RISK BASED OPTIMAL ELECTRICITY GENERATION PLANNING USING MODERN PORTFOLIO THEORY

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DECLARATION

I hereby certify that this dissertation does not incorporate without acknowledgement of any material previously submitted for a Degree or Diploma in any University, and to the best of my knowledge and belief it does not contain any material previously published or written by another person or myself except where due reference is made in the text.

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ABSTRACT

At present majority of electric power systems are carbon intensive, supply driven and highly centralised. A high percentage of countries still have regulated monopolised markets and utilization of fossil fuel fed power plants proliferated rapidly to bridge the supply and demand gap.

Least cost and merit order methods are widely used for generation expansion planning. These methods incorporates present value based least cost generating technologies and favoured by policy makers. Generally least cost method favours fossil fuel based technologies over the renewable technologies irrespective of many other benefits rendered by renewable technologies. Therefore, energy supply is susceptible to fuel price volatilities. From an energy security perspective, the economies rich with diverse natural resources such as coal, crude oil, hydro, wind and superior technologies such as nuclear transcend above others. But countries which import crude oil face severe hardships due to sudden price hikes. Presently the governments are increasingly pressurised to decarbonise their electricity generation to combat global climate change even though low carbon emitting generating technologies impend relatively high initial capital outlays, exposing the system with greater risk from generation shortfalls.

The objectives of this dissertation are to determine the most efficient portfolios that abate cost and risk and to establish a quantitative framework to determine the efficient generating portfolios from the societal perspective. It further evaluates the sensitivity of risk and expected cost when incorporating a new power generating technology to existing portfolio.

Portfolio based generation planning is used to explicate the portfolio performance not only by cost (return) basis but more importantly by risk basis. Markowitz's (1952) Portfolio theory is well established, proven and robust model used in finance to determine the optimal portfolios of assets. The analysis for electricity generating technologies based on modern portfolio theory lays out a consistent framework which provides much better view into the portfolio cost and risk.

Therefore, it could infer that efficient portfolios (minimum expected cost and risk) determined are in dissonance with extant generation expansion plan of Ceylon Electricity Board. Secondly, the environmental adders were incorporated to find the efficient portfolio having least societal risk. A sensitivity analysis gives the direction that the existing portfolio will move in terms of expected cost and risk when adding a new generating source to the system. It is possible to use standard deviation as a predictor as well as a variable that measures diversification of generating technologies.

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LIST OF ACRONYMS

CCY	Combine cycle power plant
CEB	Ceylon Electricity Board
CPC	Ceylon Petroleum Corporation
DSM	Demand Side Management
GHG	Green House Gases
GoSL	Government of Sri Lanka
GWh	Giga Watt Hour
IEA	International Energy Agency
IPP	Independent Power Producer
kWh	Kilo Watt Hour
LKR	Sri Lanka Rupees
LNG	Liquefied Natural Gas
LOLP	Loss of Load Probability
MPT	Modern Portfolio Theory
MW	Mega Watt
MWh	Mega Watt Hour
NCRE	Non Conventional Renewable Energy
PV	Present Value
US$	United States Dollar
USCents	United States Cents
WASP	Wein Automatic System Planning Package

LIST OF SYMBOLS

μ	Expected cost, mean
σ	Standard deviation
ω	Weights
Ω	Covariance matrix
EV_t	Previous value
BV_t	Current value
δ	Lagrange multipliers

CHAPTER I

INTRODUCTION

1.1 BACKGROUND

The rational investors who invest in financial assets show great interest in reducing their exposure to fluctuations of the market by possessing a diversified portfolio of assets. Markowitz (1952) constructed a set of efficient portfolios considering portfolio variances (standard deviations), co-variances, and expected return. Theoretically, it was proven that an efficient portfolios do not create unnecessary risk for a given expected returns (Zweifel & Krey, 2005). Although, Modern Portfolio Theory (MPT) is extensively applied in finance, later there were many instances where construction of efficient portfolios used in the areas of non-finance.

The construction of an efficient portfolio of electricity generating technologies (energy sources) should be performed by the policy makers. Renewable and non-renewable sources are used to generate electricity. Selection of electricity generation sources is necessarily subject to the availability of natural resources in a particular country. It is obvious that every country does not have an equal amount of natural resources. Those countries which do not possess adequate natural resources such as hydro, fossil fuel, coal etc would have to import either fuel or electricity or a combination of both. In any case, then the energy becomes a liability since the payments must be made to the rest of the world. Except in few areas in the world where cross border electricity sales are done (Europe and North America), importation of fuel for electricity generation had been the trend for many years. Over the years electricity generation using non-renewable energy sources (fossil fuel and coal) was popular among policy makers due to relatively low initial investment costs. Therefore, carbon intensive, supply driven, centralised, geographically dispersed electricity generating plants were constructed. However, associated difficulties in accurate prognosis and high volatilities of crude oil prices have been continuously causing multiple effects to the world energy prices. Economies are yet to find a plausible solution to the destruction caused by these price instabilities. Therefore, energy supply has shown a high positive correlation towards energy prices. The countries rich with natural resources (coal, crude oil, hydro, wind etc) and/or possess advance power generation technologies (nuclear, geo-thermal, photo voltaic etc) are less susceptible to global crude oil price ups and downs. Therefore they enjoy high energy security.

Carbon intensive electricity generating technologies such as fossil fuel based technologies and coal are relatively less capital intensive with respect to the renewable sources such as hydro, wind etc. Therefore, policy makers preferred the non-renewable options over the capital intensive renewable sources. However, the prices of fossil fuel and coal have been experiencing high volatility and upward trend during last few years and it is expected to continue. Therefore, least capital cost approach makes the countries susceptible to price risk. At present, the governments are increasingly pressurised to decarbonise their electricity generation to combat global climate change even though low carbon generation technologies impend relatively high initial capital outlays and exposing the system with greater risk from generation shortfalls. Further more, the (negative) rate of return on the country's energy portfolio then becomes the rate of increase of the energy bill, which is to be minimised rather than to maximised (in a financial portfolio). However, the objective of minimization of the volatility remains the same (Zweifel & Krey, 2005).

In this context, a country is required to review its objectives of the energy policy where provision of energy should be sufficient, diversified, secure, economical and environmentally compatible. Therefore, maintaining a diverse electricity generation portfolio helps to reduce the fossil fuel price risk and ensures the energy security (Huanga & Wu, 2008). According to Zweifel and Krey (2005), well established asset-liability management framework could easily accommodate above provisions. In case of sufficiency, a shortage in supply would result in an increase of energy cost in view of inelastic demand. Since the approach targets economical technologies, it limits the increase of energy cost. Further, for compatibility with the environment, there could be a surcharge, a penalty or similar approaches incorporated to the calculation resulting increase in energy cost. Therefore, the share of such technologies would be reduced in the efficient portfolio.

Sri Lanka used its hydro resources to generate more than 50% of its electricity requirement before 1990 but when the demand started rising at a rapid pace during last two decades the contribution of thermal power generation started picking up. Today approximately 40% of its electricity demand is catered by thermal power and hydro resources have already exhausted. Due to desultory strategic planning and polarised political stances, Sri Lanka continued to generate power using high cost fossil fuels whereas most of the other countries opted for coal power generation.

The first coal power plant of Sri Lanka is scheduled to commence its commercial operation in 2012-2013. In its ambitious electricity generation expansion plan, the Ceylon Electricity Board (CEB) is planning to pill up a series of coal power plants during the next decade. However, in recent years the coal prices also have started to show exponential growth with higher volatilities (Abeygunawardana, 2008).

Different kind of crude oil prices (auto diesel, residual oil, heavy fuel etc) and coal prices closely correlate each other. The renewable sources are unlikely to have any correlation with fossil price escalations, making countries less vulnerable for price risk associated with crude oil supply (Awerbuch, 2004). The least cost approach has been the most popular method that most countries adopt when deciding the best electricity generation portfolio. Natural tendency of the electricity planners is to incorporate least cost options (stand alone generating sources) without performing an extensive analysis of the possible price risk associated with the planned portfolios. The least cost method which has been used to decide the electricity generation portfolios favours fossil fuel based technologies over the renewable technologies irrespective of many other benefits rendered by renewable technologies. By operating a small number of geographically dispersed fossil fuel based power generating plants, the operators are able to manage the time varying supply and demand balance.

The least cost approach is ill-apposite to assess the cost related risks in the electricity generation portfolios. Ordinary sensitivity analysis is not geared to provide the cost versus risk relations in a portfolio (Awerbuch & Berger, 2003). According to Liu & Wu (2007) the electricity prices show higher volatility against crude oil price fluctuations than any other commodity due to unique features of electricity such as inability to store, physical and reliability constrains in transmission and distribution. One could witness that a slight increase in fuel prices cause sizable economic loss and the impact is devastating for fuel importing nations. The initial capital outlays of renewable energy technologies are relatively higher than conventional technologies. Therefore, policy makers believe that incorporation of more and more renewable sources will result in further increase in the cost of electricity generation. However, this has been proven wrong by the MPT based electricity generation planning (Awerbuch & Berger, 2003).

Portfolio based generation planning is used to analyse the portfolio performance not only by cost basis but more importantly by risk basis as well. Markowitz's (1952) Portfolio theory is well established, proven and robust model used in finance to determine the optimal the portfolios. The analysis for electricity generation technologies based on modern portfolio theory lays out a consistent framework to gain better view into the portfolio cost and risk, inherent to alternative technologies.

It is the finance theory that came up with a counter argument for this scenario. Awerbuch and Berger (2003) suggest that generating alternatives should be valued not on their *stand alone cost* but on the basis of their contribution to portfolio cost relative to their contribution to portfolio risk. MPT is used for asset management in finance which predicts that adding renewable would reduce the overall generating cost at any given level of risk, even where renewable energy technologies cost more.

Less risky efficient portfolios may minimise the nations' exposure to price risks by creating efficient overall generation portfolios (Awerbuch & Berger, 2003). An efficient portfolio will help deriving a proper cost-risk assessment. These arguments have paved a way for researchers to use Markowitz's (1952) portfolio theory to analyse the electricity generation combinations. The problem of asset allocation is one of the prime concerns in finance theory. Cohen and Natoi (2003) suggested that an asset tries to figure out the optimal allocation of funds among a set of assets, for pre-determined level of risk. Using mean-variance approach Markowitz (1952) derived an efficient frontier of portfolios which maximizes the return for a given level of risk. Today the perception of electricity generation planning has changed to portfolio based cost management approach (Awerbuch & Berger, 2003).

Well tested and robust portfolio theory based electricity generation planning is superior to arbitrary mixes of electricity generation sources. Sensitivity analysis based models are not equipped to estimate the portfolio risk. Bates (2007) argues that a sensitivity analysis could not replicate the important cost interrelationships that dramatically affect the estimated portfolio cost and risks and it is not a substitute for portfolio based approaches.

One critic of portfolio approach is that irrespective of market structure, the power producers generally evaluate their own direct cost and risk at the time of making their investment decisions. They may prefer the risk menu offered by low capital intensive, non-renewable electricity generating plants because investors in most countries are allowed to pass the fuel risk to the consumer through the regulatory mechanisms in operation. In contrast, there exist under-investments as to social expectations in renewable technologies due to capital intensity and associated uncertainties (Bates, 2007). However, efficient electricity generating portfolios are designed to minimise expected generating cost and risk, whilst improving energy security.

1.3 CONTEXT OF THE PROBLEM AND OBJECTIVES

In this context, this study is conducted to establish a suitable asset-liability management framework that helps policy makers to determine a sustainable solution to the problem of finding an efficient electricity generation portfolio and associated level of risk at the time of investment decision is being made.

While in the process of searching for an answer to above question this study aims to achieve following objectives.

1. To determine the optimal portfolios for electricity generation based on cost[1] and different levels of risk.
2. To establish a quantitative framework to determine the electricity generation portfolios from the societal perspective.
3. To evaluate the sensitivity of risk and cost when incorporating a new power generating technology to existing portfolio.

1.4 METHODOLOGY

This study uses secondary data sources generated mostly by statutory bodies operating in electricity generating sector. Further, this research focuses on the developments took place in Sri Lanka's electricity sector during last three decades. However, the outcomes of this research are in present values. It is expected to derive series of frontiers leading to an efficient frontier for electricity generation portfolios and then an optimal portfolio is decided using utility aspects in mean-variance plane. This initial outcome is further streamlined to achieve an environment risk incorporated solution.

1.5 SCOPE AND LIMITATIONS

This study mainly focuses on deriving an efficient portfolio for electricity generation considering cost and associated risks. Further, it identifies the prospective risks that investors could transfer to the consumer through regulatory framework making renewable power generation less lucrative and exposing the society to greater risk. At the time of making the system expansion decision, the proposed model helps the policy maker by illustrating the bearing that new expansion technologies will have on the portfolio risk and the expected cost. However, the model does not respond to the supply side time varying fluctuations specially that may result due to wind generation. The calculations were performed using present values. Therefore, possible technological advancement driven price (cost) reductions on generation technologies in future were not considered. It is assumed that environmental pollution is generally caused by carbon dioxide. Stringent regulatory mechanisms established by many countries successfully pushed technology to find solutions to limit other emissions such as NO_x, SO_x etc.

[1] The cost refers to expected cost/levelised cost.

1.6 SIGNIFICANCE

Present volatile and uncertain energy environment demands the need for risk associated generation planning instead of conventional least cost and merit order despatch approaches. Therefore, theoretically the portfolio theory based electricity generation planning is superior to arbitrary mix of energy sources. Other sensitivity analysis based techniques are often found to be ill-suited to address above issue (Bates, 2007). The following quote was received by the writer when consulted Prof. P D C Wijetunga to explore the significance of this study.

> "*In fact in the US they have started using risk based optimal generation planning sometime ago when the Natural Gas prices started rising rapidly. This exercise is finally carried out by the planner, in the US, it is the regulatory or Energy Planning Commission. But the risk is usually passed on to the consumer because the end-consumer price is usually linked to the fuel price. Any way it is worth looking at this in an MSc dissertation with a case study for Sri Lanka*".

Still many models determining an efficient portfolio simply omit the risk that passes to consumer by investors who often concentrate more on non renewable. Empirical importance of this study could be explained in two aspects. First, it incorporates the risk aspect in actual generation planning to ascertain whether present planning is heading in correct direction. To achieve this all possible electricity generating portfolios are mapped in mean-variance plane. Later the efficient portfolios are highlighted.

Second, this technique could be used to validate the present generation expansion plan; hence the planner would be able to perform scenario analysis arose by different levels of risks. Then the environmental risk is incorporated to above ascertained efficient portfolios.

Further more, a nation having a resilient energy system could easily achieve their goals that lead to energy security. This system should be capable of withstanding various threats through a combination of active and passive security measures. These passive security measures could be redundancy, duplication of critical equipments, diversity in fuel, other sources of energy and reliance of less vulnerable infrastructure (Brown et al, 2003). The fuel types used for power generation and other energy sources have a direct impact on energy security of a particular country. Mean-variance portfolio technique helps policy makers to evaluate the costs and the risks of alternative electricity generating technologies when added to existing portfolio. This would help them to create efficient portfolios that meet the energy security. These efficient portfolios minimise the expected cost for any given level of risk while minimizing risk for every given level of expected cost.

1.7 CHAPTER OUTLINE

The underlying fundamentals of Markowitz's (1952) Portfolio Theory are elaborated at the beginning of the Chapter II. It reviews the literature relating to application of Modern Portfolio Theory (MPT) in energy and related areas. The Chapter II further discusses portfolio selection in mean-variance plane which used in determining the optimum portfolio.

Third chapter provides insights into Sri Lankan Electricity Sector. History of the power generation sector and future plans are further discussed based on the reports published by the CEB and other statutory bodies. Further, the Chapter III comprehends the existing generation expansion planning method.

The chapter IV elaborates the methodology used in this study. It starts with outlining conceptual model and extends to data collection and method of data analysis. The secondary data validation and model validation are also outlined.

The analysis of data followed by designing of scenarios for different portfolios contain in the fifth chapter. The summary of findings is listed in the Chapter VI. The discussion is performed in line with the objectives that were set in the beginning of the study. Finally, Chapter VII provides conclusions to the study followed by implications. It further glances at possibilities of further research.

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

The problem of asset allocation is one of the fundamental concerns of finance theory (Cohen & Natoi, 2003). It is always interesting to see how optimal allocation of funds among a set of assets is performed for a predetermined level of risk. Generally, risk (resulted from uncertainty) refers to the possibility of exposing to a harm or loss. According to Lir & Wu (2007), the expected profit is an indication of expected profitability. Further, the variance or the standard deviation of the profit could be considered as an indication of the risk involved (Liu & Wu, 2007). According to Bhalla (2004), Bernoulli and Cramer in 18th century had stated that decisions under conditions of uncertainty could not be made solely on the basis of expected (mean) return. Before Markowitz's (1952) introduction of portfolio theory (MPT), the investors tended to assess risks and returns of individual assets to construct their portfolios. Therefore, the assets that offer highest expected return at a minimal risk were chosen. This had resulted in investors carrying single asset portfolios containing a single commodity that gave best risk-return characteristics (Kienzle, Koeppel, Stricker, & Anderson, 2007). Markowitz (1952) stressed the importance of considering diversification when constructing efficient portfolios and went on to provide a mathematical explanation of the idea of diversification in investments. The portfolio selection was considered as a problem of maximizing the utility of an investor's wealth under conditions of uncertainty. Each investment was defined in terms of risk and return hence Markowitz(1959) developed a means of efficiently diversifying portfolios in order to give the maximum expected return for any given level of risk or the minimum level of risk for a given rate of return (Brown, 1991). Further, it is possible to reduce the portfolio risk only by investing in the minimum of two assets where the cyclical patterns of their rates of return do not move in perfect lockstep (Refer to Figure 2.1).

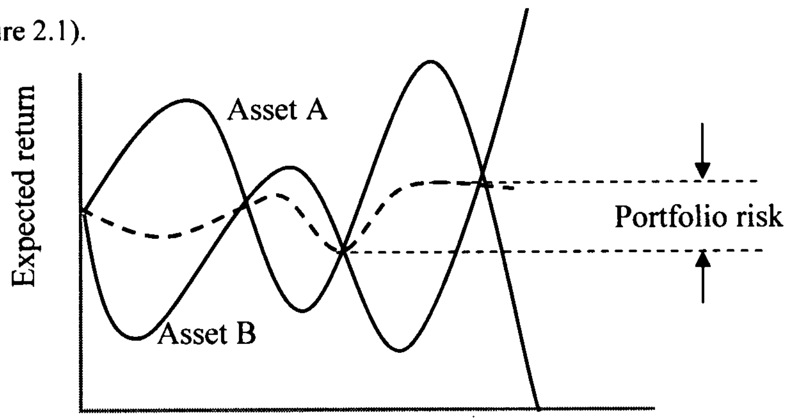


Figure 2.1 The principle of diversification
Source: Brown (1991)

For example, Figure 2.1 shows two assets, A and B, which have the same expected rate of return. However, when the expected return of asset A increases it is counter-balanced by a low return on asset B. Combination of assets A and B into a single portfolio will have an effect of eliminating risk of holding each asset on an individual basis without sacrificing the expected return (Brown, 1991).

Sharpe (1960) further explained how an aggregate of investors behave and market prices and returns are set. The model that explains this general equilibrium relationship is known as standard Capital Asset Pricing Model (CAPM). Today MPT and CAPM are considered to be the main pillars of mathematical finance. Both CAPM and MPT are conceptually forward looking (Awerbuch, 2004). Thefore, the MPT reflects the investor's future assessment of market risk and return. As mentioned earlier risk is measured as the periodic standard deviation of returns. It is presumed that the measured risk in past is a reliable guide to future.

Original MPT approach uses expected return and standard deviation as the main input parameters. However, when applying MPT to construct an efficient portfolios of energy sources, both revenue and cost approaches were used. The revenue approach is more feasible when electricity is traded in stock market whereas cost approach will have to be used in deregulated and monopolised electricity markets. Therefore, this study uses cost approach to determine the efficient portfolios for Sri Lanka electricity sector.

2.2 FUNDAMENTALS OF PORTFOLIO THEORY: THE EFFICIENT PORTFOLIO SET WHEN ALL SECURITIES ARE RISKY.

Suppose there are "m" risky securities. Let us assume that the expected return on the i^{th} security is denoted by E_i. The covariance of returns between the i^{th} and j^{th} security is denoted by σ_{ij}. The variance of the return on i^{th} security is denoted by $\sigma_{ii}=\sigma_i^2$. At this instance it is assumed that all securities are risky, $\sigma_i^2 > 0$, i=1,2,........m. It is also assumed that no security can be represented as a linear combination of the other securities, then the variance-covariance matrix of returns, $\Omega = [\sigma_{ij}]$, is non singular. The frontier of all feasible portfolios which can be constructed from these m securities is known as the locus of feasible portfolios. The significance of these portfolios is that they have the smallest variance for a prescribed expected return (Metron, 1972). Let there be N risky assets with mean vector μ and covariance matrix $\mathbf{\Omega}$. It is assumed that expected returns of at least two assets differ and the covariance matrix is of full rank. It is defined ω_a as the (Nx1) vector of portfolio weights for an arbitrary portfolio "a" with weights summing to unity.

Portfolio "a" has mean return $\mu_a=\omega^T{}_a\mu$ and variance $\sigma_a^2=\omega_a^T\Omega\omega_a$. The covariance between any two portfolios "a" and "b" is $\omega_a\ \Omega\ \omega_b$. Given the population of assets the minimum-variance portfolio is considered in the absence of a risk free asset (Campbell, Lo, & Mackilay, 1997).

Definition. *Portfolio p is the minimum-variance portfolio of all portfolios with mean return μ_p if its portfolio weight vector is the solution to the following constrained optimization* (Campbell, Lo, & Mackilay, 1997):

Equation 2.1 $\min\ \omega^T\Omega\omega$

Subject to

$$\omega^T\mu = \mu_p$$

$$\omega^T\iota = 1$$

Where μ_p, μ, Ω and ω represent the mean return of the portfolio, mean vector, variance-covariance matrix and portfolio weights vector.

The Lagrangian function L, is formed to solve above minimization problem. Therefore, L is differentiated with respect to ω and by setting the resulting equation to zero, it is solved for ω.

Equation 2.2 $L = \omega^T\Omega\omega + \delta_1(\mu_P-\omega^T\mu) + \delta_2(1-\omega^T\iota)$,

where ι is a conforming vector of ones and δ_1 and δ_2 are Lagrange multipliers. Following equation is obtained by differentiating L with respect to w and setting the result equal to zero.

Equation 2.3 $2\Omega\omega - \delta_1\mu - \delta_2\iota = 0$

Using above results below solutions is obtained.

Equation 2.4 $\omega_P = \mathbf{g} + \mathbf{h}\mu_P$

Where g and h are (Nx1) vectors,

$$g = \frac{1}{D}\left[B\left(\Omega^{-1}\tau\right) - A\left(\Omega^{-1}\mu\right)\right]$$

$$h = \frac{1}{D}\left[C\left(\Omega^{-1}\mu\right) - A\left(\Omega^{-1}\tau\right)\right]$$

and A= $\iota^T\Omega^{-1}\mu$, B= $\mu^T\Omega^{-1}\mu$, C= $\iota^T\Omega^{-1}\iota$, and D^2= BC – A^2 Campbell, Lo, and Mackilay (1997) list out number of outcomes based on above. Solving above equations, the values for δ_1 and δ_2 are obtained as a simple linear system for δ_1 and δ_2 (Metron, 1972).

$$\delta_1 = \frac{(C\mu - A)}{D}$$

$$\delta_2 = \frac{(B - A\mu)}{D}$$

From the definition of σ^2,

Equation 2.5 $$\sigma^2 = \frac{C\mu^2 - 2A\mu + B}{D}$$

Therefore the frontier in mean-variance plane is a parabola. Examination of the first and the second derivatives of Equation 2.5 with respect to μ shows that σ^2 is a strictly convex function of μ with a unique minimum point where $\sigma^{2\prime}$=0 i.e., μ =(A/C).

