 8 Iterations

	Technology	*Cost of Emission Avoided from S0 (RM per tCO_2-eq.)*							
		I1	***I2***	***I3***	***I4***	***I5***	***I6***	***I7***	***I8***
1	S0-BAU	-	-	-	-	-	-	-	-
2	S1-PV	1,804	1,394	1,387	2,887	1,602	5,968	942	**2,570**
3	S2-Hydro	-41	-71	**-73**	-	-	-	-	-
4	S3-Biomass	23	17	17	73	**47**	-	-	-
5	S4-EE Supply	74	75	76	83	109	**125**	-	-
6	S5-CCS	132	132	133	137	153	173	-	-
7	S6-Industrial EE	**-321**	-	-	-	-	-	-	-
8	S7-Green Building	241	-42	-40	273	313	379	**559**	-
9	S8-EE Light	-189	**-215**	-	-	-	-	-	-
10	S9-Bakun Import	-47	-35	-32	**-25**	-	-	-	-
11	S10-Nuclear	207	210	202	242	250	-	-	-

Table 8-19: Average Generation Cost for Each Iteration

	Technology	*Average Generation Cost (RM / kWh)*							
		I1	***I2***	***I3***	***I4***	***I5***	***I6***	***I7***	***I8***
1	S0-BAU	0.2042	0.2016	0.2005	0.1970	0.1950	0.1977	0.2060	0.2347
2	S1-PV	0.2082	0.2060	0.2051	0.2033	0.1991	0.2024	0.2117	**0.2389**
3	S2-Hydro	0.2023	0.1983	**0.1970**	-	-	-	-	-
4	S3-Biomass	0.2073	0.2036	0.2025	0.2025	**0.1977**	-	-	-
5	S4-EE Supply	0.2128	0.2100	0.2091	0.2050	0.2038	**0.2060**	-	-
6	S5-CCS	0.2373	0.2341	0.2332	0.2260	0.2225	0.2246	-	-
7	S6-Industrial EE	**0.2016**	-	-	-	-	-	-	-
8	S7-Green Building	0.2271	0.1911	0.1905	0.2214	0.2231	0.2262	**0.2347**	-
9	S8-EE Light	0.2029	**0.2005**	-	-	-	-	-	-
10	S9-Bakun Import	0.2001	0.1985	0.1978	**0.1950**	-	-	-	-
11	S10-Nuclear	0.2415	0.2390	0.2355	0.2264	0.2173	0.1977	-	-

8.10 Conclusion

Following the methodology systematically, a low GHG emission solution has been found in this chapter after eight iterations.

In the solution found, the emission factor is reduced from 480 g CO_2–eq. per kWh to 164 g CO_2–eq. per kWh. This represents a significant 66% reduction. The total GHG emission has been reduced from 132.711 million tCO_2-eq to 45.252 million tCO_2-eq.

The emission reduction is achieved with minimum increase in the electricity cost. The average electricity cost is increased from RM0.2042 per kWh to RM0.2389 per kWh. This represents a 18% increase in price. Following the methodology, the most cost effective option is adopted. As a result, the additional cost is kept to a minimum.

Consistent with the NEP, the resulted solution also achieves the fuel diversification objective. As shown in Table 8-13, the fuel mix in 2030 has been expanded to include fossil fuel, hydro power, imported power from the Bakun Dam, Biomass, Solar PV, and the various EE measures in green building, industrial energy reduction and energy efficient light bulbs. By using this approach, any developing region can identify the most appropriate energy mixture to achieve GHG reduction with minimal increase in electricity generation cost.

The methodology will be suitable for most developing economies other than Sabah. The key criteria of the methodology are: (a) GHG emission reduction (b) low cost power options; (c) power option not requiring high level of technical expertise; (d) scalability of the options to meet the increasing demand of the developing economies. These criteria are all applicable to other developing economies.

CHAPTER 9

SUMMARY AND CONCLUSION

9.1 Summary

This research has been designed to address one of the most critical challenges the world is currently facing – Global Warming. In this research, a methodology has been developed to assist the policy makers to systematically identify the most cost effective options with the highest impact in GHG emission reduction, especially for the developing countries. The methodology has been applied in a case study for Sabah to assess its effectiveness.

In this concluding chapter, the Energy Policy is revisited to verify if its criteria are achieved with the optimal solution. The chapter is concluded with the discussion on the significance of the research findings and potential future research in this area.

9.2 Consistency with National Energy Policy of Malaysia

The optimal solution found in Chapter 8 satisfies the objectives set out in the NEP for fuel diversification, low environmental impact, cost effectiveness and fuel security. It can be implemented in a large capacity to ensure adequate supply to meet the local demand. The proven technology will be able to ensure the stability of the supply. It is cost effective in comparison to the sole dependence on RE technology from the Malaysian RE energy policy. The cost in the optimal solution is only marginally higher than that of the conventional power plant technology. It can also reduce the GHG emission significantly, consistent with the clean utilization and environmental objectives of NEP. An array of different technologies with differing energy sources has been included in the optimal solution. The fuel mix in the solution include fossil fuel, hydro power, imported power from the Bakun Dam, Biomass, Solar PV, and the various EE measures in green building, industrial energy reduction and energy efficient light bulbs. This is consistent with the fuel diversification objective.