Equation 2.6 $$\frac{d^2\sigma^2}{d\mu^2} = \frac{2C}{D} > 0$$

Further, it could be shown that when μ = (A/C) the variance becomes σ^2 = 1/C. From Equation 2.5 and Equation 2.6 frontier in the mean-variance plane is deducted.

Equation 2.7 $$\sigma = \sqrt{\frac{(C\mu^2 - 2A\mu + B)}{D}}$$

$$\frac{d\sigma}{d\mu} = \frac{(C\mu - A)}{D\sigma}$$

$$\frac{d^2\sigma}{d\mu^2} = \frac{1}{D\sigma^3} > 0$$

From Equation 2.7, σ is strictly convex function of μ. Further, the equation for the efficient frontier is,

Equation 2.8 $$\mu = \bar{\mu} + \frac{1}{C}\sqrt{DC(\sigma^2 - \bar{\sigma}^2)}$$

[2] D^2=BC-A^2>0, -1 is positive definite, hence B^2C- $2A^2B$ + A^2B = B (BC-A^2) = BD. B > 0, hence D > 0.

The efficient frontier and asymptotes are illustrated in Figure 2.2. The efficient portfolio frontier (the set of feasible portfolios that have the largest expected return for a given standard deviation) is the outer boundary left of the highlighted area.

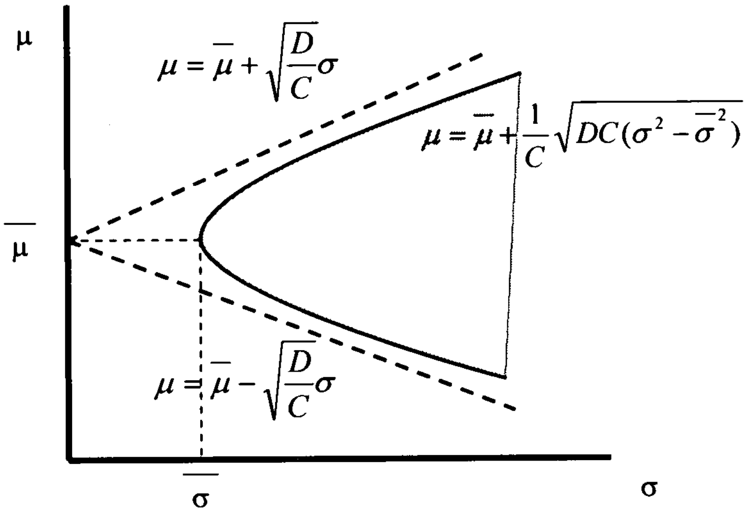


Figure 2.2. Mean-standard deviation portfolio frontier: risky assets only
Source: Metron (1972)

Result 02: *Let p and r be any two minimum-variance portfolios. The covariance of the return of p with the return of r is given by the equation stated below* (Campbell, Lo, & Mackilay, 1997).

Equation 2.9 $$Cov(R_p, R_r) = \frac{C}{D}\left(\mu_p - \frac{A}{C}\right)\left(\mu_r - \frac{A}{C}\right) + \frac{1}{C}$$

Result 03: *It is defined that the portfolio g as the global minimum-variance portfolio. For portfolio g,*

$$\omega_g = \frac{1}{C}\Omega^{-1}\tau$$

$$\mu_g = \frac{A}{C}$$

$$\sigma_g^2 = \frac{1}{C}$$

Result 4: *For each minimum-variance portfolio p, except the global minimum-variance portfolio g, there exists a unique minimum-variance portfolio that has zero covariance with p. This portfolio is called the zero beta* (Campbell et al, 1997).

Generally a portfolio is considered as an efficient portfolio when it is expected to yield the highest return for the level of risk tolerated or alternatively, the smallest portfolio risk for a specified level of expected return. To create an efficient portfolio it is required to select an expected return and assets are required to substitute until it reaches at a smallest variance. As this process is repeated for other expected returns, a set of efficient portfolios is generated. But Markowitz portfolio theory is based on number of assumptions regarding investor behaviour. Markowitz (1952) stated that the investors consider each investment alternative as being represented by a probability distribution of expected returns over some holding period. Investors maximise one period expected utility and possess utility curve, which demonstrates diminishing marginal utility of wealth. They further estimate risk on the basis of the variability of expected returns. Their decisions are solely based on expected return and variance. For a given risk level, investors prefer high returns to lower returns. Similarly, for a given level of expected return, investor prefers less risk to more risk."

2.3 INTERPRETING CORRELATION COEFFICIENT

The correlation coefficient represents a measure of diversity. Lower correlation among portfolio components represents greater diversity. A greater diversity results in reducing portfolio risk.

2.3.1 WHEN DIVERSIFICATION DOES NOT HELP TO ELIMINATE RISK - PERFECTLY POSITIVELY CORRELATED RETURNS

The return from two securities are perfectly positively correlated when a cross plot gives points lying precisely on an upward-sloping straight line (Refer to Figure 2.3).

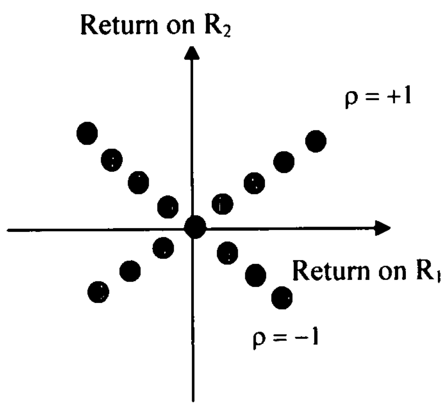


Figure 2.3. Perfectly positively and negative correlated returns

Since two assets are perfectly correlated,

$$\rho_{R_1R_2} = +1 \quad \text{and} \quad \text{cov}(r_1, r_2) = \sigma_{r_1}\sigma_{r_2}$$

Therefore,

$$\sigma^2 = \omega_{r_1}{}^2\sigma_{r_1}^2 + \omega_{r_2}{}^2\sigma_{r_2}^2 + 2\omega_{r_1}\omega_{r_2}\sigma_{r_1}\sigma_{r_2}$$
$$\sigma = \left(\omega_{r_1}\sigma_{r_1} + \omega_{r_2}\sigma_{r_2}\right)$$

When two securities returns are perfectly positively correlated, the risk combination, measured by the standard deviation of returns, is just a weighted average of risks of the component securities, under market value as weights. This principle still holds for more than two securities included in the portfolio where one could argue that the diversification does not provide risk reduction instead it gives risk averaging to the investor.

2.3.2 WHEN DIVERSIFICATION HELPS TO ELIMINATE RISK - PERFECTLY NEGATIVELY CORRELATED RETURNS

It is obvious that a single investment portfolio possesses higher risk than any diverse portfolio. It could be argued that above is true for any commodity supply, such as electricity as well. Generally, the values of different investments are not correlated. The cost structure, operational characteristics and economic drive generally varies according to the technology.

The price volatility could be reduced through diversification and one could identify two types of risks that associated with an individual investment. The unique risk (or business risk) results from events that are specific to an individual investment or resource. The risks develop due to macro-economic factors that change the demand due to recession or boom is considered as systematic or market risks.

Let consider the case where $\rho_{R_1R_2} = -1$

The covariance is determined as,

$$\text{cov}(r_1, r_2) = -\sigma_{r_1}\sigma_{r_2}$$

Therefore, $\sigma^2 = \omega_{r_1}{}^2\sigma_{r_1}^2 + \omega_{r_2}{}^2\sigma_{r_2}^2 - 2\omega_{r_1}\omega_{r_2}\sigma_{r_1}\sigma_{r_2} = \left(\omega_{r_1}\sigma_{r_1} - \omega_{r_2}\sigma_{r_2}\right)$

Further, if it assumes that a portfolio in which the proportionate holdings are inversely related to the relative risk of two securities,

$$\frac{\omega_{r_1}}{\omega_{r_2}} = \frac{\sigma_{r_1}}{\sigma_{r_2}}$$

This gives zero for the portfolio's standard deviation of returns which means that perfectly negatively correlated securities eliminate risk as shown in the Figure 2.3.

2.3.3 CONSTRUCT AN EFFICIENT FRONTIER

The graph plotted in Figure 2.4 shows the combinations of securities/assets for different correlation coefficients.

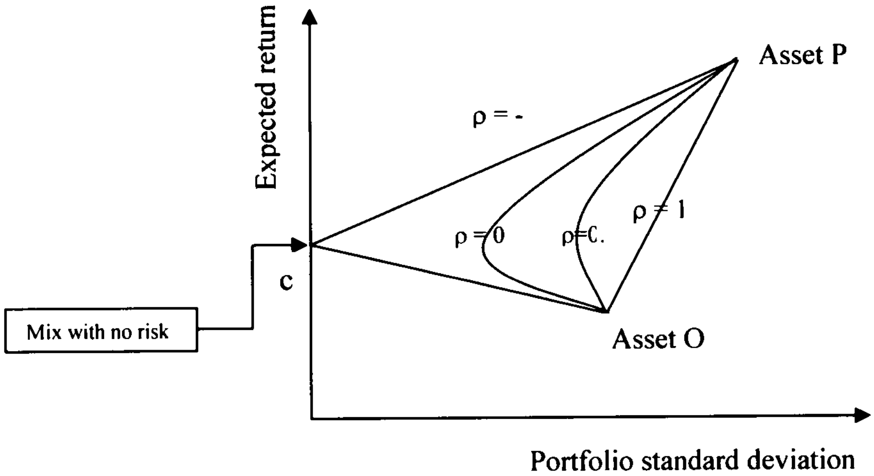
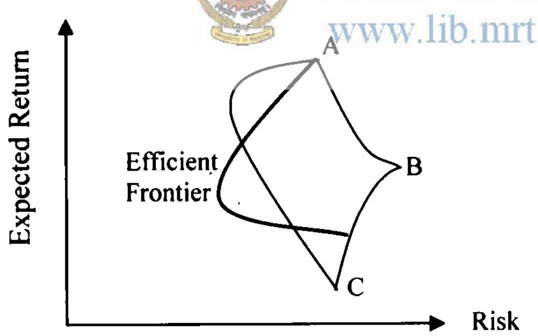


Figure 2.4. Risk and return for two-asset portfolio given different correlation coefficients
Source: Ranganatham & Madhumathi (2006)

If risk (variance) and return (expected return) of (say) 3 assets are known, respective portfolios in the mean-variance plane could be constructed as illustrated in Figure 2.5.



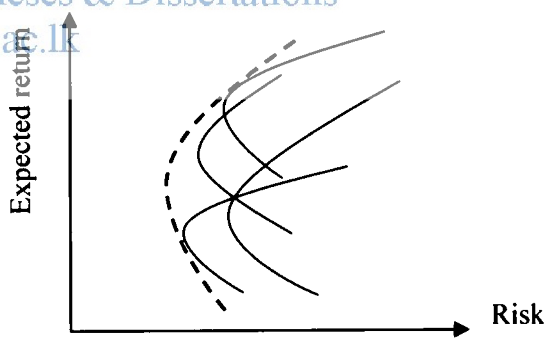


Figure 2.5. Possible risk-cost impacts

Figure 2.6. Portfolio combinations for available m-assets

Source: Ranganatham & Madhumathi (2006)

Given the expected return and standard deviation, any investment option can be represented by a point on such a plane and the set of all potential options can be enclosed by an area such as illustrated in Figure 2.7. The efficient, given by the arc PNSQ, is a boundary of the attainable set. One could derive following curves for different two asset combinations for all possible weights. Therefore, an efficient frontier represents that a set of portfolios that has the maximum rate of return for every given level of risk, or the minimum risk for every level of return. The decision maker would be delighted if his portfolio of assets could move to low cost/low risk region as much as possible.

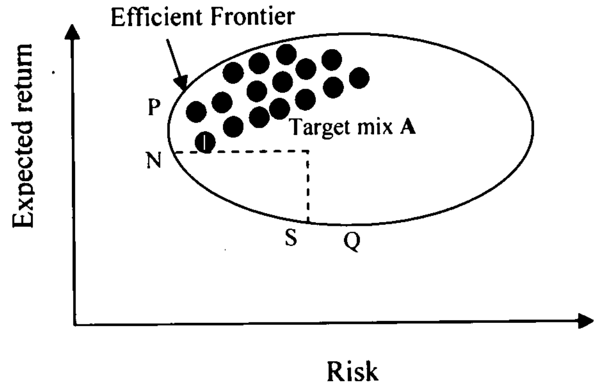


Figure 2.7. An illustration of a revenue efficient frontier
Source: Jansen, Beurskens, & Tilburg (2006)

As one could observe, the mix Q is the global minimum-cost-portfolio and P is the global-minimum-risk portfolio. Mix A represents the target mix for a particular year. So the strategy will be to reduce the risk and reach the point N or reach the point S by reducing cost or achieve both simultaneously. Therefore, a single asset or a portfolio of assets could be considered as efficient if no other asset or portfolio of assets offers higher expected return with same (or lower) risk or lower risk with the same (or higher) expected return (Refer to Figure 2.8).

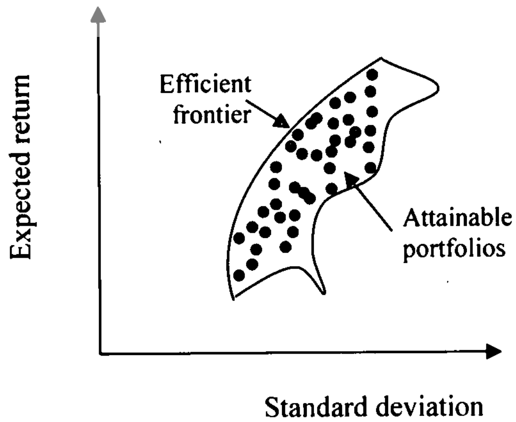


Figure 2.8. Markowitz efficient frontier
Source: Huanga & Wu (2008)

Summing up, the rational holders of a portfolio of liabilities look to minimise the expected increase of its value at a given risk or alternatively look to maximise its expected negative increase (i.e. decrease) at a given risk. The expected (negative) return of such a portfolio depends on the expected returns of the individual liabilities and the percentage of funds invested in each (Zweifel & Krey, 2005).

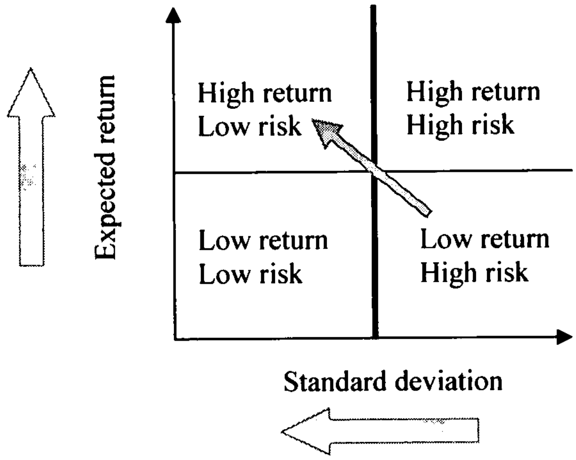


Figure 2.9. Risk-return diagram

Therefore, the typical behavior of rationale investors is illustrated in Figure 2.9. Obviously, they prefer a high return and low risk menu.

2.4 PORTFOLIO THEORY AND ENERGY

Records show that Bar-Lev and Katz first applied portfolio theory to energy assets. They used portfolio theory to analyze the fossil fuel procurement in the United States electricity utility industry (Kienzle, Koeppel, Stricker, & Anderson, 2007). The objective of the study was to determine the extent at which the utilities had been using scare resources efficiently.

Awerbuch and Burger (2003) used portfolio theory to develop an efficient generating portfolio for the European Union. Their model comprised with the risk of the different relevant generating cost streams such as fuel, operation and maintenance, and construction period costs. Their analysis reflected that more efficient portfolios could be constructed by inclusion of different technologies (especially the renewable power generation technologies) with high fixed costs but less variable cost to the existing generating mix.

Humphreys and McClain (1998) constructed efficient portfolio of U.S. energy sources using time-varying covariance matrix. Estimation of covariance and variance were performed using Generalized Autoregressive Conditional Heteroscedastic (GARCH) models.

Krey and Zweifel (2006) determine efficient electricity generating technology mixes for Switzerland and the United States using portfolio theory. They discovered that shocks in generation are found to be correlated. Therefore, they use the seemingly unrelated regression analysis (SURE) to time invariant covariance-variance matrix. They conclude that in-order to increase the expected return Switzerland needs to focus adding nuclear and solar technologies into their generating mix. The minimum risk portfolio is obtained once storage hydro and nuclear will be added to the system. For the US maximum expected portfolio comprises coal and wind power whilst minimum risk portfolio contains coal, nuclear, oil and wind.

Awerbuch (2004) in his report "building capacity for portfolio-based energy planning in developing countries" applied portfolio theory to analyze electricity generation sectors of India, Mexico and Morocco. The objectives of this report were to build capability to integrate portfolio techniques to energy policy and planning process in developing countries, to demonstrate the least cost approaches understate true fossil costs whereas renewable reduce portfolio generating cost and to develop efficient portfolios that enhances energy security.

2.6 MODEL DESCRIPTION: MEAN VARIANCE PORTFOLIO FRAMEWORK FOR POWER SYSTEM PLANNING

Modern Portfolio Theory is the most popular method in determining the optimal portfolio considering the return of assets and associated risk. When constructing a portfolio, an investor tends to assess the risk and return of an individual asset. A particular asset generally will be selected based on the expected return at a minimum risk. Harry Markowitz stressed the necessity of diversification for efficient construction of portfolios; by developing a mathematical formula to analyze the return versus risk relationship. The concept was further extended to determine how the aggregate of investors behave with reference to market prices and returns (Kienzle, Koeppel, Stricker, & Anderson, 2007). It is always interesting to see the possibility of fitting finance model to energy market analysis. The application of portfolio theory for energy assets related study was first reported in the US; Ban-Lev and Katz used portfolio models to analyze fossil fuel procurement in the US electric utility industry. The study conducted by Awerbuch and Berger (2003) evaluating potential applications of portfolio theory to develop an efficient generating portfolio to the EU will be concomitant with this dissertation.

2.6.1 EXPECTED COST AND STANDARD DEVIATION

Originally MPT approach provides return versus risk relationship for portfolio of financial assets. The expected return is determined from the historical prices using time series analysis (using GARCH or simple holding period return approach). Similarly, the risk is ascertained by determining the standard deviation of above price series. However, this study uses expected cost in place of expected return and standard deviation remains the same. Further, the expected cost is determined not using conventional time series method. It uses the levelised cost of generating technologies as a proxy to expected cost (Eillis, 1996).

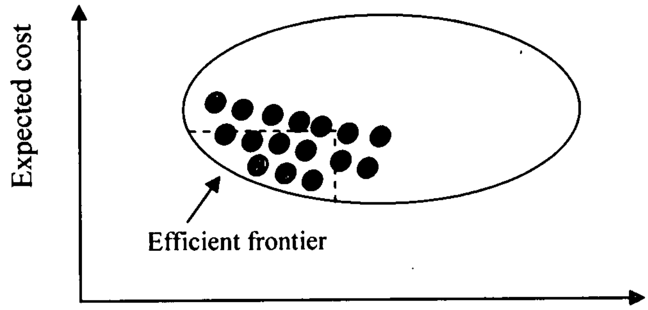


Figure 2.10. An illustration of a cost efficient frontier
Source: Jansen, Beurskens, & Tilburg (2006)

Figure 2.10 illustrates how efficient frontier behaves in expected cost and risk approach. The frontier lies in the lower parts of the curve since the energy planner's intention is to minimise the cost whilst minimising the risk. Therefore, the intention of the investors would be to acquire a low cost and low risk menu (Refer to Figure 2.11).

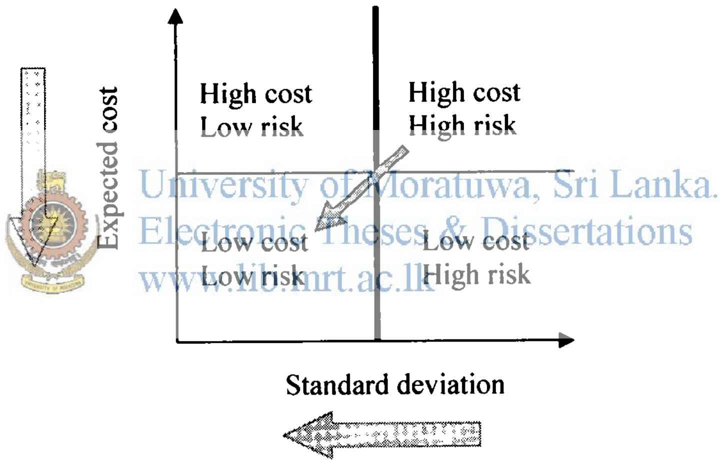


Figure 2.11. Cost-risk diagram

Further more, the analysis is done using cost which helps to look at the problem in societal point of view which is to minimize the generating cost and associated risks. Use of cost as basis eliminates the need to concern electricity market price fluctuations (Awerbuch & Berger, 2003). This is true for regulated markets as well. Efficient portfolio is selected using mean-variance approach (Markowitz, 1952). Therefore, a minimum variance portfolio is easily created for any given level of expected return (Awerbuch & Berger, 2003). The mean variance portfolio technique is used to analyse simple portfolio model. Here the technologies are assumed to be analogues to assets or securities. The weighted averages could be considered as the percentages of contribution by different technologies to entire generation of the country or the entity that is being studied. Let portfolio "*P*" contains renewable sources i.e, hydro, wind etc. Let other portfolio comprises the non-renewable sources such as auto diesel, coal, combine cycle etc. The renewable sources relatively have high generation cost and low operating cost. The market risk is measured on the basis of historic variation and covariance of the holding period returns of costs of the technologies considered (Awerbuch, 2000). Therefore, when the variance of fuel prices will be determined using financial holding period return series. (Seitz, 1990)

Equation 2.10 Holding period return[3], $r_t = \dfrac{EV_t - BV_t - CF_t}{BV_t}$

For fuel prices CF_t is zero and EV_t is the fuel price per unit (kWh) at the end of period t and BV_t is the price at the beginning of the period. Awerbuch (2003) performs his analysis on cost-basis in view of minimising the societal risk whereas conventional portfolio theory is based on revenue or market prices (Bates, 2007). The expected cost of the generating technologies is given by,

$$E(C_\Omega) = \sum_{i=1}^{N} \omega_i E(C_i)$$

Where ω_i is the fractional weights of the power generated by i^{th} technology and $E(C_i)$ is the expected levelized generating cost. The variance of the portfolio of generating technologies is given by,

$$\sigma_\Omega^2 = \sum_{i=1}^{N} \sum_{j=1}^{N} \omega_i \omega_j \rho_{ij} \sigma_i \sigma_j$$

where ρ_{ij} is the correlation coefficient between cost of technologies i and j. This expression is further deduced to,

Equation 2.11 $\sigma_k^2 = (\omega_k^C \sigma_k^C)^2 + (\omega_k^F \sigma_k^F)^2 + (\omega_k^{O\&M} \sigma_k^{O\&M})^2$

where C, F and O&M represent the investment cost, fuel cost and operating and maintenance cost for a particular technology and k is the generating source (Beltran H, 2008).

2.7 PORTFOLIO FRAMEWORK FOR POWER SYSTEM PLANNING

It was Harry Markowitz who proposed that as the investor one should pay attention on the probability distribution of his future wealth with some measure of dispersion and central tendency of this distribution. The standard deviation and expected return are used as proxies for above measures respectively (Markowitz, 1952)

[3] CF_t is the cash flow during each period "*t*" (Awerbuch, 2004).

2.8 ASSUMPTIONS AND LIMITATIONS

As stated in the initial discussions it is a well known fact that Markowitz portfolio theory is originally developed for financial assets. One key assumption that made in this study is that holding period returns of fuel prices are distributed normally, which is not that case. Fuel prices are often modelled as random works using financial time series techniques such as GARCH/ARCH models. This study focuses on the cost risk to the society. Therefore, taxes, duties and levies were ignored (Awerbuch & Berger, 2003).

2.9 DETERMINATION OF CONSTRUCTS AND VARIABLES

The key constructs of this study are expected costs of generating technologies, standard deviations of those technologies and emission of carbon. The first construct (expected cost) is determined using variables such as investment costs, capital outlays during operation, fixed and variable operation and maintenance costs and salvage values if available. The portfolio risk is a function of fractional share of each cost stream for each technology present in the overall mix, the standard deviation of the annual changes to that cost stream and the correlation coefficient (and covariance) between that cost stream and all other cost streams (Awerbuch,2004). The third construct is determined by calculating carbon emission relevant to different technologies (Refer to Figure 2.12). Therefore, optimal portfolio is constructed using expected cost, standard deviation and emissions.

Equation 2.12

$$\text{Optimal portfolio} = f(\text{expectd cost}(\mu), \text{standard deviation}(\sigma), \text{emissions}\ (CO_2 / kWh))$$ [4]

[4] This model was adopted from Eillis (1996) and Awerbuch (2004).

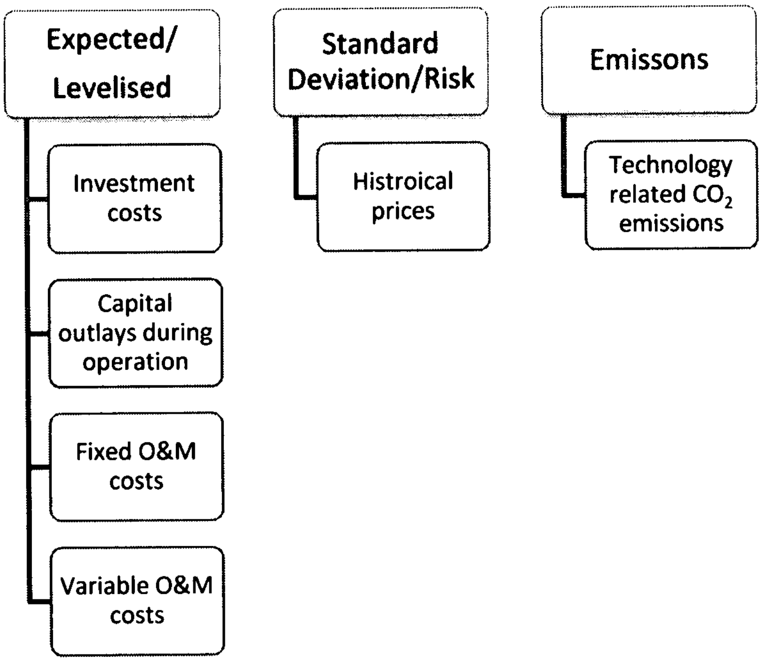


Figure 2.12. Variables of the study

2.9.1 DETERMINING CAPITAL COSTS

In a generating system one could see primarily two types of technologies, namely existing technologies and new technologies. Estimation of initial capital outlays for new technologies is much clear and in most cases it is well defined. But determining costs for plants already had installed may be 20 years ago is not straight forwards as new technologies. Awerbuch and Berger (2003) define three possibilities to estimate the relevant capital costs for already installed plants.

a) 100% Capital costs for embedded assets:

   Full capital costs of embedded assets are included for portfolio cost computations according to standard accounting assumption of cost incurred to be recovered.

b) Societal approach: 0% capital costs for embedded assets:

   Past capital outlays for existing assets are considered as sunk. Therefore, these costs are not relevant for societal decision making.

c) Utility costing for embedded assets:

   The approach reflects the idea that in their electricity purchases utility consumers pay a set of capital charges that decline over time as assets age and book depreciation is charged.

2.9.2 CONSIDERING ENVIRONMENTAL COSTS

It is important that the environmental adders to be incorporated to determine the real cost exerted at the society. Therefore, emissions such as CO_2, SO_2, NO_X and smoke are incorporated in a well executed generation expansion plan. Apart from carbon emissions and smoke, others are controllable using better emission techniques. Generally in most cases the impact of carbon emissions is incorporated as taxation or a penalty. It indirectly assumes that emissions are positively correlated with technological and fuel cost elements. In this study, carbon emission is considered as a separate cost variable that uses to further optimise the attained portfolios. One must pay equal attention on environmental issues such as displacement of people, emission of gases etc created by renewable sources (large hydro). The next task is to determine the expected cost for different types of power generation options using above cost components. It is used the levelized bus bar cost as the proxy to expected return (Eillis, 1996).

2.9.3 DETERMINATION OF LEVELIZED BUS BAR COST

The levelized cost per kilo Watt hour is the ratio of total cost of erection and operating a power station over its life span to the net electrical output over the same period which is one of the widely used techniques to express the generation cost. The levelized cost calculation accounts for the time value of money spent on site acquisition, erection, installing and commissioning, operation and maintenance, subsequent spending on fuel management (in the case of non renewable) and plant decommissioning for both renewable and non-renewable power plants (Ellis, 1992). All costs are discounted back to the base year and total levelized cost is derived by adding all costs (in present value terms) together. Ellis (1992) states that results obtained using constant-value (real) monetary units and a discounted rate reflecting the required real return on capital could be tolerated instead of using financial market interest rates with the introduction of additional uncertainty with the number of assumption made. Eillis (1996) further stated that the real levelized generation cost is determined by dividing the present value cost by sum of the discounted annual electricity output over the plant's life yield".

Equation 2.13 Levelised cost calculation

$$\text{Levelized generating cost} = \frac{\sum_{t=1}^{T} \frac{C_t + O\&M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{e_t}{(1+r)^t}}$$

Where C_t, $O\&M_t$ and F_t are annual expenditure on capital investment, operation and maintenance and fuel respectively. e_t represents the annual electricity generations whilst r denotes the discounting rate. Different type of generating plants will have cost components in different magnitudes and timing of cost incidents will again vary to plant to plant and type to type. As mentioned above renewable sources will have higher investment costs but they arguably carried low or no fuel costs. The picture is different when one analyses the fossil fuel based generation. Other important aspect is how levelized generation cost looks at cost imposed by these technologies at communities. The community cost reflects the harm that these technologies may cause the society. But this could not always measure in monetary terms in every single case. Ellis (1992) brings the concept of carbon tariff as a cost compensation for societal impact caused by different technologies. Further, these costs will have to be weighted according to the country's dependency towards each cost item. For example countries that are importing crude oil will show a negative dependency towards fossil fuel based generating options with regard to sources that are freely available in those countries.

2.9.4 INPUT DATA

Generation Cost Minimization (GCM) model is fed following data.

- Fuel price are acquired from historical yearly average fuel prices.
- Technology cost and operational costs
  - Investment and Operating costs (annual)
  - Fuel efficiency
  - Capacity/load factors
- Correlation coefficient, ρ, is used to measure the diversity. To create greater diversity it is necessary to have portfolio components with low correlation. When it comes to energy portfolios, certain technologies show very low correlations among them (example – hydro versus thermal). However, certain technologies are highly correlated (example – auto diesel versus residual oil). According to Awerbuch (2005), adding a fuel-less technology to a risky generating portfolio lowers the expected cost at any given level of risk, even if the technology costs more. In case of fuel less renewable technologies, fuel risk is almost zero and its correlation with fossil fuel cost is also zero. The involvement of fossil fuel at material sourcing and manufacturing stages of renewable technologies were not accounted. For example, the amount of fossil fuel used to manufacture components of hydro power generation plant was not considered.

Table 2.1 Correlation coefficients for different technologies

Outlays		Technology X			
		Construction period	Annual fuel	Annual variable O&M	Annual fixed O&M
Technology Y	Construction period	0.7	0.0	0.1	0.1
	Annual fuel	0.0	Varies	0.0	0.0
	Annual variable O&M	0.1	0.0	0.7	0.1
	Annual fixed O&M	0.1	0.0	0.1	0.7

Source: Awerbuch & Berger (2003)

- Variance-covariance matrix

  The variance-covariance matrix for different generating technologies is determined using below mentioned expressions.

$$\sigma_P^2 = \sum_{i=1}^{n} \omega_i^2 \sigma_{ii} + \sum_{i=1}^{n} \sum_{j=1}^{n} \omega_i \omega_j \sigma_{ij}$$

Where ω_i, ω_j denotes the technology shares of the portfolio, σ_{ii} denotes the variance and σ_{ij} denotes the covariance between technologies *i* and *j*. The variances are illustrated in the diagonal of the variance-covariance matrix (Refer to Table 2.2).

Table 2.2. Variance-covariance matrix

Generating technology	*1*	*2*	*3*	....	*n*
1	$\omega_1\omega_1\sigma_{11}$	$\omega_1\omega_2\sigma_{12}$	$\omega_1\omega_3\sigma_{13}$	....	$\omega_1\omega_n\sigma_{n1}$
2	$\omega_2\omega_1\sigma_{21}$	$\omega_2\omega_2\sigma_{22}$	$\omega_1\omega_3\sigma_{13}$	....	$\omega_1\omega_n\sigma_{n2}$
3	$\omega_3\omega_1\sigma_{31}$	$\omega_3\omega_2\sigma_{32}$	$\omega_1\omega_3\sigma_{13}$	....	$\omega_1\omega_n\sigma_{n3}$
....	....	....	....	....	
n	$\omega_n\omega_1\sigma_{n1}$	$\omega_n\omega_1\sigma_{n1}$	$\omega_n\omega_3\sigma_{n3}$	....	$\omega_n\omega_n\sigma_{nn}$

Source: Author derived

- Current generation portfolio mix of the country.
- Expected future generating mix (in case of Sri Lanka it would be mix of 2020) which is termed as the reference or business as usual (BAU) (Bates, 2007).

2.10 PORTFOLIO CHOICE

The traditional portfolio methods are based on risk –returns combinations. The Sharpe Single Index Portfolio Selection Method and the Markowitz Portfolio Selection Method are commonly used by practitioners. Sharpe's (1964) justification was that the portfolio risk is to be identified with respect to their return co-movement with the market and not necessarily with respect to within the security co-movement in a portfolio. He further concluded that the desirability of a security for its inclusion is directly related to its excess return to beta ratio (β).

Equation 2.14 Single index portfolio selection

$$\frac{R_i - R_f}{\beta_i}$$

Where R_i is the expected return on security i, R_f is the return on a riskless security and β_i is the beta of security i. The result gives the best securities that are to be selected for the portfolio.

2.10.1 CUT-OFF RATE

The cut-off rate determines the number of securities that are to be selected. This rate ensures that all securities with higher ratios are included into the portfolio.

Equation 2.15 Cut-off rate

$$C_i = \frac{\sigma_{m_i}^2 \sum_{i=1}^{i} \frac{(R_i - R_f)\beta_i}{\sigma_{ei}^2}}{1 + \sigma_{m_i}^2 \sum_{i=1}^{i} \frac{\beta_i}{\sigma_{ei}^2}}$$

Where σ^2_m market variance, R_i security return, R_f risk free return, security β_i and security error variance. The percentage of investment in each of the securities in a portfolio with optimal C* cut-off rate is given by below equation.

Equation 2.16 Percentage of investment in each security

$$\omega_i = \frac{Z_i}{\sum_{i=1}^{n} Z_i} \quad \text{where } Z_i = \frac{\beta i}{\sigma_{ei}^2}\left(\frac{R_i - R_f}{\beta_i} - C^*\right)$$

However, application of Sharpe's single index portfolio selection method for electricity generation portfolio selection is not practicable if one uses cost (levelised) instead of returns. There is hardly any meaning of having a point in the risk-cost plane where generating cost with zero risk. One could argue that wind and other renewable may have minimal of risks which may be acceptable for the existing plants but for candidate plants there could be considerable risks. Therefore, this study restrain from constructing a tangent from zero risk return (cost) to the efficient frontier to determine the optimal portfolio.

2.10.2 MARKOWITZ PORTFOLIO SELECTION IN MEAN VARIANCE PLANE

Markowitz portfolio selection method tries to identify the investor's unique risk-return preferences. This model is based on below stated assumptions. Investors are

- risk averse.
- preferred to maximize utility than return.
- subjected to the same time period.

The utility theory provides the base for the theory of choice under uncertainty. The economists use cardinal and ordinal theories as alternatives to describe how people and societies choose to allocate scares resources and to distribute wealth among one another over a period of time. Further, economists define the relationship between psychological satisfaction and wealth as "utility" and its behaviour against wealth is according to the diagram shown below.

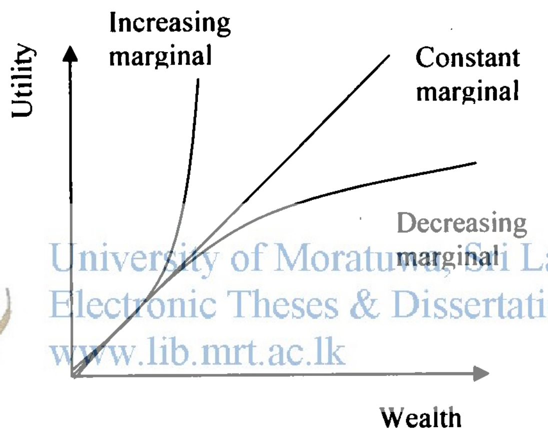


Figure 2.13. Wealth and utility

If the investor increases the amount invested in risky assets as wealth increases, then the investor said to exhibit decreasing absolute risk aversion. If the investor's investment in risky assets is unchanged as wealth changes, then the investor is said to exhibit constant absolute risk aversion. Finally, if the investor invests fewer dollars in risky assets as wealth increases, then the investor is said to exhibit increasing absolute risk aversion.

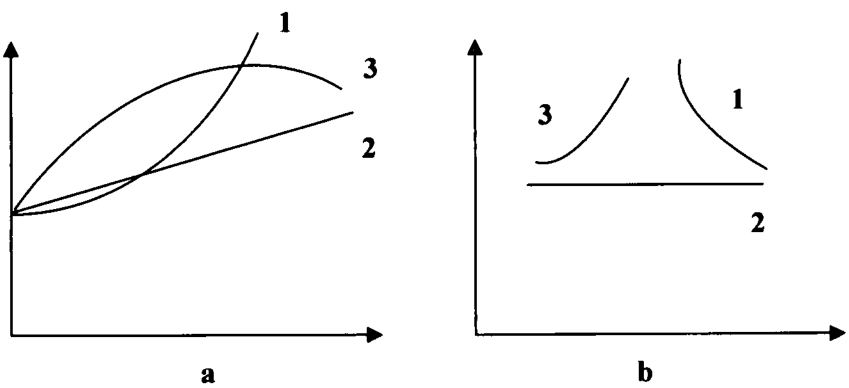


Figure 2.14. Characteristics of the functions with different risk-aversion coefficients

The curves 1, 2 and 3 of figure 8 represent the utility function of a risk seeking, risk neutral and risk-averse investor respectively.

2.10.2.1 INDIFFERENCE CURVES

Indifference (utility function) curves are abstract theoretical concepts. They can not as a practical matter be used to actually measure how individuals make investment decisions or and other decisions, for that matter. They are, however, useful for building models that illustrate the relationship between risk and return. The investor's utility function can be utilised conceptually to derive the indifference curve, which shows the individual preference for risk and return. Let R_1 and R_2 will yield same level of satisfaction or utility to consume. Such analysis is based on the ordinal utility theory. Any indifference curve could be plotted in the risk-return space such that the investor's utility is equal all along its length. Figure 2.15 maps the indifference curves for a risk-averse investor.

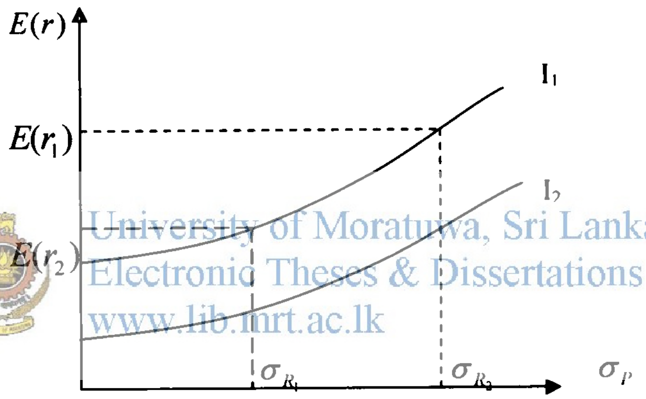


Figure 2.15. Indifference curves for a risk-averse investor

Can indifference curves be intersected? As shown in the Figure 2.15, it could consider a situation where two indifference curves I_1 and I_2 intersect at a point K which means that all portfolios on I_1 are desirable as those on I_2. But I_1 and I_2 curves themselves represent different levels of desirability. Therefore, in order for there to be no contradictory situation, indifference curves could not intersect at any point. Having made the assumptions, non-satiation and risk-aversion, the indifference curves will become positively sloped and convex. But different investors will have varying degree of risk aversion as illustrated by the Figure 2.16 below.

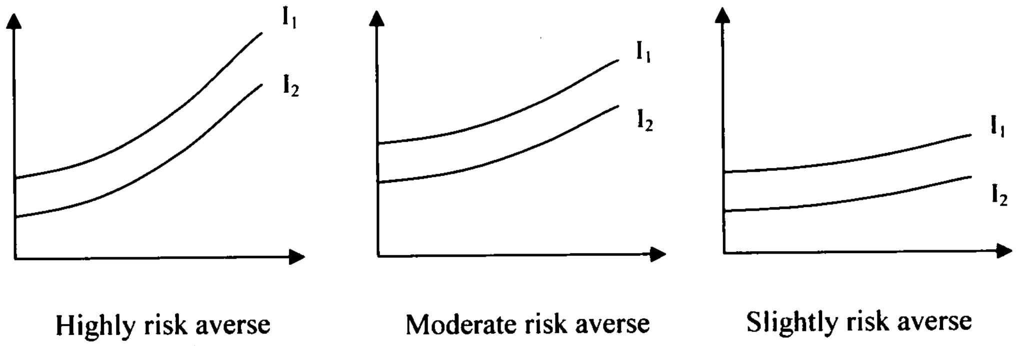


Figure 2.16. Indifference curves for different type and risk averse investors

Source: (Elton & Gruber, 1997)

2.10.2.2 THE EFFICIENT FRONTIER AND INVESTOR UTILITY

The utility curves for an individual investors specify the trade-offs that they are willing to accept between expected return and risk. The curves labelled I_j are for risk averse investor where j is the number of indifference curves and I'_j curves represents the risk taking investments.

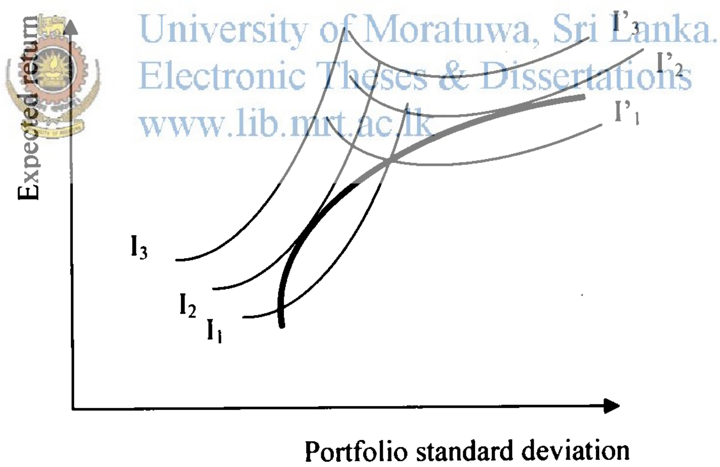


Figure 2.17. Optimal portfolio selection

The optimal portfolio is the portfolio on the efficient frontier that has the highest utility and it lies at the point of tangency between the efficient frontier and the curve with the highest possible utility. Baron (1977) expressed that the choice model in which alternatives are ordered in terms of the mean and variance of their return has been utilised in a variety of fields with the best developed, both theoretically and empirically, being that of portfolio selection. Further according to Baron (1977), Markowitz had demonstrated it is only quadratic function that is consistent with an ordinal expected utility function that totally depends on the mean and variance of the return if the ordering of alternatives is to satisfy the von Neumann-Morgenstern (NM) axioms of rational behaviour.

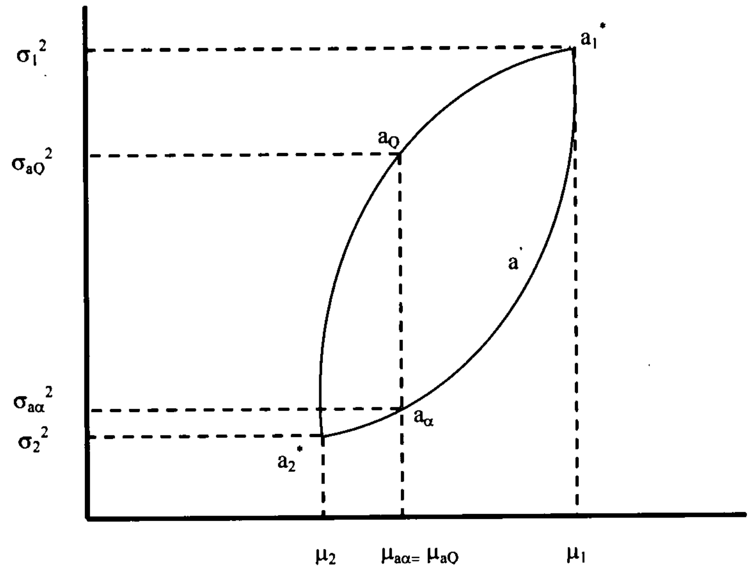


Figure 2.18. Mean and variance of four alternatives
Source: (Baron, 1977)

According to Baron (1977) the above figure illustrates means and variances of four alternatives a_1*,a_2*,a_α and a_Q. According proposition 01 (Baron, 1977), the mean-variance utility function $V(\mu,\sigma^2)$ that agrees with that preference ordering can only correspond to quadratic NM utility function $U(x)^2$. Given the alternatives a_1 and a_2 and their corresponding random returns X_1 and X_2 with distribution functions $F_1(x)$ and $F_2(x)$, respectively, the continuous utility function U(X) such that X_1 is preferred to X_2 if and only if $EU(X_1)>EU(X_2)$. The $E(X_i)$ could be written as below expression (Baron, 1977).

Equation 2.17 Expected utility

$$V(\mu,\sigma_i^2) \equiv EU(X_i) = \int U(x)dF_i(x)$$

If and only if $V(\mu_1,\sigma_1^2) > V(\mu,\sigma_1^2)$ it could be safely stated that X_1 is preferred X_2.