The various options as investigated in this research are more cost effective than solely depending on the typical green technology such as RE. Therefore, to achieve optimal GHG emission reduction, the policy makers should be encouraged to consider a wider range of technology options. For example, there is currently no incentive or legislation in the NEP to promote the use of the advanced combustion technology in power generation. A lot of emphasis in the energy policy is towards RE such as the Green Technology Policy and SREP. Based on the research findings, it is hoped that the policy makers will study the viability of including these alternative emission reduction options in the policy framework.

Similarly, at the international level, little incentives are available in promoting these technologies. Even the UNFCCC has yet to recognise CCS for the CDM (UNFCCC, 2010). This is unfortunate because, with the cost effectiveness of the technologies, the advanced combustion technology will be able to deliver a significant higher level of GHG emission reduction compared to other technologies such as renewable in the immediate short and medium terms, for an equivalent amount of budget allocated.

9.3 Significance of this Research

The main objective of this research is to develop a systematic methodology to assist the developing countries to address the challenges of meeting the GHG emission requirements within the known constraint and their needs for development. In the optimal scenario from the methodology, the GHG emission has been reduced by 66% when the electricity generation cost has been reduced by a mere 18%. From the results, it can be seen that the research has successfully met the key objective, with the following main contributions:

- Identification of common characteristics in developing economies which are having the direct influence as the key constraints and considerations in the development of a sustainable power system as concluded in Chapter 2;
- Identification of a wide array of options for the developing countries in GHG reduction technologies, in addition to the typical RE options;
- Findings from the in depth study of these GHG reduction options based on real industry data of the power sector in Sabah, from the technical, financial and emission reduction

perspective;

- An algorithm has been developed to identify the optimal location and size of oil palm waste biomass power plant based on the availability of biomass waste, distance to power grid, transportation cost, cost of biomass waste, plant capital cost and plant operation cost;
- Development of a methodology that enables the policy makers to systematically identify the most cost effective combination of the available options in GHG emission reduction for developing countries

Based on the methodology developed in this research, the developing countries will be able to minimise the negative impact of their deficiency in terms of technological advancement in the GHG emission reduction technologies and limitation in their financial capabilities. They will be able to achieve the maximum GHG emission reduction with a fixed amount of financial allocation within their capabilities.

9.4 Further Research Areas

This research is conducted at a macro level to provide a comprehensive assessment of all available emission reduction technologies for the developing countries. Within each type of technologies, a representative technology is selected for assessment. For example, a BIPV system was used in this research to represent the solar energy. Therefore, there are further research opportunities in investigating the differences in the various solar energy technologies, such as concentrated solar power, solar heating, solar air-conditioning, and solar thermal electricity. These differences may affect the viability of their application in a developing country. Similarly, different technologies in biomass energy, hydropower, building energy efficiency, nuclear power, combustion technologies, wind energy and other power technologies may be researched further.

In this research, Sabah has been selected as the case study in evaluating the different emission reduction options. Although Sabah does embody the common characteristics of a developing economy, there are subtle differences in each developing economies. For example, there are differences among the developing economies in terms of the available natural resources, the RE endowment, the size of the economy and the climate. Therefore, further research may be carried out to study the effect of these differences on the viability and cost effectiveness of each technology option in emission reduction.

Currently, there is little connection between the transportation sector and the power sector in Sabah. Hence, this research investigates only the power sector without taking into consideration the transportation sector. However, inline with the trend of hybrid and electric vehicles, the transportation sector may become part of the power sector as these vehicles will be getting the energy from the power grid. Therefore, further research may also be carried out on the impact of electrical vehicle on the power sector and the technology options for emission reduction.

In conclusion, this research has successfully met the original objective of developing a systematic methodology to assist the developing countries to address the challenges of meeting the GHG emission requirements within the known constraints and their needs for development. With Sabah as a case study, an optimal solution has been found based on this methodology. In the optimal solution, the GHG emission of the power sector in Sabah has been reduced significantly with minimal additional cost.

In this research, it is found that the need for energy at a competitive price can be achieved with options which do not damage the environmental. The renewable and green options evaluated in this research are technologically proven, financially attractive and emitting little GHG. They are also superior in enhancing the economic growth and ensuring better fuel security of the country.

Appendix A

DOWNLOAD LINKS FOR SOURCE CODE

1.0 Biomass Waste Power Plant Optimisation (Chapter 6)

https://www.dropbox.com/s/6cfwzdvsjuaxd6j/Biomass%20Plant%20Optimization_Fortran.zip

2.0 LEAP Energy Model for Sabah (Chapter 8)

https://www.dropbox.com/s/6bu63p96gbs6sec/Sabah%20All%20I8%20v3.zip

3.0 LEAP Results Analysis in Excel Spreadsheet (Chapter 8)

https://www.dropbox.com/s/st25eftz6srv318/LEAP%20Results%20Analysis.zip

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