If two pure strategies a_1*,a_2* are considered where a_1* is indifferent to a_2* and let q denotes the probability of obtaining a_1* and (1-q) obtaining a_2*. If μ and σ^2 denote the mean and variance of respective alternatives according to proposition 01 (Baron, 1977) the mean and variance of mixed strategy a_Q is given by,

Equation 2.18 Mean of mix strategy a_Q

$$\begin{aligned}\mu_q &\equiv \int xd(qF_1(x)+(1-q)F_2(x))\\ &= q\int xdF_1(x)+(1-q)\int dF_2(x)\\ &= q\mu_1+(1-q)\mu_2\end{aligned}$$

Equation 2.19 Variance of mix strategy a_Q

$$\begin{aligned}\sigma_q^2 &\equiv \int(x-qx_1-(1-q)\mu_2)^2 d(qF_1(x)+(1-q)F_2\\ &= \int(q(x-\mu_1)+(1-q)(x-\mu_2))^2 d(qF_1(x)+(1-q)F_2(x)\\ &= \int(q^2(x-\mu_1)^2+2q(1-q)(x-\mu_1)(x-\mu_2)+(1-q)^2(x-\mu_2)^2)d(qF_1(x)+(1-q)F2(x))\\ &= q\sigma_1^2+(1-q)\sigma_2^2+q(1-q)(\mu_1-\mu_2)^2\end{aligned}$$

The form of the indifference curve is obtained solving Equation 2.18and Equation 2.19.

$$\mu_q - b(\mu_q^2+\sigma_q^2)=k$$

where b and k are constants. The form of the indifference curves will be,

$$V(\mu,\sigma)=\mu_q-b(\mu_q^2+\sigma_q^2)=\int(x-bx^2)dF_Q(x)$$

In his paper it further illustrates that the NM utility function that corresponds to V is the quadratic function $U(x)=x-bx^2$.

The indifference curves in the mean-variance half-plane therefore have slope

$$\frac{d\sigma^2}{d\mu}=\frac{(1-2b\mu)}{b}$$

The indifference curves in the (μ,σ) half-plane are concentric semi-circles with centre at point (1/2b,0) and slope

$$\frac{d\sigma}{d\mu}=\frac{(1-2b\mu)}{2b\sigma}$$

The value of the constant b is given below.

$$b=\frac{\mu_1-\mu_2}{\mu_2^2-\mu_1^2+\sigma_2^2-\sigma_1^2}$$

It is then formulated a risk-penalty system using above results. The value assigned for b is compensating investment portfolios based on the expected return and risk of those portfolios. The utility value derived from the probability distribution could be written as,

Equation 2.20 $U = \mu - b_0\sigma^2 + b_1M_3 - b_2M_4 + b_3M_5 - .....$

where U represents the utility value and b represents the investor's risk aversion (Bodie, Kane, & Marcus, 2005). According to Samuelson's "Fundamental approximation theorem of portfolio analysis in terms of means, variances and higher moments" proves that the importance of all moments beyond the variance is much smaller than that of expected value and variance. Therefore, one could safely disregard the higher moments with out material affect on the portfolio choice. Further he states that variance is as important as the mean to investor welfare (Baron, 1977). According to Eillis (1996) all moments higher than the variance (M_2) could be expressed using variance (standard deviation) (Refer to Equation 2.21).

Equation 2.21 $M_n = \frac{n!}{2^{\frac{2}{n}}\left(\frac{n}{2}\right)!}\sigma^n$

The utility function could be reduced to,

Equation 2.22 $U = E(x) - f(\sigma^2)$

Therefore, expected cost and standard deviation provide adequate information to select the desired risk-cost efficient electricity generating portfolio (Eillis, 1996).

2.10.3 ENERGY PORTFOLIO SELECTION

The energy portfolio is constructed in expected cost and risk plane. Therefore, the choice needs to be performed in view of obtaining less risky portfolios. Further, the optimal portfolio choice illustrated in Figure 2.17 would have to be changed as shown in Figure 2.19. The efficient portfolio is in a quasi-convex downward form which is a minimum.

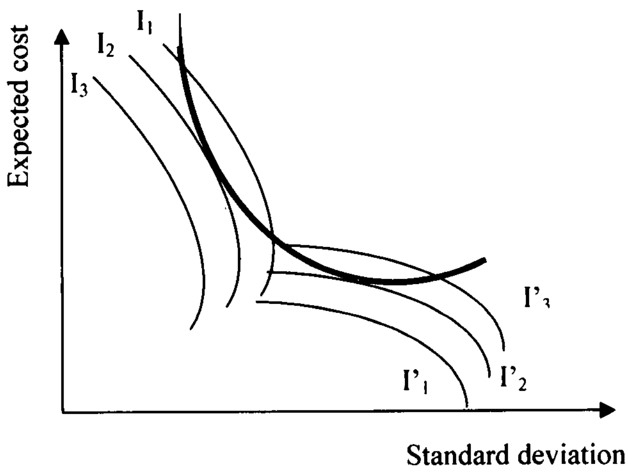


Figure 2.19. Energy portfolio choice

In the case of expected cost versus risk the utility curve depicted in Equation 2.20 is altered in the form of $U=\mu + b\sigma^2$ (Baron, 1977).

2.11 ENVIRONMENTAL RISK AND SOCIETAL RISK

The third objective of the study is to determine the societal risk caused by present least cost based generation expansion planning policies. Generally the factors such as low capital involvement, number of displacements, access to fuel etc had become the priority concerns when deciding to put up an electricity generating facility. Many environmentalists and other pressure groups were complaining on displacement of people, disruptions caused to eco-systems, incidents of land slides, unexpected floods and risks of earth quacks due inequalities in pressure on earth surface caused by large hydro projects in many parts of the world. Therefore, both environmental as well as societal impacts were caused by these mega projects. However, in many countries that trend had already over and there only handful of opportunities are available to exploit at present. The possible reasons are exhausted hydro resources, relatively high capital intensity when compared with other power generation technologies, negative cost benefits and environmental and societal risks are beyond the threshold limits.

When the countries focused on thermal power generating options, the pertaining issues that they faced with are more severe than earlier ones. Thermal generation emits SO_2, NO_X, matter, smoke, CO_2 and other substance that destroys ecosystems. These affects are ranging from problems of acid and nutrient nitrogen, regional concentration of fine particles and ozone. Apart from above loss of forest cover, biodiversity and degradation of coastal zones are alarmingly increasing in many countries including in Sri Lanka. However, technological advancements resulted due to stringent regulatory measures are in a position to manage the emissions such as SO_2 and NO_X. Today the green house gas (GHG) emission is considered as the paramount issue that threatens the livelihood of mankind and entire eco-system. Therefore, the societal risks that had been discussed in yester era are no longer present. However, the environmental risks caused by GHG emissions have been already started to impact negatively on earths' eco-system and the human society as a whole.

2.11.1 PORTFOLIO CARBON EMISSION

There are different thoughts on incorporating risk of GHG emissions into power generation. Awerbuch and Berger (2003) had incorporated carbon emission into generating cost by means of a taxation. Therefore, the thermal generation cost would have the generation cost as well as the cost of environmental adders. Another argument had been to impose a scheme that detarmines GHG saved per kWh which is deducted from the renewable electrcity generating cost (Abeygunawardana, 2008).

In this study, the portfolio carbon emissions are measured using the life cycle CO_2 emissions of each technology (Eillis, 1996). Therefore, carbon emission is considered as the third dimension that measures the efficiency of electricity generating portfolios. For each technology, the amount of carbon emits are individually measured according to life cycle CO_2 emission method. According to ECA, RMA AND ERM (2010) draft issue in general, the life cycle emissions associated with direct and indirect (mining, transport, material inputs, construction and decommissioning) are illustrated in Figure 2.20.

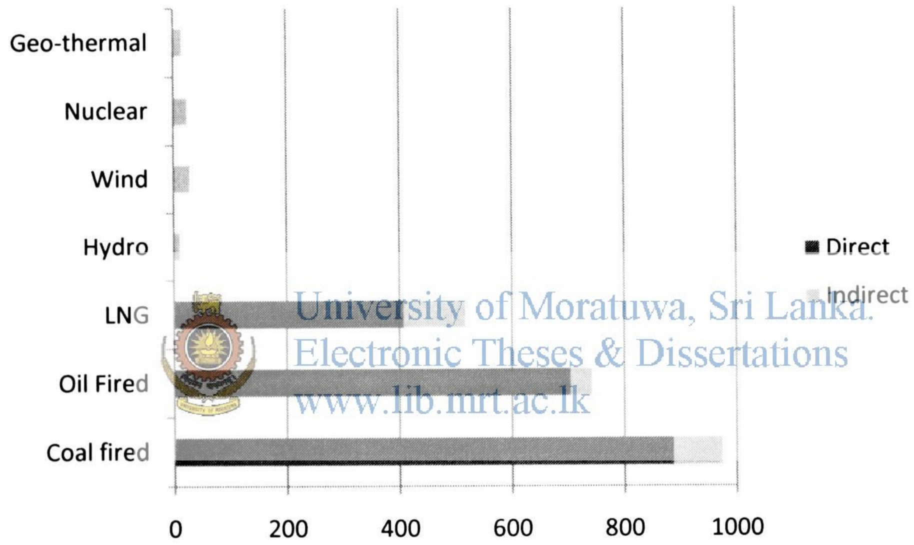


Figure 2.20. Life Cycle CO_2 emissions
Source: ECA, RMA and ERM[5] (2010)

The carbon emission relevant to individual technology is assessed. The portfolio emission is determined according to the technology shares that each portfolio possesses. The emissions indicated as a separate dimension perpendicular to the mean-variance plane that determined previously (Eillis, 1996).

2.12 CHAPTER SUMMARY

The least cost based generation expansion planning which is more often labelled as operational planning model neglects the effect of fuel price fluctuations at the time of decision making. Therefore, over the years least cost approach had pilled up carbon intensive

[5] Economic Consulting Associates (ECA), Resource Management Associates (RMA), Environment Resource Management (ERM)

generating technologies into the generating portfolios in many countries. There is not much difference in the situation in Sri Lanka too. The direction that Sri Lanka's power sector is heading may not change the situation much. Ceylon Electricity Board in their long term generation expansion planning considers having approximately 50% of total power generating to be done by coal.

Therefore, one could observe that there has been very little concern over the future fuel price volatilities when deciding expansion planning process. More importantly concerns on carbon emissions seem to be totally neglected in CEB's ambitious expansion plans.

Therefore, at the moment both price and environmental/societal risks are given less significance in CEB's generation expansion planning. Based on these facts risk based generation expansion planning definitely would have paid dividends entire economy.

CHAPTER III

SECTOR HIGHLIGHTS - SRI LANKA ELECTRICITY GENERATION

3.0 INTRODUCTION

Ceylon Electricity Board (CEB) is the statutory body established by an Act (Act No. 17 of 1969) passed in the Parliament of Sri Lanka making CEB responsible for power generation, transmission and distribution of electricity for most parts of the country. Deficiencies in electricity sector had negative impacts on many sectors of the country. Power outages during droughts and total blackouts due to system instabilities had been occurring frequently affecting the day to day life. There were many disputes and arguments against the tariff system which had also had several alterations down the line. As expected there exists a correlation between the GDP growth rate and generation growth rate of Sri Lanka (Refer to Figure 3.1). It had been further noticed that number of social unrests occurred last thirty years correlates with the level of electrification of the country. Still, approximately 40% of population is deprived of electricity (Ceylon Electricity Board, 2008). The Government of Sri Lanka (GoSL) with the help of number of donor agencies have started several programmes to provide electricity either by expanding the national grid or by means of relatively small stand-alone (off-grid) systems.

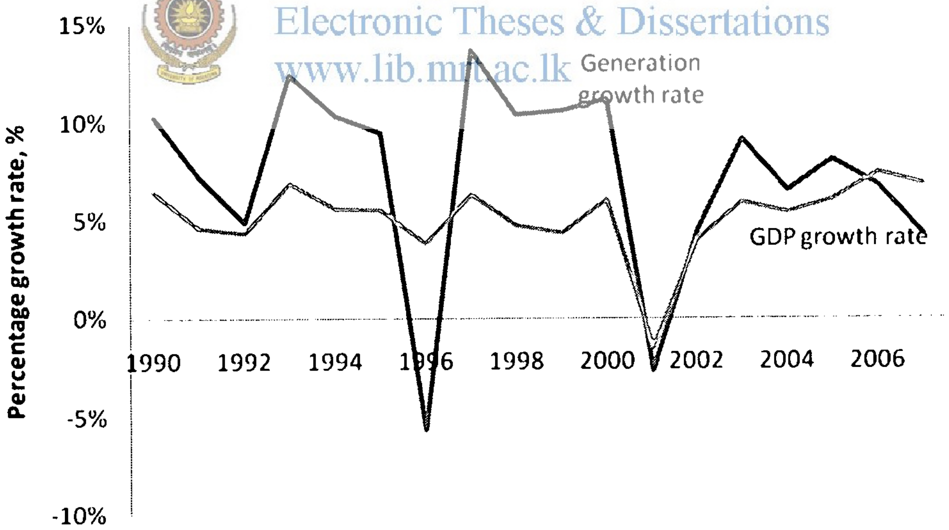


Figure 3.1. Growth rates of GDP and Electricity sales
Source: Ceylon Electricity Board (2008)

Clearly, the demand for electricity has positive correlation with the country's GDP growth rate. Generally it is accepted as every decade the demand for electricity doubles. Figure 3.2 illustrates the shift took place in terms of generating technologies in last two decades i.e., from hydro to thermal.

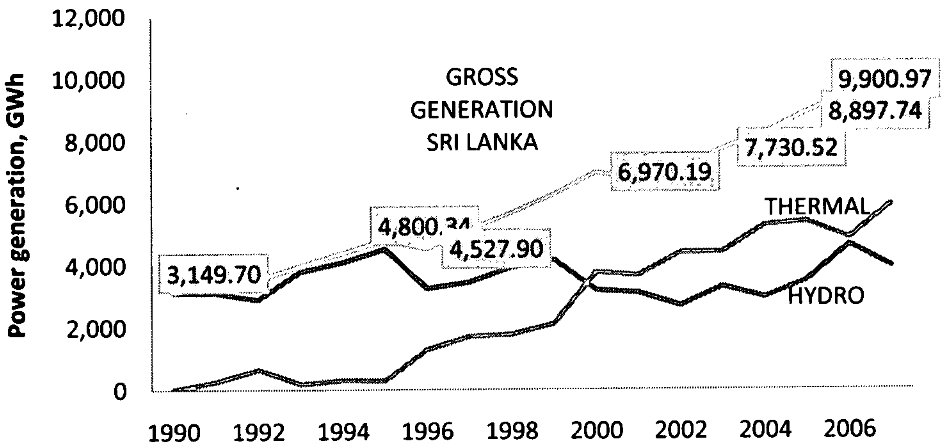


Figure 3.2. Gross electricity generation
Source: Ceylon Electricity Board (2008)

With the commencement of new millennium, thermal power generation had stared leading hydro. At the moment the potential for hydro power generation is almost exhausted. Referring to Figure 3.1 the pattern of generation growth rate from 1990 to 2006 is identified and importantly two negative dips are identified in 1996 and 2001 where country faced with severe power shortage in first case and in 2001 the country was facing an economic down turn due to war situation prevailed. The water levels of major reservoir decline due to drought conditions time to time. During 1996 most of the reservoirs in the country experienced the sever drought transferring heavy burden to thermal generation which were not adequate to cater the existing demand. Therefore, scheduled and unplanned power outages were witnessed. Ceylon Electricity Board invited expressions of interest for number of thermal power plants during this period. The fossil fuel based power plants were preferred by Government of Sri Lanka (GoSL) because of their short erection period which was ideal for the situation and relatively less capital intensive.

3.1 SECTOR REVIEW - FROM 1990 TO 2008

Around 7.2% rapid growth was recorded per year during the period. One could witness that Sri Lanka's power generation mix had shifted from hydro dominated (before 1990 with 94%) to mixed hydro thermal system by 2008 (42% of hydro generation). In 1990 the Government of Sri Lanka (GoSL) permitted Independent Power Producers (IPP) to supply power to the national grid. Addition of oil-fired power generating plants resulted in substantial increase in generation costs. Today as a result the electricity prices in Sri Lanka to be among the highest in the region (Refer to Table 3.1).

Table 3.1 Capacity shares

	Installed capacity, MW (Capacity shares)					
	1980	1990	2000	2007	2012+ coal	2012+ renewables
Conventional hydro	315(75%)	997(78%)	1117(61%)	1187(49%)	1187(39%)	1187(33%)
Oil	90(21%)	266(21%)	685(37%)	1115(46%)	1115(37%)	1115(31%)
Small hydro	17(4%)	21(2%)	33(2%)	133(5%)	133(4%)	250(7%)
Solar PV	0(0%)	0(0%)	0(0%)	0(0%)	0(0%)	0(0%)
Biomass	0(0%)	0(0%)	0(0%)	2(0%)	0(0%)	0(0%)
Wind	0(0%)	0(0%)	0(0%)	3(0%)	0(0%)	400(11%)
Coal	0(0%)	0(0%)	0(0%)	0(0%)	600(20%)	600(17%)
LNG	0(0%)	0(0%)	0(0%)	0(0%)	0(0%)	0(0%)
Imported electricity	0(0%)	0(0%)	0(0%)	0(0%)	0(0%)	0(0%)
Total	422(100%)	1284(100%)	1838(100%)	2440(100%)	3035(100%)	3552(100%)

Source: ECA, RMA and ERM (2010)

Rows reserved for LNG and imported electricity are not indicating any figure. But there are plans by GoSL to establish a power link that share power between India and Sri Lanka. Even though Sri Lanka do not have adequate infrastructure to handle LNG, still it is worthwhile looking at LNG as an alternative source due to its high regard as an efficient and a clean source of power generation.

The CEB assesses that demand for electricity will increase by 7%-10% per annum over the next twenty years (Ceylon Electricity Board, 2008). CEB plans to have 150 MW of hydro power, 935 MW of oil-fired plants and 3300 MW of coal power in the year 2020. In order to cater interim demand, CEB will have to construct additional oil-fired power plants during the period concentrated above. By the end of year 2020, the CEB expects to cater 10% of total demand with renewable sources (Refer to Figure 3.3).

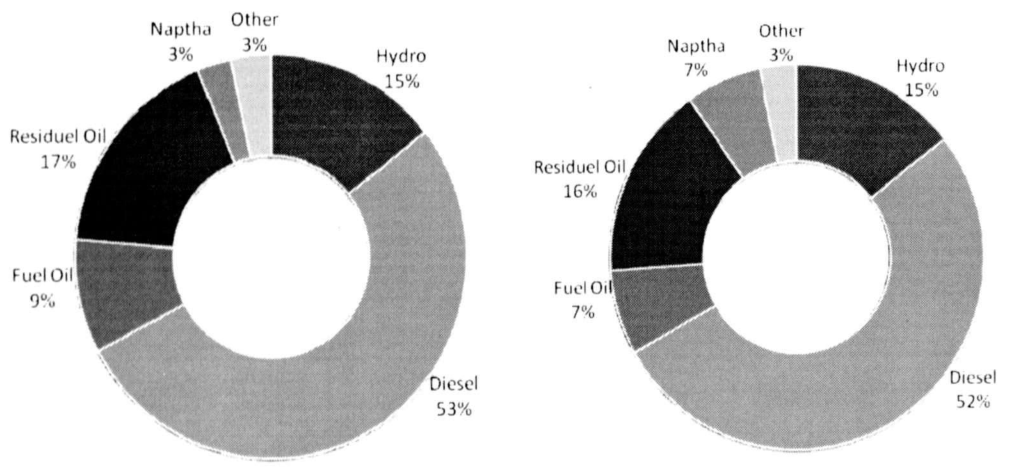


Figure 3.3. Energy generation by source (GWh) – 2002 and 2003
Source: Ceylon Electricity Board (2008)

It seems that the focus on developing renewable power generation sources is not adequate especially at the time whole world is looking seriously at renewable options. One reason is that value of investments in renewable power generation is rising day by day. Second reason is that the cost of renewable technologies continuously dipping (Abeygunawardana, 2008). This study points the third reason, which is diversifying ones portfolio will reduce the portfolio risk. In other words, opting for renewable technologies will make the CEB less vulnerable for adverse market conditions such as sudden fuel price hikes, adverse issues in coal mining and coal price fluctuations etc. Unchecked growth strategies in non renewable technologies will have a heavy bearing on increasing societal risk. It is not clear how CEB will implement CO_2 taxations and other compensation mechanisms for toxic gas emissions.

3.2 GENERATION EXPANSION PLANNING

In general, power generation expansion planning could be defined as when and which power plants should be commissioned to minimise the present worth of the expected investment and operation costs to cater the future power reliably. The importance of the introduction of the planning is to avoid economically unacceptable levels of risks. For the costs and benefits of power projects one could broadly group the uncertainty factors in uncertainty with respect to:

- site conditions
- cost levels (equipment, fuel, materials, labour)
- keeping deadlines
- economic and financial conditions(discount rate, financing, credit issues, exchange rate escalations etc)
- realization of benefits.

Generation planning is considered to be the heart of the entire power system. It is obvious that reliability of the entire power system depends largely on the reliability shown by the power generation system. The generation system shall be geared to supply the demand at all times under planned and forced outages. In conventional generation planning approach, when the demand rise the best technology is decided based on the least cost.

3.2.1 REASONS FOR LONG-TERM POWER SYSTEM PLANNING

Three major reasons could be listed out to illustrate the need for long term generation planning (Engelbertus, 1988). Engelbertus (1988) stated that the long lead time and the long period of utilization of electric power facilities make it necessary to select project to be studied some 6 to 12 years before commissioning and to evaluate at least some 15 to 20 years of project operation. Hence, planning studies most look 'ahead' some 20 to 30 years. Engelbertus further expressed that the electric power sector is highly capital intensive and often constitutes the largest single investor in the country. The expenditure in the power sector and the required electricity tariffs affect the development of the national economy. For long range economy planning, long-term development plans for the electricity sectors are a major prerequisite. Long-term needs of the electricity sector need to be known by other organizations which also require long-term planning to gear their capacity to the needs of the country.

In Sri Lanka, the Ceylon Electricity Board (CEB) uses computer-based WASP (Wien Automatic System Planning Package) to develop generation addition sequence Power System Master Plan which determines least-cost generation addition sequences based upon the load characteristics, schedule maintenance, forced outage, and reliability level plant cost etc. The least cost generation addition sequence includes peak and base load plants of optimum unit size. Similar methodology is used by most of the countries around the world. The system controller will have the opportunity to select the least cost option in terms of power generating source/plant out of the system given options to set out the best mix power generation portfolio for that particular instance of time. But the important point is that in the controllers' perspective the investment cost is sunk. Therefore, the planner is left with only those plants that are currently installed.

3.2.2 METHODOLOGY OF THE WASP MODEL

The model is developed to find the optimal expansion plan for a power generating system over a period of time (up to 30 years), within constraints given by the planner. The optimum is determined in terms of the minimum discounted total costs. The objective function (cost function) to be determined by the WASP is represented by:

Equation 3.1 $$B_j = \sum_{t=1}^{T} \left(\overline{I_{j,t}} - \overline{S_{j,t}} + \overline{F_{j,t}} + \overline{L_{j,t}} + \overline{M_{j,t}} + \overline{O_{j,t}} \right)$$

Where Bj is the objective function attached to the expansion plan j, t is the time in year (1,2,...,T), T is the length of the study period (total number of years) and the bar over the symbols has the meaning of discounted values to a reference date a given discount rate i.
The optimal expansion plan is defined by:

Equation 3.2 Minimum B_j among all j

3.2.3 DETERMINATION OF COSTS

The calculation of various cost components in the Equation 3.1 is performed accounting the characteristics of load forecast, thermal and nuclear plants, hydroelectric plants, stochastic nature of hydrology and cost of the energy not served. The models for thermal and nuclear plants are described by maximum and minimum capacities, heat rate, maintenance requirements, failure probability (forced outage rates), emission rates and specific energy use, capital investment cost, variable fuel cost, fuel inventory cost (for candidate plants), fixed cost and variable component of (non-fuel) operating and maintenance costs and plant life. Similarly hydroelectric projects are defined by identifying the minimum and maximum capacities, energy storage capacities of the reservoirs, energy available per period, capital investment cost, fixed operating and maintenance costs and the plant life.

Equation 3.3 Calculation of Capital investment costs and salvage value

$$\overline{I_{j,t}} = (1+i)^{-t} \sum \left(UI_k \bullet MW_k \right))$$

$$\overline{S_{j,t}} = (1+i)^{-T} \sum \left(\delta_{k,t} \bullet UI_k \bullet MW_k \right)$$

Where UI_k represents the capital cost of unit k, expressed in monetary units per MW and MW_k is the capacity of unit k in MW.

Equation 3.4 Fuel cost calculations

$$\overline{F_{j,t}} = (1+i)^{-i-0.5} \sum_{h=1}^{NHYD} \left(\alpha_h \bullet \Psi_{j,t,h}\right)$$

Where α_h is the probability of hydro-condition h, $\Psi_{j,t,h}$ the total fuel costs (sum of costs for thermal and nuclear units) for each hydro condition and NHYD represents the total number of hydro-conditions defined.

Equation 3.5 Fuel inventory cost

$$\overline{L_{j,t}} = \left[(1+i)^{-t} - (1+i)^{-T'}\right] \sum UFIC_k \bullet MW_{kt}$$

Where $UFIC_{kt}$ is the unitary full inventory cost of unit kt.

Equation 3.6 Operations and maintenance costs

$$\overline{M_{j,t}} = (1+i)^{-t-0.5} \sum UFO\ \&\ M_l \bullet MW_l + UVO\ \&\ M_l \bullet G_{l,t}$$

$UFO\&M_l$ is the unitary fixed O&M cost of unit l, expressed in monetary units per MW-year and $UVO\&M_l$ is the unitary variable O7M cost of unit l, expressed in monetary units per kWh. Each cost component of the objective function had been derived considering each expansion candidate as one single unit (pump storage, hydro, thermal or nuclear) (Refer to Table 3.2).

Table 3.2. Generation expansion plan 2008 -capacity additions

Year	Peak demand (MW)	Capacity additions				LOLP(%)
		CCY[6]	Coal	Hydro	Total	
2009	2058	180			180	0.400
2011	2367		285+		285	0.352
2013	2681		820		820	0.000
2015	3031		300		300	0.001
2017	3426		300		300	0.007
2019	3881					0.140
2021	4401		300		300	0.114
2022	4686		300		300	0.125
		270	3155	150	3575	

Source: Ceylon Electricity Board (2008)

[6] Combine Cycle Power Plant (CCY)

3.4 SRI LANKAS' RENEWABLE ENERGY POLICY

The Energy Policy and Strategies of Sri Lanka (2006) states a target of reaching 10% of energy from Non-Conventional Renewable Energy (NCRE) by 2015 (ECA, RMA and ERM , 2010).

Table 3.3. NCRE Parameters

Technology	Capital Cost (LKR million/MW)	Levelised cost (UScts/kWh)	Levelised cost (LKR/kWh)	Fuel cost (LKR/kWh)
Mini hydro	190	8.47	9.75	None
Wind	230	13.31	15.31	None
Biomass	217	12.45	14.32	7.14
Agro & Industry waste	217	8.95	10.30	3.56
Municipal waste	313	9.48	10.91	None

Source: ECA, RMA and ERM (2010)

The table below shows how levelized cost of energy for alternative energy generation technologies is becoming increasingly competitive with conventional non renewable generation technologies.

Table 3.4. Generating technologies and their state of maturity

		Carbon Neutral	State of Technology	Dispatch		
				Intermittent	Peaking	Base Load
ALTERNATIVE ENERGY	Wind	✓	Mature	✓		
	Biomass	✓	Mature		✓	
	Municipal waste	✓	Mature	✓		
CONVENTIONAL	Coal	×	Mature			✓
	Heavy Fuel	×	Mature		✓	✓
	Hydro	×	Mature			✓
		×	Mature			✓

Source: Author derived data

The energy share contributed by each technology is stated in below table. The information is retrieved from Long Term Generation Plan for 2008 published by CEB. In 2010 the contribution from coal related technologies towards the national electricity system is nil but it is seen a substantial dependency on coal technologies shown in 2015 and the trend is further increased in 2020. Therefore, the CEB/GOSL has already decided coal as the savvier for them in years to come. These decisions are mostly based on least cost assumptions.

Table 3.5. Energy share of each generation technology

Technology	2010	2015	2020
Hydro	40.9%	29.2%	20.0%
NCRE	4.4%	2.9%	2.0%
Oil	54.7%	8.7%	2.3%
Coal	0.0%	59.2%	75.7%

Source: CEB (2008)

3.5 CHAPTER SUMMARY

The Chapter III contains a brief description of electricity generating sector of Sri Lanka. The sector was reviewed from 1990 to 2008 highlighting the shift of generating technologies from hydro power generation to thermal power generation. Also this chapter features fuel use by different power plants and further geographical spread of power system also was shown.

Further, this chapter outlined the components of least cost based generation expansion planning approach and its major components. Finally, the Chapter III concludes with providing insights of Sri Lanka renewable energy initiatives and electricity generating technology share of 2010, 2015 and 2020.

CHAPTER IV

METHODOLOGY

4.1 INTRODUCTION

This chapter describes the conceptual model adopted in the study. The equations and formulae extracted from Chapter III are discussed under each segment of the model. The methods of data collection and analysis are discussed later in the chapter.

This study aims at finding an efficient electricity generating portfolio and associated level of risk at the time of investment decision is being made. The conceptual framework is established to find the solution to above stated problem follows series of steps formed based on the following objectives. First is to determine the best mixing portfolios based on cost versus risk on investor perspective and next is to establish a quantitative framework to determine the generating mix from the societal perspective. Lastly the study evaluates the sensitivity of risk and expected cost when deciding to incorporate new power generating technology to existing portfolio.

4.2 CONCEPTUAL FRAMEWORK

The conceptual framework developed for the study is illustrated by Figure 4.1. Initially, the model defines the input variables used in Blocks "α","β" and "γ" The block "α" determines the efficient frontier for electricity generating portfolios using series of two asset portfolios. The expected cost (levelised cost) of electricity generating sources, standard deviation derived from historic prices, correlation and variance-covariance matrices of electricity generating technologies were used as inputs[7]. Having determined the efficient frontier, the optimal portfolios lying on the efficient frontier are calculated by solving the minimization problem derived in Equation 2.1 . The indifference curves were used to determine the optimal portfolio.

In block "β", environmental risk aspect of the electricity generating mix was determined. Life cycle CO_2 emissions for individual technologies were used as inputs and outputs were emissions for the efficient portfolios. In block "γ", the sensitivity analysis for addition of a new generating technology was analysed. The direction which the found optimal electricity generating portfolio could shift then determined.

[7] Historical fuel prices were used to calculate covariance-variance matrix.

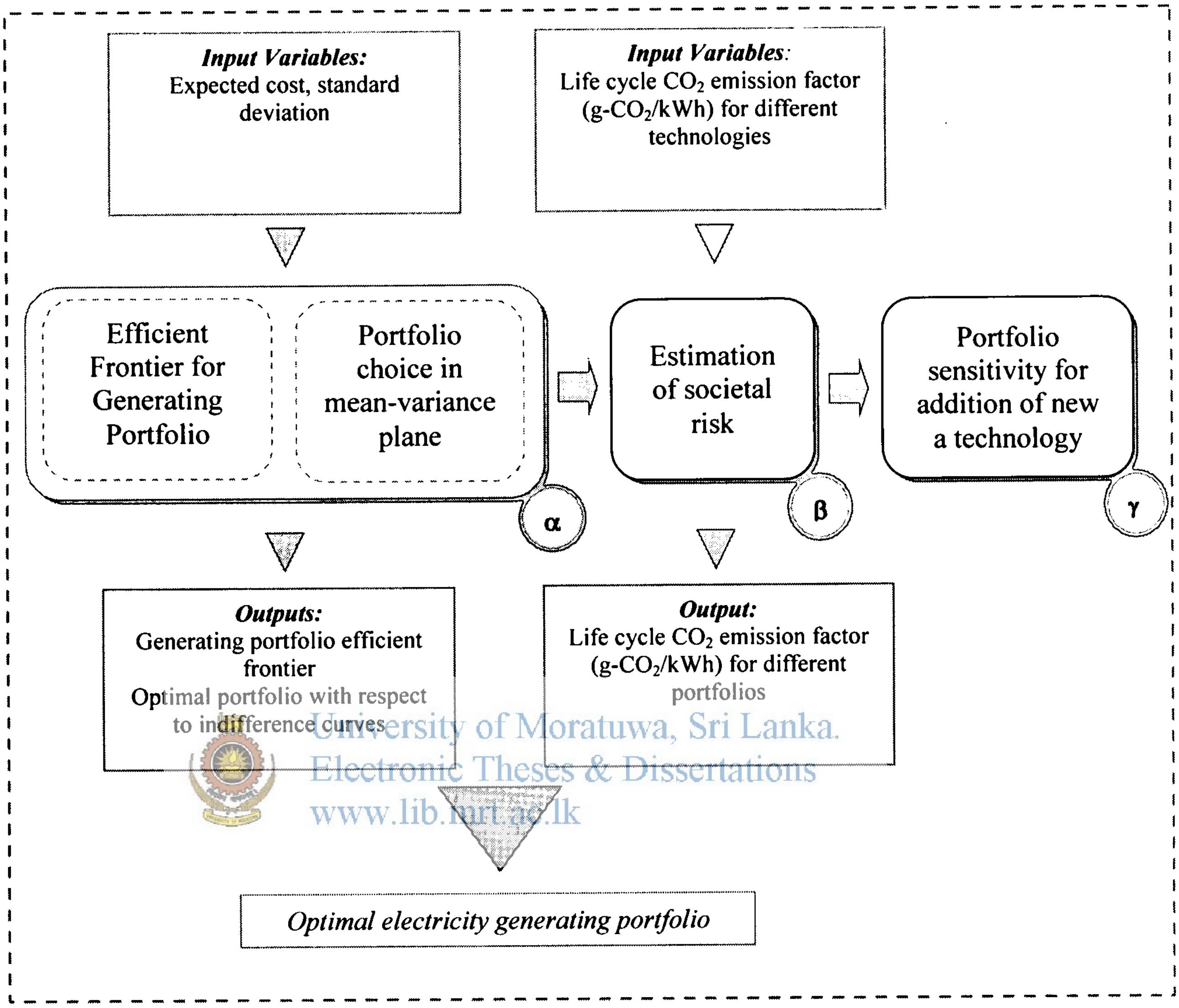


Figure 4.1. Conceptual Model developed for the study

By considering two electricity generating technologies per instance (two assets), the set of electricity generating portfolios were constructed as illustrated in Figure 4.2. The figure shows the behaviour of four assets when the entire share is 100% of a particular asset and subsequently the share of other asset starts to increase. When the portfolio comprises with 100% auto diesel, the risk is relatively higher and when coal is introduced the overall portfolio risk starts to reduce.

The societal risk is determined considering the life cycle CO_2 emissions for each portfolio selected. The least CO_2 emission portfolio is considered to be the most environmental friendly and less risky portfolio.

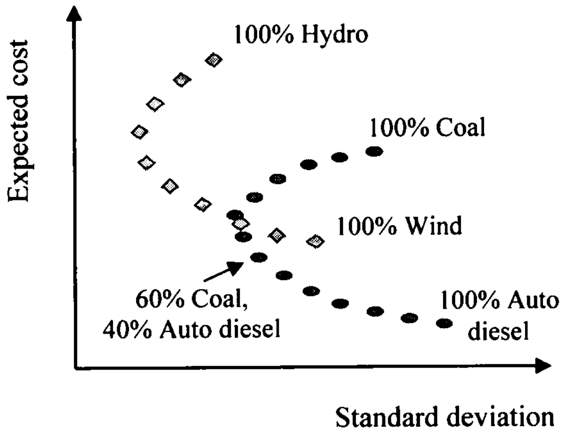


Figure 4.2. Electricity generating portfolios

The efficient frontier is constructed using above obtained portfolios for electricity generating technologies. (Refer to Figure 4.3)

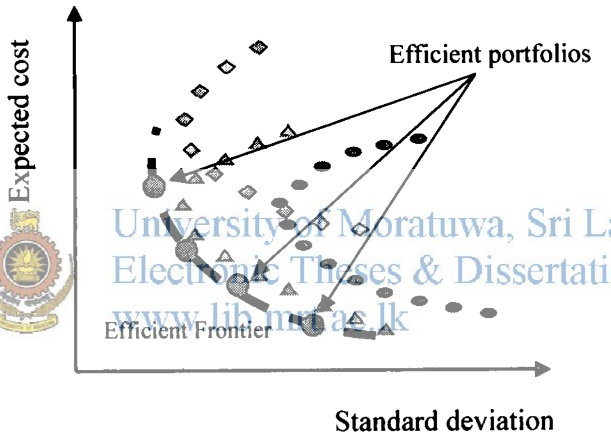


Figure 4.3. Efficient electricity generating portfolios

Block α comprises of plotting an efficient frontier for generating portfolios and portfolio selection in mean variance plane. Therefore, underlying theory for the derivation of possible optimal portfolios lying on the efficient frontier is given by following minimization model. Objective function is illustrated by Equation 4.1.

Equation 4.1 **min** $\omega^T\Omega\omega$

Subject to the following constraints.

$$\omega^T\mu = \mu_p$$

$$\omega^T\iota = 1$$

Above model minimises the variance whilst determining minimum expected cost (E) related to different installed capacities (ω_i) of generating sources. Selection of the optimal portfolio from the possible portfolios lying on the efficient frontier is performed using indifference curves plotted in the mean-variance plane were used to locate the optimal portfolio. (Refer to Equation 2.20 in page 33 and Figure 4.4).

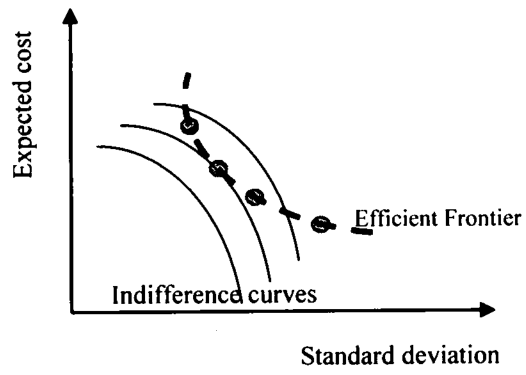


Figure 4.4 Determination of optimal portfolio

The block β of the conceptual model describes how carbon dioxide emission is taken into consideration when determining the societal/environmental risk. The life cycle carbon emissions of electricity generating technologies are used to determine the total carbon emission of all possible portfolios lying on the efficient frontier. Using a three dimensional plot, the less environmentally risky portfolio is identified[8] (Refer to Figure 4.5).

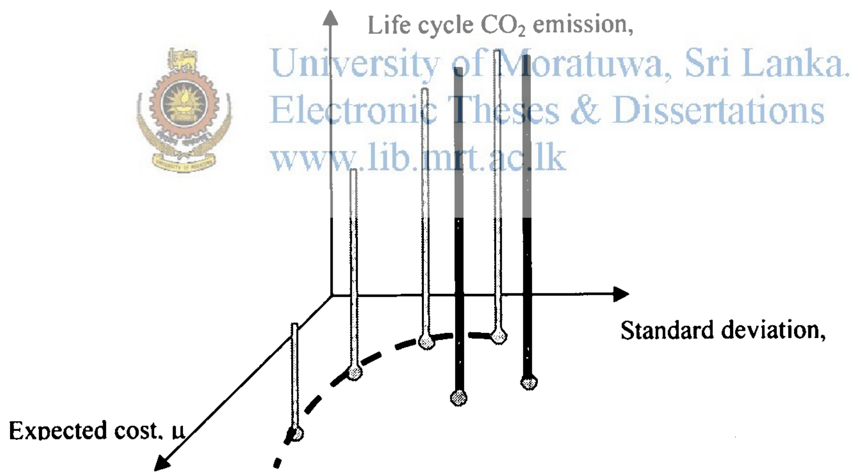


Figure 4.5. Optimal electricity generating portfolio

Next the sensitivity analysis is performed to evaluate impact that causes to the efficient portfolio when adding a new power plant as illustrated in Figure 4.6. For example, when 1000 MW of coal power is added, the directional change[9] occurs to the existing optimal portfolio is shown in this diagram.

[8] Using lowest life cycle CO_2 emission portfolio
[9] Sensitivity analysis is used.

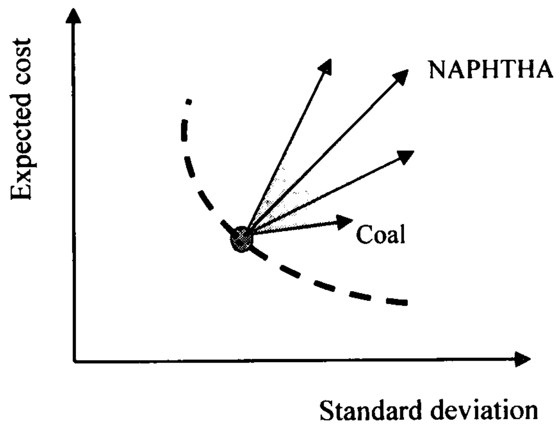


Figure 4.6. Sensitivity analysis

4.3 METHODS OF DATA COLLECTION

This research is conducted using secondary data available in the secondary data sources published by organizations related to power and energy sector in Sri Lanka. The internal data of CEB were acquired from internal publications such as Long term Generation Expansion Plan and Annual Reports. Petroleum data were acquired from the National Energy Balance published by Sri Lanka Sustainable Energy Authority. Following secondary data sources were extensively used to obtain data for this research.

- Annual Reports of Ceylon Electricity Board.
- Technical data of 2004, 2005, 2006, 2007 and 2008 published in the Annual Reports of System Control Centre, CEB.
- Long term Generation Expansion Plan published by CEB in 2008 (Ceylon Electricity Board, 2008).
- National Energy Balance published by Sri Lanka Sustainable Energy Authority in 2007 (Sustainable Energy Authority , 2007).
- Sri Lanka: Environmental Issues in Power Sector- draft final report published by Economic Consulting Associates, Resource Management Associates and Environmental Resource Management (ECA, RMA and ERM , 2010).
- Viability of coal and oil-fired power plants in Sri Lanka (Abeygunawardana, 2008).

The data acquisition was done carefully after getting verified the accuracy of data by cross checking each data item of an internal publication against a third party publications and vice versa.

4.3.1 SECONDARY SOURCES AND DESCRIPTION OF DATA ACQUIRED

Table 4.1 illustrates the nature and description of data acquired from different secondary data sources that used to conduct this research. Certain instances it was found that one or more documents containing same data. In such cases original publication was considered as the source and the third party publication was used as a control source. The discrepancies found in these documents were negligible, however all discrepancies in published data were again confirmed by another source or direct contacting the relevant authority. Further, the data used were directed to experts in order to examine the accuracy and adequacy of data. Further more, findings were also presented to the experts to examine the appropriateness of those finding to the industry as a whole.

Table 4.1. Secondary data sources and description of data acquired

Secondary data source	*Description and nature of data*
Long-term Generation Expansion Plan	Electricity generating mix in 2008 (provisional) and expected mix in 2019. Characteristics of existing and committed owned thermal plants (Levelised Fixed and variable O&M costs) Description of candidate plants Description of Non conventional renewable energy (NCRE) Capital cost details of thermal expansion candidates Cost calculations of candidate hydro power plants Capacity balances for base case (2007)
National Energy Balance 2007	Fossil fuel (Auto diesel, Heavy Fuel and NAPTHA) prices from 1990 to 2008
Sri Lanka: Environmental Issues in Power Sector	Prices of LNG and Coal from 1990 to 2008 Levelised cost of electricity generating technologies Description of Non conventional renewable energy (NCRE) Capacity shares in 1970, 1980, 1990, 2000, 2007, (2012+coal) and (2012+renewable) National ambient air quality standards Proposed stack emission standards for large plants Economic characteristics of existing generation plants Purchased price from small power produces (for dry and wet seasons)
CEB Annual Reports	Initial capital outlays (loan commitments)

4.4 METHODS OF EVALUATING VALIDITY AND RELIABILITY OF DATA

4.4.1 CRITERIA FOR VALIDATING SECONDARY DATA

Mainly secondary data sources were used to collect necessary data for this research. But it is required to be sensible when using secondary data since they have been collected for purpose other than the problem at hand, their usefulness to may be limited (Malhotra, 2004). The objectives, nature, and methods used to collect the may not be pertinent to this research. It is important to check the accuracy, dependability and timing.

4.4.1.1 ACCURACY OF DATA

Common issue associated when searching for data was the incompleteness of available data at the CEB. Therefore, the data collected from individual power generation plant offices were compared with both CEB and non-CEB publications. The main source of collecting data was the Long term Generation Expansion Plan published by CEB in 2008. Further Annual Reports of CEB in last 10 years were used to cross check the investments and loan repayments. Sri Lanka Energy Balance in 2004 and 2007 and Environmental Issues in Power Sector of Sri Lanka (EIPS) published in 2010 were used as sources as well as for validation purposes.

4.4.1.2 CURRENCY (TIME BOUND)

The Long term Generation Expansion Plan is published in 2008 and Environmental Impacts of Power Sector was published in 2010. Therefore, the time between the data collection and publication is relatively short. The Long term Generation Expansion Plan, Annual Reports and Sri Lanka Energy Balance are annually updated by relevant authorities.

4.4.1.3 PURPOSE FOR WHICH DATA WERE COLLECTED

The purpose of the ECA, RMA AND ERM (2010) is to provide a quantitative analysis that will help decision makers assess various power sector policy options in terms of trade-offs between environment, cost and other impacts. Similarly the objectives of the Long term Generation Expansion Plan of CEB is to identify the potential generating sources that could be able to cater future demand economically.

4.4.1.4 NATURE AND RELIABILITY

It is said that contents of the data should be examined in line with the definition of constructs; units of measurement and the relationships (Refer to Figure 2.12). The reliability of collected data is obtained by examining the expertise, credibility and reputation of the sources

(Malhotra, 2004). Most of the secondary data sources were published by authorities operating under GoSL and these authorities are directly involved in the electricity sector in Sri Lanka. Therefore, the credibility of the data is relatively higher than third party sources.

4.4.2 MODEL RELIABILITY

Markowitz's Portfolio Theory is proven and established model in finance. It uses expected return and standard deviation as key constructs where as this research uses expected cost and standard deviation to determine the efficient electricity generation portfolio (Awerbuch & Berger, 2003). The model validation is done comparing the behaviour of standard deviation against the behaviour of Herfindhal index (H)[10] which is widely used in the industry to measure the diversity of power generating sources (ECA, RMA and ERM , 2010). Therefore, it is expected that standard deviation to perform in relation to H-index selected as a meaningful criteria (Malhotra, 2004)(Refer to Chapter V).

4.5 METHODS OF DATA ANALYSIS

Historical fuel price data (annual) from 1992 to 2008 is used to determine variance for generating technologies. The variance and covariance of each generating technologies used to derive correlation matrix and variance-covariance matrix[11] (Refer to Table 5.8). For candidate power plants, risk of capital outlays during the construction period need to consider other than the price risk.

Levelised generating cost considered as a proxy to expected cost of generating technologies (Refer to Equation 2.13 in page 24). The annual expenditure on capital investment, initial capital outlays, variable operation and maintenance and fixed operation and maintenance costs considered when determining the levelised generating cost.

The levelised generating cost (expected cost) and correlation and variance-covariance matrices are considered as the input data for minimization model. The minimization problem is solved using "*Solver Micro Soft Excel add-ins*" and "*Matlab- Financial Tools*" (Refer to Annexure 01). Using "Matlab" software package the Life cycle CO_2 emission was plotted in the three dimensional plane (risk, expected cost and carbon emission).

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[10] A measure widely used to describe the concentration of firms in an industry $H = \sum_n S_i^2$

[11] By considering the holding period returns of two technologies per instance the variance and covariance for selected technologies were determined.

Finally, a sensitivity analysis was performed to determine possible directions that optimal portfolio would move in terms of expected cost and risk when a new generating technology / plant is added.

4.6 CHAPTER SUMMARY

The chapter III introduced a conceptual framework to propose a solution for problem underlying this research. The model was formed in line with the objectives formed in the Chapter I. The type of input data required for each section of the model was defined and outputs at each section also were described. The processes at each component were shown graphically as well as using formulae.

Further, this chapter listed out the secondary sources used to acquire data. The type of data and description also were tabled. The evaluation of validity and reliability of collected data, constructs and model was outlined. The validity of data was measured using several dimensions established by literature. Furthermore, chapter III stated the methods used to check the validity and the reliability of the model developed and variables used for the study.

SCENARIO DESIGN AND DATA ANALYSIS

5.0 INTRODUCTION

The chapter V contains a data analysis aiming at determining an efficient frontier. Different scenarios (electricity generating mixes) are analysed to qualify the optimal electricity portfolio generating mix. The indifference curves plotted in mean-variance plane was used to obtain the optimal electricity generating portfolio. Further, the societal risk based portfolio selection was performed by considering the carbon emissions of each generating technologies.

5.1 PORTFOLIO RISK ESTIMATION FOR SRI LANKA ELECTRICITY GENERATING MIXES

The total portfolio risk is a function of

- fractional share of each cost stream for each technology present in the overall mix
- the Standard deviation of the annual changes to that cost stream
- and the correlation coefficient (and covariance-variance) between that cost stream and all other cost streams (Campbell, Huisman, & Koedijik, 2001).

Therefore, it is required to find the correlation coefficients for each components of the generating source that is the risk exert due to construction of a technology, fuel related risks, price escalations in variable operation and maintenance and fixed operation and maintenance costs. First, covariance-variance matrix was determined. The correlation coefficients in the case of fuel prices determined from the historical fuel price series (deduced from covariance-variance matrix). Other correlations are estimated as proxies (Awerbuch & Berger, 2003). According to (Bates, 2007) when determining the lowest cost portfolio for a generation mix, it is essential to know the amount of risk incorporated in that portfolio and also the key risk components relate to each source. Already it was discussed the fact that lack of correlation exist between renewable sources and fossil fuel prices; which means that renewable sources are not affected by sudden fuel price fluctuations. But this does not mean that renewable sources are risk free. Investment cost risks obviously varies according to the technology type, duration take for erection and complexities. According to Awerbuch (2003) the older plants have low risk compared to new plants. He further says that investment risks relate to existing technologies is almost zero.

In the Sri Lankan context, the debt financing is sourced at different rates by different financial organizations. It is not prudent to treat both CEB and IPPs expose to same level of risk in terms of financing (Abeygunawardana, 2008).Table 5.1 lists out the fuel cost of different electricity generating technologies (non-renewable only) available in Sri Lanka from 1995 to 2008.

Table 5.1. Cost of fuel types used for different plants

	Fuel cost per unit Rs per kWh / year								
Technology	1995	1998	2000	2001	2005	2004	2006	2007	2008
Kalenitissa GAS(A D)	5.24	4.29	7.65	9.43	22.02	14.14	30.05	28.31	29.29
Kalenitissa NEW GAS		3.13	5.85	7.02	14.78	10	19.27	19.22	27.86
Kalenitissa (CC) Naptha				4.43	8.79	6.74	11.78	11.87	18.24
Sapugaskanda (HF)	1.26	1.32	1.65	2.87	5.40	4.38	7.48	7.70	13.39
Sapugaskanda (HFI) Ext			1.58	2.72	4.95	4.04	6.96	7.15	12.49

Source: Sustainable Energy Authority (2007)

Table 5.2 contains the historic fuel prices of Sri Lanka except for coal prices. The coal prices were not available since there were no major coal base activity taken place during past. Therefore, the prices of Australian coal were used for this study.

Table 5.2. Historic fuel prices[12]

Fuel type	*1990*	*1995*	*2000*	*2005*	*2006*	*2007*
LNG (US$/bbl)		1.05	0.9	0.67	0.61	0.62
NAPHTHA (US$/bbl)	23.72	17.61	28.26	50.74	61.81	79.57
Auto Diesel (US$/bbl)	29.32	21.53	32.2	67.45	67.45	67.45
Heavy Fuel (US$/bbl)	103.21	92.96	152.3	254.10	329.02	377.88
Coal (US$/ton)	28.48	21.64	33.19	46	40	54

Source: Sustainable Energy Authority (2007)

To determine the covariance-variance matrix and thereafter the correlation coefficients, it is required to find the holding period returns of above fuel prices. Table 5.3 shows the holding period returns of different types of fuels used for electricity generation in Sri Lanka for selected number years.

[12] Annual fuel prices from 1992 to 2008 were used to determine the holding period returns.

Table 5.3. Holding period return for different fuel types

	2000	2001	2002	2003	2004	2005	2006
LNG (US$/bbl)	0.322	-0.092	-0.213	-0.035	-0.183	-0.089	0.0164
NAPHTHA (US$/bbl)	-0.158	0.0468	0.223	0.354	0.231	0.218	0.287
Auto Diesel (US$/bbl)	-0.155	0.0045	0.183	0	1.088	0	0
Heavy Fuel (US$/bbl)	-0.154	0.122	0.148	0.087	0.4085	0.2949	0.149
Coal (US$/ton)	0.062	-0.206	-0.107	0.6	0.15	-0.130	0.35

Source: Sustainable Energy Authority (2007)

The price of NAPTHA increases at a rapid pace after the year 1990 (Refer to Figure 5.1). Sri Lanka commenced its first NAPHTHA operated power plant in 1999. It is clear that the rate of price growth almost doubled during 2002 to 2005 and subsequent years experienced an exponential growth[13].

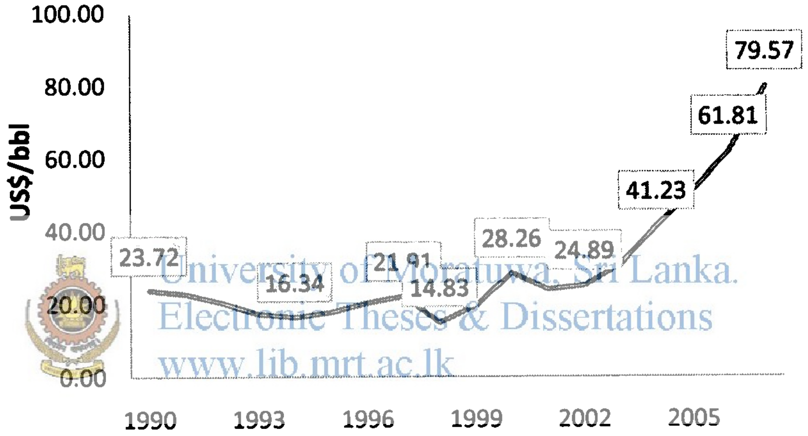

Figure 5.1. NAPHTHA price trends
Source: Sustainable Energy Authority (2007)

Using holding period returns technique (Refer to Figure 5.2) the standard deviation of NAPTHA is calculated.

[13] This graph is plotted using data given in Table 5.3.

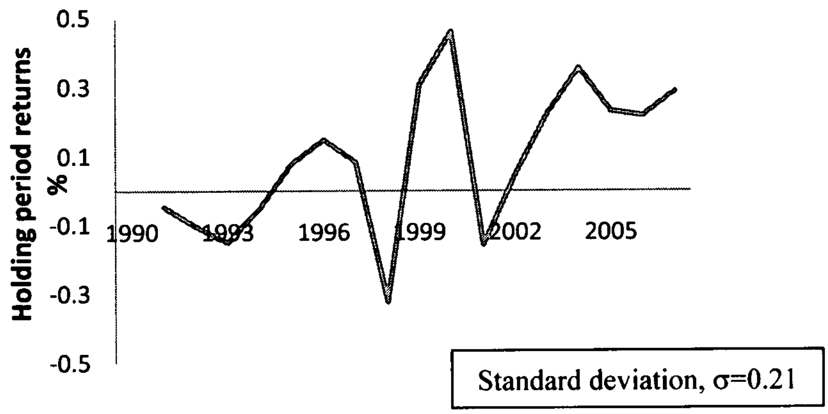

Figure 5.2. Holding period returns for NAPHTHA

Source: Sustainable Energy Authority (2007)

From 1990 to 2001 the GAS Oil prices shows less volatility but after the year 2000 the prices are shown upward trend.

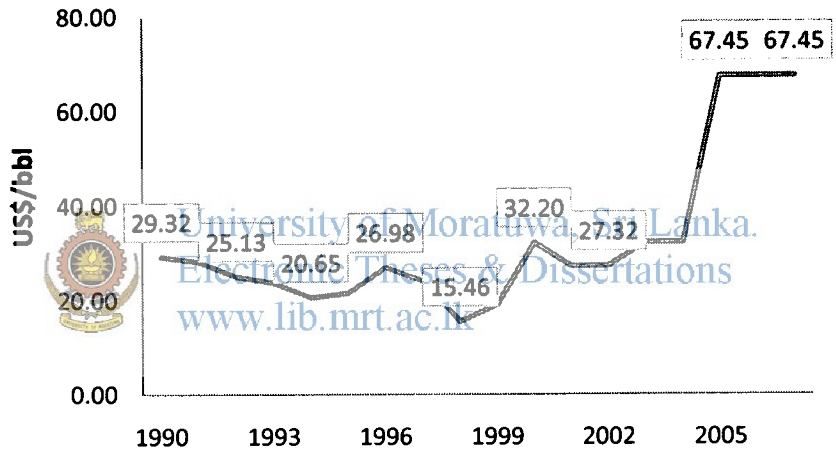

Figure 5.3. GAS Oil price trend

Source: Sustainable Energy Authority (2007)

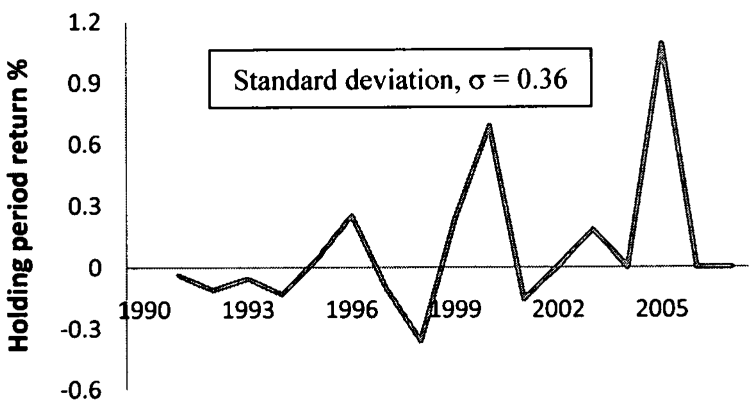

Figure 5.4. Holding period returns for GAS Oil

Source: Sustainable Energy Authority (2007)

The volatility of GAS Oil is relatively higher than other crude oil base products (σ=0.36). Figure 5.5 illustrates the time dependent price variation of Heavy Fuel Oil from year 1990 to 2008. Again towards end of 1990s the prices had started picking up and upwards trend continues.

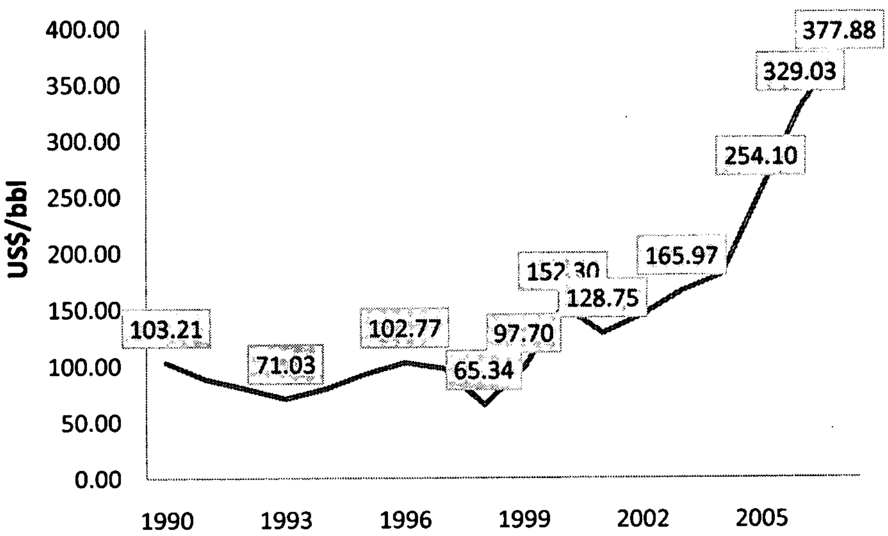

Figure 5.5. HFO trend

Source: Sustainable Energy Authority (2007)

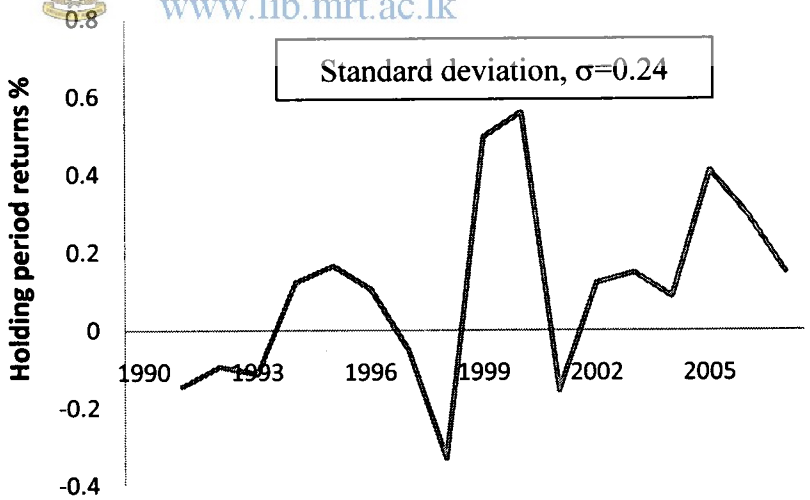

Figure 5.6. Holding period returns for HFO

Source: Sustainable Energy Authority (2007)

The holding period return gives variance of 0.06 for HFO which is less than Auto Diesel compared with the dame period. The coal also shows relatively high volatility which is around 0.04 (variance).

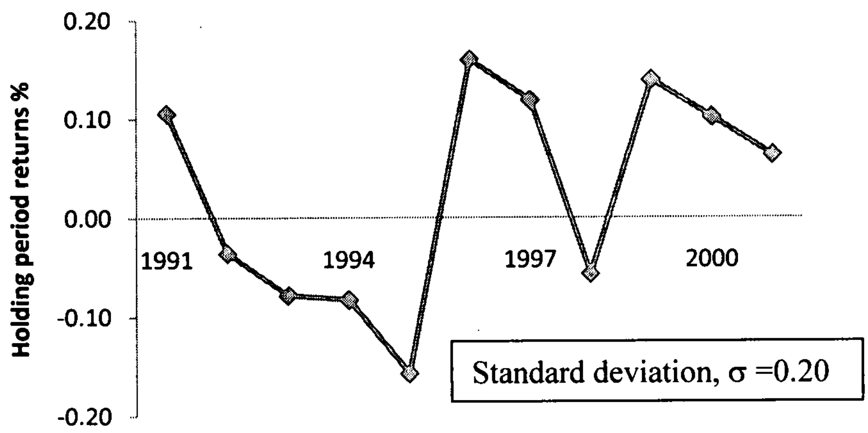

Figure 5.7. Holding period returns for Coal

Source : ECA, RMA and ERM (2010)

Using the annual holding period returns from 1992 to 2008 for different fuel types the variance-covariance matrix is determined (Refer to Table 5.4).

Table 5.4. Covariance-variance matrix of different fuel types

	Diesel	*Heavy Fuel*	*Coal*	*Naphtha*	*LNG*
Diesel	0.12	0.06	0.01	0.04	-0.03
Heavy Fuel	0.06	0.06	0.02	0.04	-0.02
Coal	0.01	0.02	0.04	0.02	0.00
Naphtha	0.04	0.04	0.02	0.04	-0.02
LNG	-0.03	-0.02	0.00	-0.02	0.02

Source: Author derived data

Figure 5.8 shows how Sri Lanka's decision makers opted or compelled to opt for different fuel typed during last decade. The important observation is that power generated using these technologies are showing a positive trend which is not a healthy sign for a poor economy like Sri Lanka. NAPHTHA was incorporated into the system very recently (after 1999). Majority of power plants use HFO and Residual oil with cold starting may be performed using Auto Diesel.

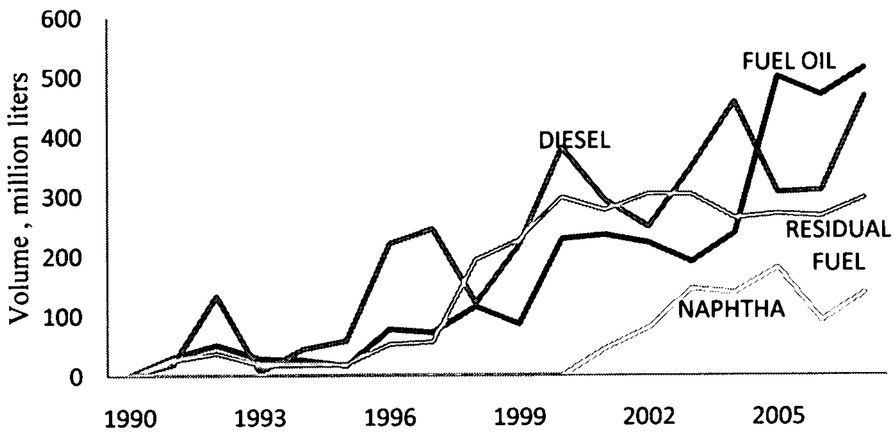

Figure 5.8. Fuel use for electricity generation
Source: Sustainable Energy Authority (2007)

Next, the correlation matrix for non-renewable energy sources that had been used by Sri Lanka to generate electricity is determined using the equation $\rho_{ij}=\sigma_{ij}/\sigma_i\sigma_j$ for every $i \neq j$ (Refer to Table 5.5). The prices of fossil fuel base products behave in similar manner having positive correlation to one another. But LNG price variations show negative correlation against most of the crude oil products.

Table 5.5. Estimated fuel correlation matrix[14]

	Diesel	Heavy Fuel	Coal	Naphtha	LNG[15]
Diesel	1.00	0.93	0.78	0.94	-0.91
Heavy Fuel	0.93	1.00	0.86	0.99	-0.54
Coal	0.78	0.86	1.00	0.90	0.12
Naphtha	0.94	0.99	0.90	1.00	0.30
LNG	-0.91	-0.54	0.12	0.30	1.00

Source: Author derived data

Figure 5.9 gives a better view on different fuels used for electricity generation along the year of inception of each technology. This figure gives a better view of introduction of different thermal technologies into the system and their share. Auto diesel shows high proportion of utility in early 1990s but reduces its contribution to approximately 20% in recent years. But it manages to produce 20% at a steady state for most of the period. It seems that this trend is likely to continue for rest of the period as well. Having started with a niche in the year 2000 NAPTHA contributes around 10% of total generation at present.

[14] The values for different technologies were obtained considering the holding period returns of two individual technologies at a time.
[15] Liquefied Natural Gas

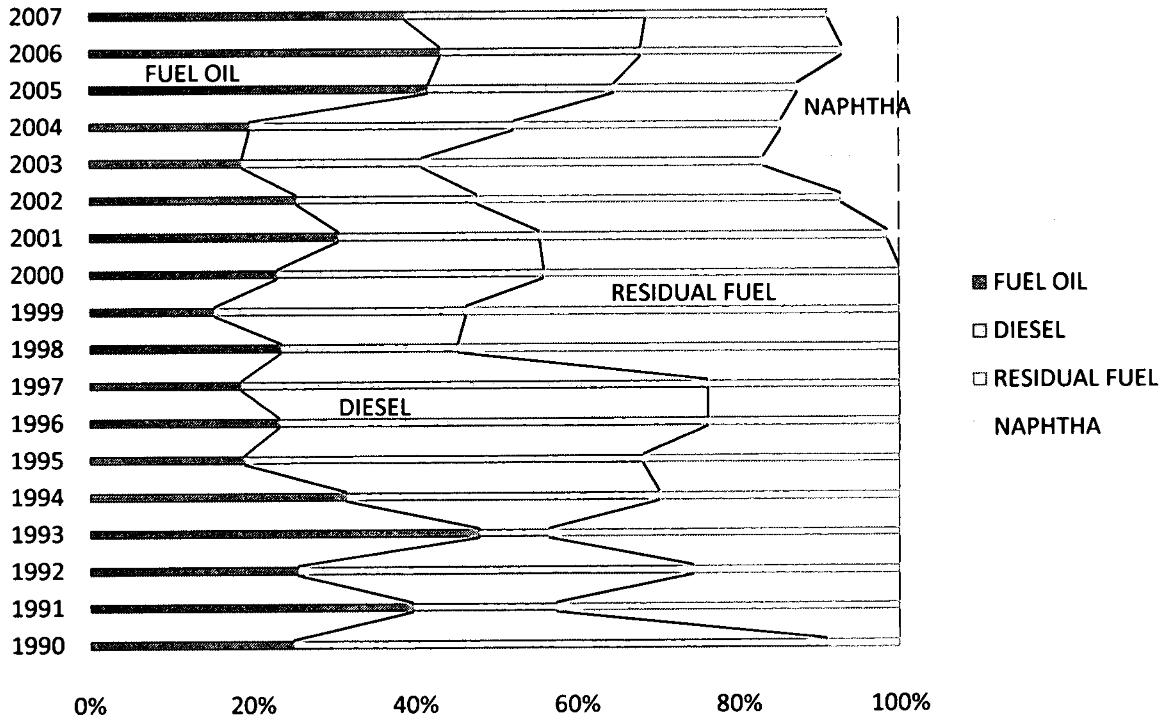

Figure 5.9. Gross generation by fuel type
Source: Sustainable Energy Authority (2007)

5.1.1 DETERMINATION OF LEVELISED COST FOR DIFFERENT GENERATING TECHNOLOGIES

The levelised cost was equated to expected cost of portfolios (Refer to Chapter II, section 2.9). This formulae uses initial capital cost, subsequent capital outlays, variable and fixed operations and maintenance cost.

$$\text{levelized generating cost} = \frac{\sum_{t=1}^{T} \frac{C_t + O\&M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{e_t}{(1+r)^t}}$$

Where C_t, $O\&M_t$ and F_t are annual expenditure on capital investment, operation and maintenance and fuel respectively. e_t represents the annual electricity generations whilst r denotes the discounting rate. Relevant data that is being used to determine the levelised cost of existing electricity generating plants are listed in Table 5.6.

Table 5.6. Economic attributes of existing generation plants

Existing power plant	Annual units generated	Full load efficiency	Levelised variable O&M	Levelised Fixed O&M
Kelanitissa GT (Old)	24.806	18.4%	0.24	1.47
Kelanitissa GT (New)	94.016	27.8%	0.29	0.55
Kelanitissa CC	1043.538	42.3%	0.16	0.34
Sapugaskanda Diesel	383.459	35.2%	0.97	0.61
Sapugaskanda Diesel (Ext)	527.239	38%	0.73	0.69
Lakdhanavi – Diesel	18.422	35.5%	1.50	0.69
Asia Power – Diesel	361.725	35.7%	1.02	0.60
AES CC	786.885	45.2%	0.09	0.48
Colombo Power – Diesel	456.343	36.9%	0.71	0.72
Horana –Diesel	142.412	35.4%	0.90	0.74
Matara – Diesel	147.708	35.3%	0.95	0.69
Puttalam – Diesel	682.650	41.2%	0.94	0.09
Embilipitiya – Diesel	663.027	36.1%	0.65	0.20

Source: Ceylon Electricity Board (2008)

Table 5.7 shows the estimated economic costs of candidate generation technologies that could realise years to come. According to conventional least cost scenario base portfolio decision model, it is very clear that even when the crude oil price at 125 US$/bbl, still the coal will considered as preferred choice.

Table 5.7. Estimated economic costs of candidate plants

Levelised cost (USCts/kWh)				
Conventional technologies			Non-Conventional Renewable Energy	
	Oil @US$/bbl 75	Oil @ US$/bbl 125		
CC GT	22.49	36.89	Mini hydro	8.47
CC -Diesel	14.08	22.67	Wind	13.31
Coal	6.40	8.87	Biomass	12.45
			Agro & Industry waste	8.95
			Municipal waste	9.48

Source: ECA, RMA and ERM (2010)

5.1.2 STANDARD DEVIATION FOR DIFFERENT GENERATION TECHNOLOGIES

The expected costs of existing and candidate technologies are determined followed by the standard deviation (risk) for each technology. The fuel related risk (variance) is determined by fuel time series referred above. There will be no construction related risk for existing plants but for candidate technologies it is required to include construction related risk other than risk due to variable O&M and fixed O&M.

Below table depicts the covariance-variance matrix for different technologies. Previous table in page 60 (Refer to Table 5.4) displayed the variance-covariance values for non-renewable generating technologies generally derived from historical prices using holding period return method. The variance of hydro power derived using the price at which IPPs were paid by CEB for the period 1996 to 2008. It was assumed that hydro as a proxy to wind giving similar volatilities for wind.

Table 5.8. Covariance - Variance matrix for generating technologies

	L/ Cost	*Diesel*	*Heavy Fuel*	*Coal*	*Hydro*	*Naphtha*	*Wind*	*LNG*
Diesel	14.08	0.1169	0.0588	0.0122	-0.0058	0.0433	0.0007	-0.0321
Heavy Fuel	11.15	0.0588	0.0578	0.0195	-0.0171	0.0409	-0.0003	-0.0203
Coal	6.40	0.0122	0.0195	0.0407	-0.0078	0.0195	0.0003	0.0039
Hydro	8.47	-0.0058	-0.0171	-0.0078	0.0394	-0.0179	0.0016	0.0100
Naphtha	8.73	0.0433	0.0409	0.0195	-0.0179	0.0449	0.0003	-0.0182
Wind	13.31	0.0007	-0.0003	0.0003	0.0016	0.0003	0.0394	-0.0001
LNG	8.67	-0.0321	-0.0203	0.0039	0.0100	-0.0182	-0.0001	0.0248

Source: Author derived data

Information regarding existing generating mix and generation mix in 2020 (Long term Generation Expansion Plan published by Ceylon Electricity Board) is shown in Figure 5.10. The 2019 mix has installed capacity of 13% of crude oil based generating sources which is about 5% less than today. But the actual installed capacity is around 700 MW which is twice the current installed capacity which would not help the cause. Next important highlight is that the installed capacity of coal is even surpassing 50%. The trend is obviously upward. During the period between 2007 and 2009, the coal prices (Australia and South Africa) shot up exceeding 150 $/tonne.

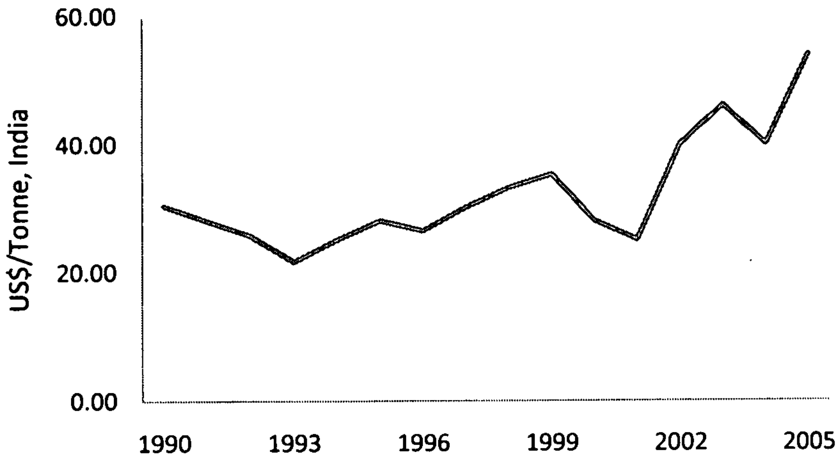

Figure 5.10. Coal price trend
Source: ECA, RMA and ERM (2010)

It is important to observe the present and planned electricity generating portfolios in 2008 and 2019 declared in the long term generation expansion plan published by the CEB in 2008. Even though there could be a risk of high volatility in coal in future, CEB ambitiously plans to pill up coal power generation facilities during next decade (Refer to Table 5.9).

Table 5.9. Present and future generation mix

Technology		2008 Generation mix	2019 Generation mix
Existing and Candidate	Diesel	16.26% (363 MW)	11.56% (688 MW)
	Heavy Fuel	23.12% (516 MW)	1.21% (72 MW)
	Coal	0%	56.39% (3355 MW)
	Hydro	53.09% (1185 MW)	22.44% (1335 MW)
	Naphtha	7.39% (165 MW)	2.77% (165 MW)
	Wind	0.13% (3 MW)	1.09% (65 MW)
	LNG	0%	4.54% (270 MW)

Source: Ceylon Electricity Board (2008)

5.1.3 RESOURCE CONSTRAINTS

For any country, there exist constraints for renewable energy developments due to resource limitations which country specific. In this analysis, it would be grate if one could have country's generation portfolio only comprising of renewable but in practice our preference is hindered by availability of natural resources and supply of equipments. The Table 5.10 indicates the potentiality of each source.

Table 5.10. Resource Limitations

Technology		capacity constraint for 2008 generation mix	capacity constraint for 2019 generation mix
Existing and Candidate	Diesel		
	Heavy Fuel		
	Coal	Not installed	
	Hydro	1185 MW	1335 MW (resource limitations)
	Naphtha		
	Wind	3 MW	65 MW potential
	LNG	Not installed	

Source: CEB Generation Expansion Plan (2008)

It is worthwhile to state that a small country like Sri Lanka would not be in a position to acquire technologies as Sri Lanka wishes due to economical, technological and resource limitations. For example the hydro resource availability is exhausted within next few years leaving out hydro as a growing technology. Therefore, hydro power will have to have upper cap in the minimization problem. Potential of the off-shore wind power generation may be high. But wind power generation has its own limitations. The wind speed itself is highly volatile. There could be instances where there will be no wind situation at times. If wind generation is too high compared to other sources, there could be sudden blackouts due to inability of the system to respond to high fluctuations in very short time frame. Anyway Sri Lanka's installed capacity is relatively small and 20% wind generation would need additional system side precautions and reserve capacities. Therefore, it needs to establish an upper cap for wind as well.

5.2 SCENARIO DESIGN: PORTFOLIO ANALYSIS AND INTERPRETATION OF GRAPHICAL OUTPUT

The first objective is to determine the efficient electricity generating portfolios. Figure 5.11 illustrates the efficient portfolio generated for three electricity generating sources. The Auto Diesel plants show highest risk whilst Hydro plants show lowest risk. The efficient frontier is plotted taking into consideration all possible scenarios. However, this efficient frontier is developed for existing sources. This study focuses on electricity generating using existing and candidate technologies. Therefore, the efficient frontier developed for all possible options and other electricity generating combinations could be considered as a risk embedded snap shot for the electricity generating sector in Sri Lanka.

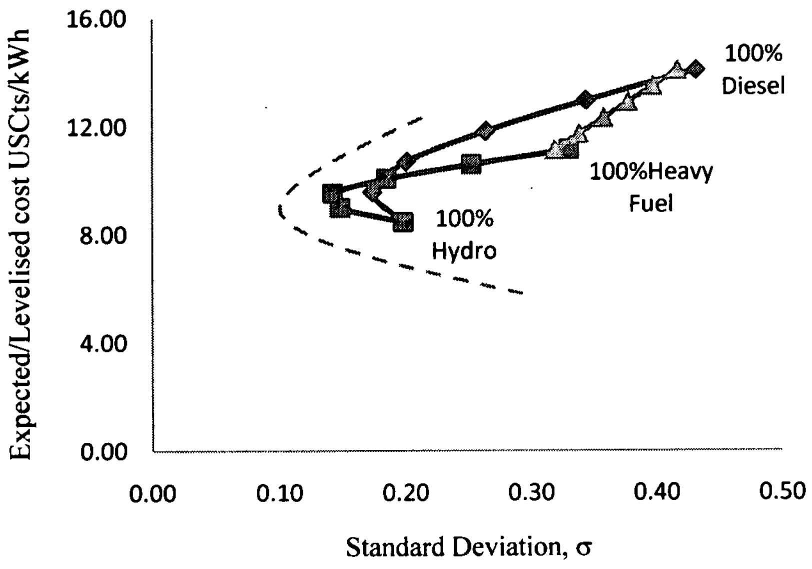

Figure 5.11. Expected cost versus standard deviation for 3 technologies

The efficient frontier was plotted using Financial Tools available in MATLAB (Version R2008a). The inputs were covariance-variance matrix of electricity generating technologies and expected cost matrix.

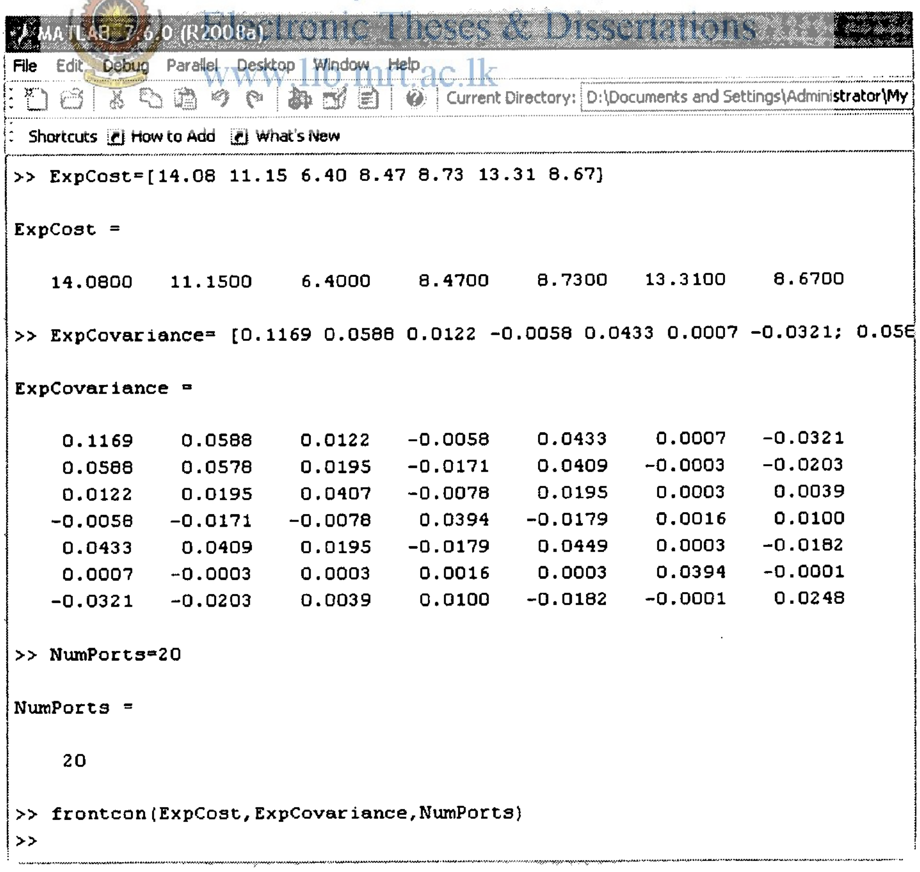

Figure 5.12. MATLAB window - Constructing efficient frontier

5.2.1 DETERMINATION OF PORTFOLIO WEIGHTS

The possible portfolios lying on the efficient frontier were obtained using "*[PortRisk,PortReturn,PortWts]=frontcon(ExpCost,……………,NumPorts)*" command in MATLAB. The number of feasible points (NumPorts) were determined after performing several trial with different numbers from 15 to 25. However, the percentage of different technologies obtained when Numports is 20 and 22 would not make a material difference. That is 20% of wind would not make a much difference to 22% of wind of total installed capacity. The points lying on the efficient frontier and their respective weights (shares of each technology) are shown in Figure 5.13. In this figure one could identify number of efficient portfolios lying in the efficient frontier. However, sometimes these efficient portfolios are implementable due to technical and/or policy constraints. For example, zero percent coal may be given by an efficient portfolio. However, portfolio with zero percent coal share is not acceptable to a developing country like Sri Lanka. Financially, due to relatively low initial capital cost requirement and low fuel cost compared with crude oil prices, as a policy decision country had decided to built number of coal power facilities. However, the analysis suggests that having a large share of coal (example 60% of total demand) may lead to disaster if coal prices also start to show high volatility.

PortWts =

0.0398	0.0647	0	0.1510	0.2299	0.1122	0.4023
0.0573	0.0768	0	0.1329	0.1913	0.1365	0.4052
0.0747	0.0889	0	0.1147	0.1527	0.1607	0.4081
0.0922	0.1010	0	0.0966	0.1142	0.1850	0.4110
0.1097	0.1131	0	0.0784	0.0756	0.2093	0.4140
0.1272	0.1252	0	0.0602	0.0370	0.2335	0.4169
0.1450	0.1356	0	0.0417	0	0.2582	0.4195
0.1712	0.1067	0	0.0140	0	0.2933	0.4148
0.1951	0.0786	0	0	0	0.3312	0.3950
0.2166	0.0516	0	0	0	0.3721	0.3598
0.2380	0.0246	0	0	0	0.4129	0.3245
0.2580	0	0	0	0	0.4541	0.2879
0.2636	0	0	0	0	0.4989	0.2375
0.2692	0	0	0	0	0.5437	0.1870
0.2749	0	0	0	0	0.5886	0.1366
0.2805	0	0	0	0	0.6334	0.0861
0.2861	0	0	0	0	0.6782	0.0357
0.3807	0	0	0	0	0.6193	0
0.6904	0	0	0	0	0.3096	0
1.0000	0	-0.0000	0	0.0000	0	0.0000

>>

Start

Figure 5.13. MATLAB window - Efficient portfolios

Figure 5.15 shows feasible efficient portfolios lying on the efficient frontier. The points indicated as "Mix P", "Mix Q" and "Mix R" could be considered as possible portfolios.

However, even these efficient portfolios may not be feasible and/or not be implementable. Both "Mix P" and "Mix Q" portfolios contain approximately 40% and 22% LNG which is highly unlikely for a country like Sri Lanka.

First, LNG is not in the priority list of energy technologies at the moment and furthermore, Sri Lanka does not have the technology to handling LNG. In "Mix P", the percentage of coal is around 2% which is highly unrealistic. Ceylon Electricity Board expects to have few 1000 MW of coal power during next two decades. In that case, "Mix P" could not be considered as a feasible option.

However, "Mix P" has the least risk when compared with other cases. "Mix R" seems to be somewhat feasible since it has 60% of coal and only 5% of LNG which is more inline with Long-term Generation Expansion Plan proposed by CEB (2008). However, the risk is around 0.13 which is relatively high. Also there is not prominence given for renewable energy sources.

5.2.2 DETERMINATION OF FEASIBLE PORTFOLIO

The problem of this approach is that there is no constraint considered when arriving at the efficient portfolios. In real case, there are many constraints that required attention by the planning authorities. Therefore, first it is required to establish existing constraints then determine the optimal portfolio based on these constraints.

Table 5.11. Possible generating portfolios

	Mix P	Mix Q	Mix R	Feasible Portfolio[16]
Portfolio cost, E	8.72	7.89	7.23	8.67
Portfolio risk , σ	0.074	0.097	0.13	0.122
Diesel	0%	0%	0%	0%
Heavy Fuel	0%	0%	0%	9%
Coal	1.47%	32.40%	60.73%	28%
Hydro	20.72%	26.76%	31.78%	30%
Naphtha	35.79%	18.59%	2.05%	13%
Wind	2.25%	0%	0%	10%
LNG	39.76%	22.25%	5.43%	10%

Source: Author derived data

For example, one constraint may be the availability of hydro power. The hydro power resources are already exhausted and it is expected that approximately 30% of demand in 2020 would be catered by hydro power sources (Ceylon Electricity Board, 2008). Now it is clear

[16] Feasible portfolio was obtained by careful determination of constraints and other country limitations.

that introduction of more renewable sources would help to reduce the risk level. However, again practically it might mot be prudent to introduce certain renewable sources without any control. The main argument against this had been the escalation of cost of electricity generation when renewable energy share increases. According to Abeygunawardana (2008), the cost of renewable technologies show negetive trend which means that inclusion of renewable sources would help to reduce the portfolio expected cost in future. Having stated that, inclusion of high percentage of wind to a relatively smaller system would cause issues of unplanned blackouts if the system is not resilient to the frequent fluctuations due to volatile wind speeds. Therefore, the electricity generation system should equiped with an additional protection schema to accommodate wind power generation. However, more than 10% of total demand catered by wind may be seen as unrealistic by many advocates in the industry.

Therefore, the determination of feasible portfolios was performed after undergoing establishemnt of all possible constraints. In order to perform this task "Micrsoft Office Excel (Solver)" was used (Refere to Figure 5.14). The constrains identified for different sources were indicated in the "constraints window" as shown in the figure.

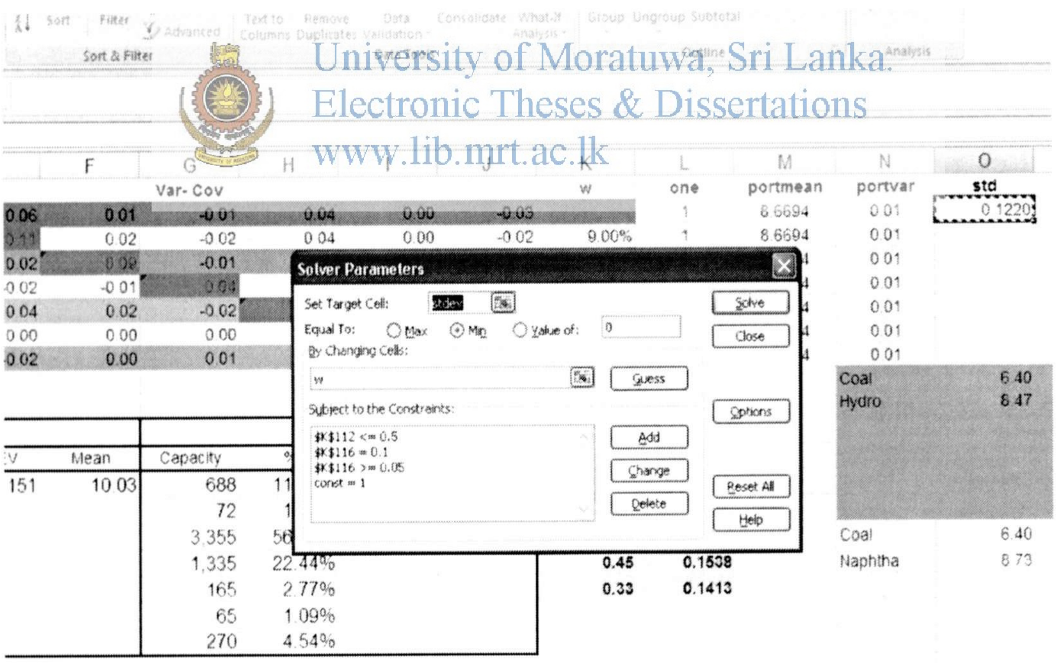

Figure 5.14. MS Excel Solver output

The feasible portfolio is illustrated in Table 5.12 along with the electricity generating portfolios in 2008 and 2019 (Ceylon Electricity Board, 2008).

Table 5.12. Feasible, 2008 and 2019 electricity generating portfolios

	Mix 2008		Mix 2019[17]		Feasible Portfolio for 2019	
Portfolio cost, E	10.03		8.05		8.67	
Portfolio risk , σ	0.151		0.18		0.122	
Diesel	16.26%	363MW	11.56%	688MW	0%	0MW
Heavy Fuel	23.12%	516MW	1.21%	72MW	9%	535MW
Coal	0%	0 MW	56.39%	3355MW	28%	1666MW
Hydro	53.09%	1185MW	22.44%	1335MW	30%	1785MW
Naphtha	7.39%	165 MW	2.77%	165MW	13%	773MW
Wind	0.13%	3 MW	1.09%	65MW	10%	773MW
LNG	0%	0 MW	4.54%	270MW	10%	595MW

Source: Author derived data

The portfolio risk in the feasible portfolio is less than that of both 2008 existing electricity generation portfolio and expected portfolio in 2019 by CEB. The estimated risk of 2019 portfolio is significantly at higher levels mainly due to CEB's ambitious plans on pilling up large volumes of coal power. Figure 5.15 illustrates entire picture efficient, feasible, existing (2008) and planned (2019) electricity generating portfolios in the mean-variance plan.

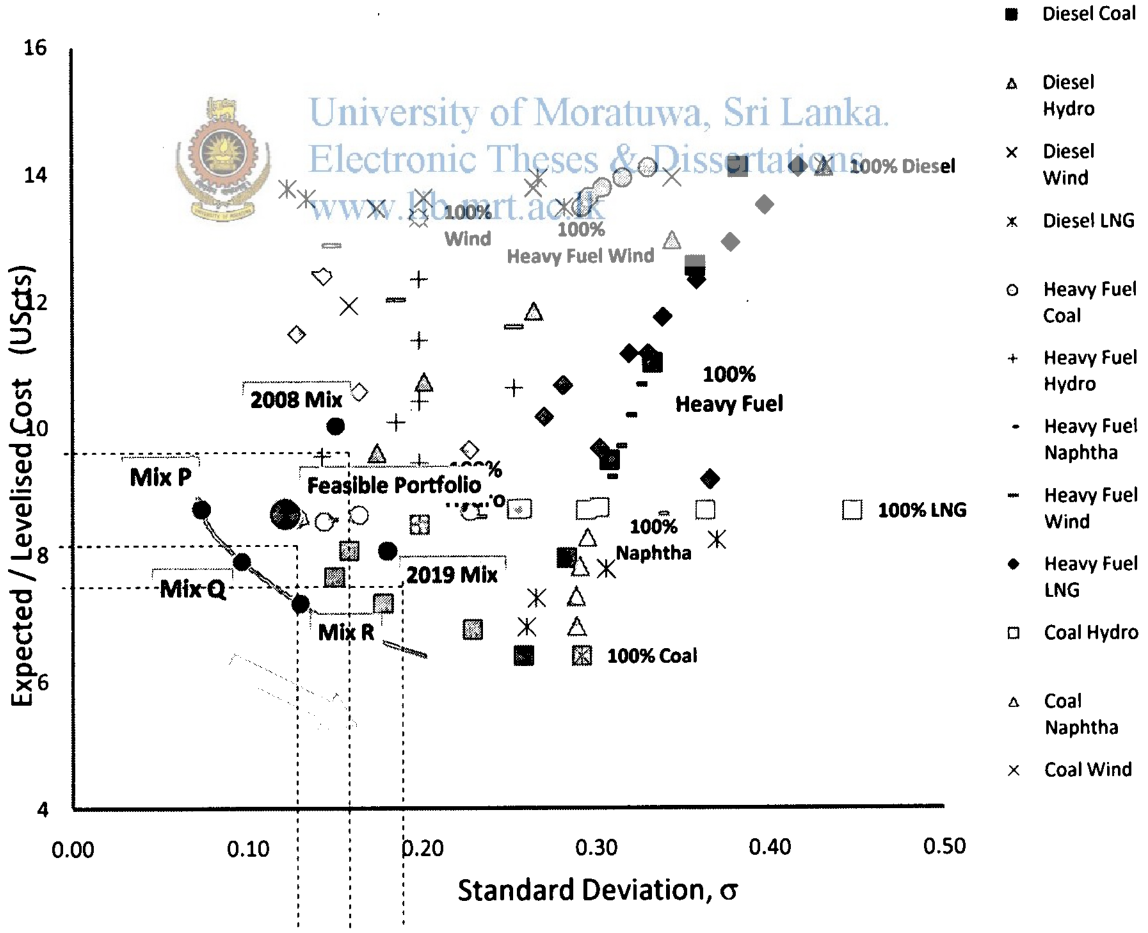

Figure 5.15. Combinations of electricity generating technologies

[17] The mix for 2019 was determined using the data available in Generation Expansion Plan 2008.

Generally, it is advisable to reduce the risk as illustrated in Figure 5.15. Overall risk of expected electricity generating portfolio in 2019 is riskier than the existing one. The main reason is that in 2019 CEB plans to have 60% of its total demand covered by coal power. This may be seen as even more riskier than present scenario where less than 40% is catered using thermal power.

Historically, coal prices were shown less volatility; recent years the prices has started to pick up in rapid pace (Refer to Figure 5.10). Therefore, it is not a prudent expansion strategy to acquire large pill of coal facilities mainly due to expected price escalations and also secondary issues such as finding a reliable supplier, quality of coal (Grade), efficient transportation and storage of coal etc.

5.3 ELECTRICITY GENERATION PORTFOLIO OPTIMIZATION USING INDIFFERENCE CURVES FOR SRI LANKA

Previously, the efficient frontier was plotted using covariance-variance matrix and number of points lying on the frontier was selected as efficient electricity generating portfolios. However, certain points were eliminated due to lack of implementability. Therefore, "Mix R" was considered as the empirically feasible efficient electricity generating portfolio.

The utility theoretic approach is used to further convince the selection of "Mix R". The indifference curves will be constructed in the mean-variance plane. The point at which the indifference curves tangents to the efficient frontier is considered as the optimal portfolio denoted by "Mix R" in Figure 5.16 shown below. The indifference curves were plotted using the Equation 2.20 in page 33; the value for constant *b* is estimated. The value further adjusted using empirical results.

Table 5.13. Expected cost, standard deviation and b

Expected cost, μ_q	*Standard deviation,* σ_q	*b*
9.81	0.117	-0.0525
9.22	0.119	-0.0564
8.51	0.128	-0.0619
7.64	0.15	-0.0674

Source: Author derived data

The selected optimal electricity generating portfolio "Mix R" may be considered as the ideal scenario for the country. The lesson learnt from the selection of "Mix R" is that addition of Wind and other renewable would reduce the overall portfolio risk; inclusion of LNG which is almost neglected by CEB would provide less risky electricity generating portfolio. Furthermore, it is advisable to reduce the thermal share of total supply. Since "Mix R" seems to be highly theoretical, writer suggests a feasible portfolio lying inside the efficient frontier which may be implemented empirically.

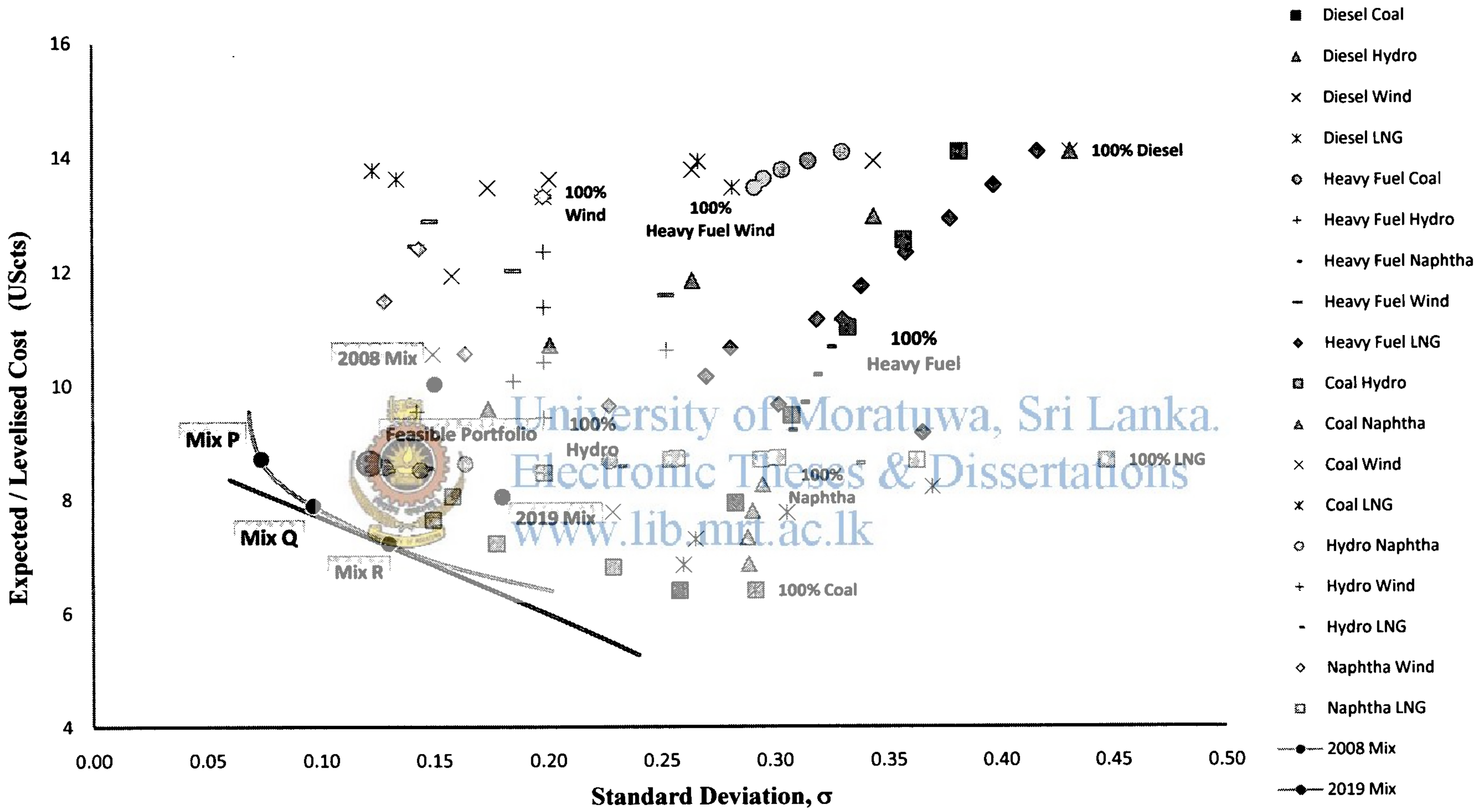

Figure 5.16. Indifference curves in mean variance plane

Many argue that there shall be higher risk involved with relatively new technologies. This factor is considered in this study by incorporating risk associated with initial capital outlays during construction and other complexities. However, as stated throughout the study, the cost trend shows negative growth for renewable technologies (Abeygunawardana, 2008). Therefore, Sri Lanka should seriously consider on expanding its renewable options whilst reducing the thermal generation.

5.4 SOCIETAL RISKS AND ENVIRONMENTAL RISKS

Incidents of large number of displacements of people and disruptions to eco-systems were the main short term issues the governments faced when construction of large hydro plants in many countries. Even after completion of such mega plants, the environmentalists complains about the threats of land slides, unexpected floods and risks of earth quacks caused by inequalities in pressure on earth surface due to large hydro projects.

However, when the countries focused more on thermal power generation, the issues that they had to address were became greater. Apart from some of early issues, these thermal electricity generation plants emit SO_2, NO_X, matter, smoke, CO_2 and other substance that destroys ecosystems. These affects are ranging from problems of acid and nutrient nitrogen, regional concentration of fine particles and ozone. Apart from above loss of forest cover, biodiversity and degradation of coastal zones are alarmingly increasing in many countries including in Sri Lanka. Although emissions such as SO_2 and NO_X are negatively affect the ecosystems, it is GHG emissions that are considered as paramount issue at presence that threatens the livelihood of mankind and entire environment. Therefore, this study uses the environmental risk i.e., GHG emissions (CO_2 particularly) as a proxy to societal risk.

Based on the draft guideline for the CDM eligibility of hydro projects, the net CO_2 emissions from the reservoirs of the candidate power projects are ignored. The GHG emission is measured for hydro power projects using power density that is Watts/m^2 of reservoir area. According to the UNFCCC projects with power densities less than or equal to 4 W/m^2 are excluded; projects with power densities between 4 W/m^2 and 10 W/m^2 could be eligible but with an emission penalty of 90 gCO_2eq/kWh. The projects having more than 10 W/m^2 are eligible with out a penalty. Since majority of Sri Lanka's hydro power plants exceed this value and therefore, there is no penalty imposed. But a value of 15gCO_2/kWh is charged for the life cycle emission associated with materials and construction of hydro power plants. IPCC default values are considered for the emissions from coal and natural gas combustions.

Further, the life cycle emissions for coal power plants are escalated by 10% than that of combustion impacts and 40% escalation is accounted for LNG.

The life cycle emissions is measured all power generating technologies including renewable as well. Renewable generation such as wind positively contribute to GHG emissions when it require energy for manufacture of equipment, fuel extraction, transportation and decommissioning. According to ECA, RMA AND ERM (2010) draft issue in general, the life cycle emissions associated with mining, transport, material inputs, construction and decommissioning represent in the below chart.

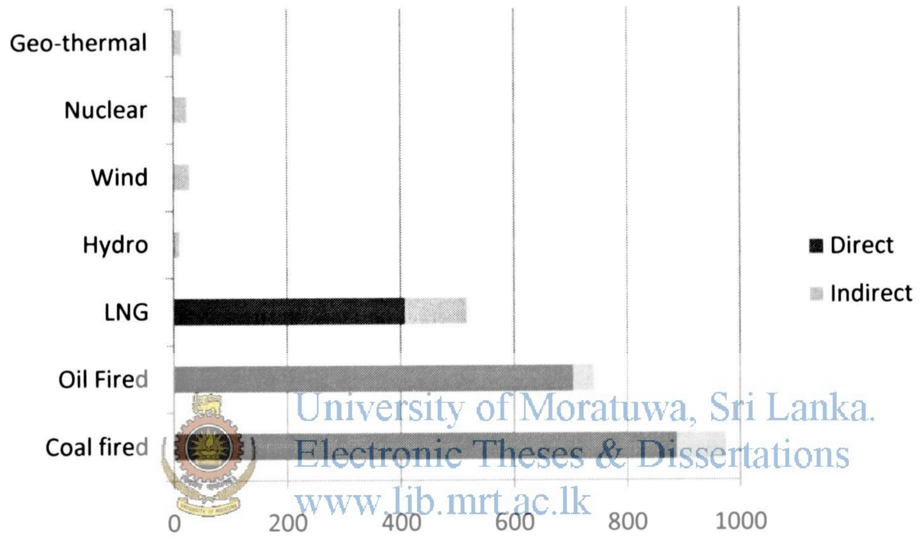

Figure 5.17. Life Cycle CO_2 emissions
Source: ECA, RMA and ERM (2010)

Based on above data the CO_2 emissions for each portfolio is determined. Present portfolio of CEB records lowest emissions of 353gCO_2/kWh whilst proposed 2019 portfolio will have highest emissions mainly due to inclusion of coal technologies into the system. More than 50% of the installed capacity the 2019 electricity generating portfolio is made up with coal power. Therefore, the amount of GHG emission is significant than other portfolios. "Mix P" and "Mix Q" possess less coal and crude oil power generation. However, LNG and wind shares are relatively high. Therefore, the GHG emissions are less than that of major coal based portfolios. Further, "Mix R" also contains approximately 60% of coal which emits relatively high amount of GHG. Table 5.14 provides life cycle carbon dioxide emission factors in gCO2 per kilo Watt hour for electricity generating portfolios of existing (2008), 2019 (according to CEB's Generation Expansion Plan) and proposed by this study (Mix P, Q, R and Feasible portfolio).

Table 5.14. Life cycle emission for different generating mixes

Generating mix	*Life cycle CO_2 emission factor gCO_2/kWh*
2008 Mix	353
2019 Mix	695.5
Mix P	524.5
Mix Q	592.1
Mix R	643.84
Feasible P/F	503.24

Figure 5.18 illustrates the share of different technologies appearing in each portfolio. Therefore, it is clearly evident the level of impact of coal in overall estimation environmental risk.

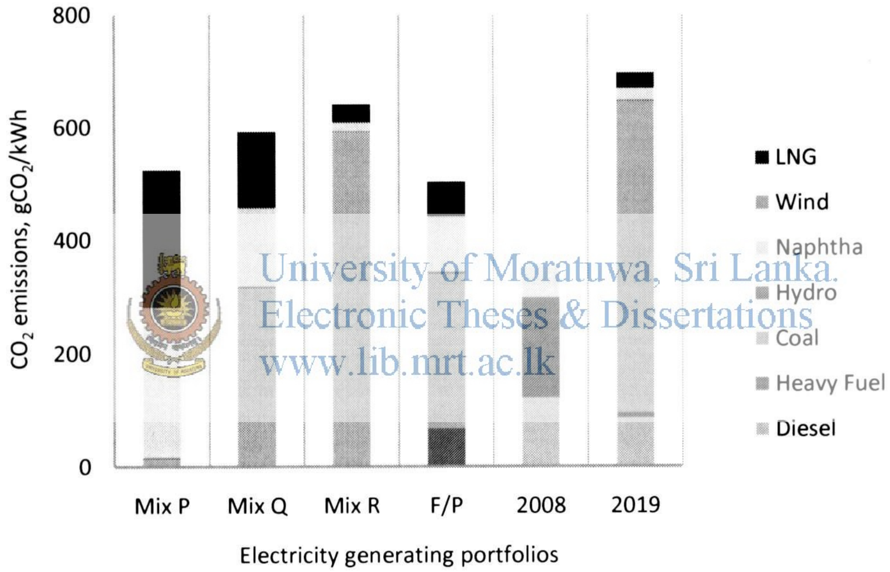

Figure 5.18. CO_2 emissions for different portfolios

The portfolios on the efficient frontier are having life cycle CO_2 emissions in the range from 400 to 500. The feasible portfolio suggested in the study having 503.24gCO_2/kWh could be considered as the best portfolio that gives lower risk and moderate emissions.

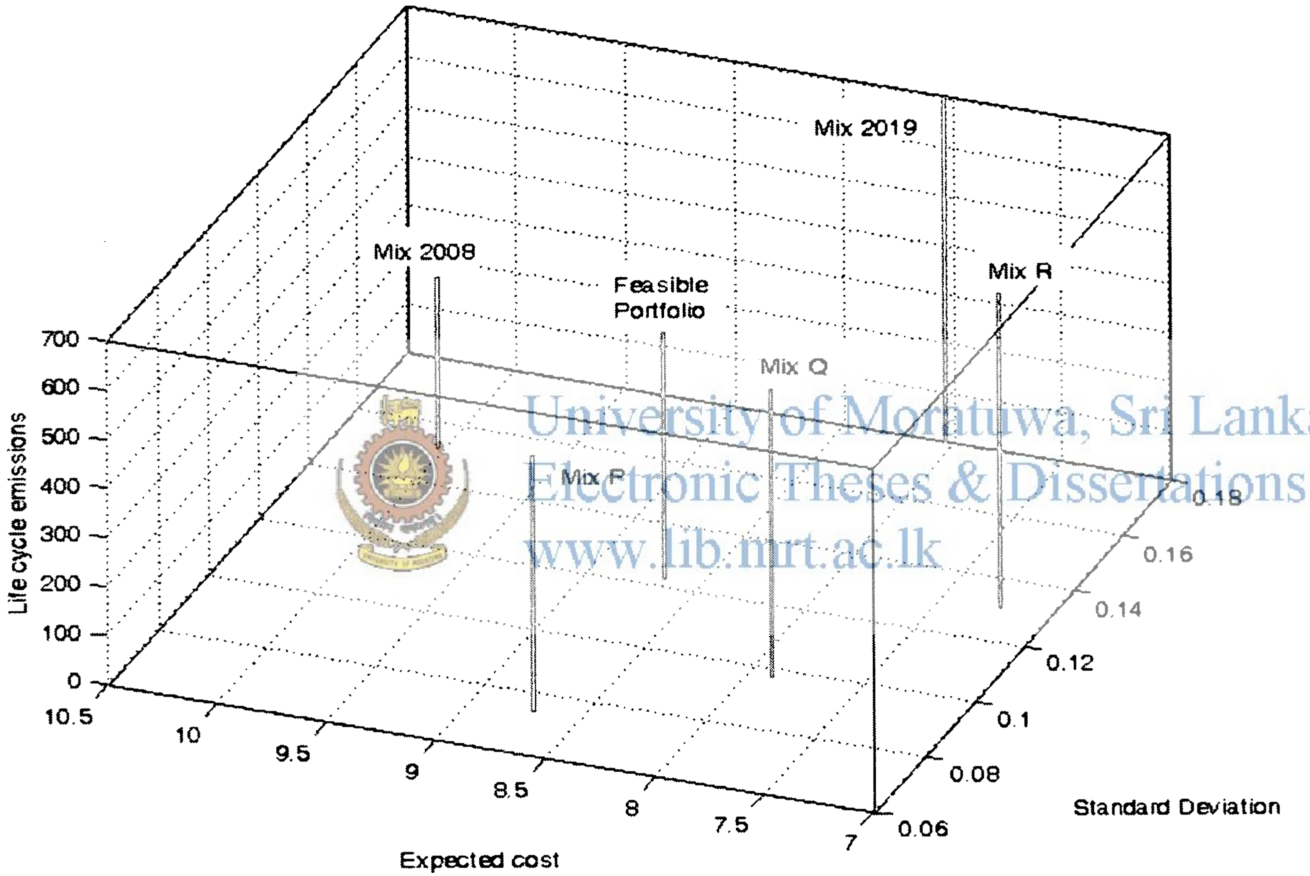

Figure 5.19. Portfolio CO_2 emissions, Expected cost and Risk

5.7 CHAPTER SUMMARY

This chapter synthesises Modern Portfolio Theory and its applicability to power generation sector considering expected cost and standard deviation instead of traditional parameters, expected return and standard deviation. In the same note, the problem became a minimization instead of maximization. The constraints for the minimization problem were derived rationally looking at the Sri Lanka's power sector. A graphical out put was obtained showing efficient frontier for all possible efficient portfolios for Sri Lanka's electricity generation sector.

In section 4.3 finding the optimal portfolio in the mean-variance plane performed. Widely used CAPM model in finance was not adoptable to determine the best mix. Therefore, indifference curves plotted in mean-variance plane approach was useful in finding the best generating mix.

These best generating mixes were determined in the investors' perspective. But it was equally important to include the societal risk into the portfolio selection criteria. Although several studies had included environmental related costs or penalties, it was not entirely justifiable inclusion of emissions into generating costs except for SO_2, NO_X and few others. Still this was possible in the countries that have imposed strict air quality regulations. Sri Lanka having lower standards than what WHO proposed was not a candidate to include emissions into respective generating cost. Therefore, less carbon emitting portfolios were analysed using a 3D plot. It was not the minimum emission portfolio that was selected in the earlier study; it needs to consider the portfolio's expected cost, risk and ability to implement. The feasible portfolio selected considering above aspects was having 0% diesel, 9% heavy fuel, 28% coal, 30% hydro, 13% Naphtha, 10% LNG and 10% wind of total installed capacity.

CHAPTER VI

SUMMARY OF FINDINGS AND DISCUSSION

6.0 INTRODUCTION: INTERPRETATION OF FINDINGS VERSUS OBJECTIVES

The chapter VI interprets the findings of the study against each objective stated in the first chapter. Under first objective, it lists out all possible options available for planning authority. Next, it lists outs electricity generating options considered in this study. Further, this chapter discusses the finding under second and third objectives. The environmental risk estimation is discussed under the existing regulatory framework. Hirfindhal Index (H-index), a well established method used to determine the diversity of the electricity generating system is compared with the standard deviation (variance) derived in this study to establish the validity of the model. Finally, the third objective is fulfilled by performing a sensitivity analysis. The response of the model (feasible portfolio) is investigated when new electricity generating technology added to the system.

6.1 OBJECTIVE 01: DETERMINATION OF EFFICIENT ELECTRICITY GENERATION PORTFOLIO

The main objective determines the best mixing portfolios based on cost and risk from the investors' perspective and importantly it will include the portfolio effect into a quantitative framework to determine the generating mix from the societal perspective. In 2008, Sri Lanka's power generation mix was mainly comprised with heavy fuel, auto diesel, naphtha, residual oil and hydro. Power generation using wind and biogas was at insignificant levels. Next, it is important to assay the sources available in future power generation for Sri Lanka.

- Coal: The first coal power plant will come in to the system in 2012 and the CEB is focusing on adding more and more coal power plants which will provide approximately 50% of the electricity demand in year 2020.

- Liquid Natural Gas: The SO_X emissions and particle matter is very low and leaves no solid waste. Combine cycle power plants provide very high efficiency and generally account for low CO_2 emissions.

- Demand Side Management: The CFL programme was launched in 1995 targeting at reducing the demand by 47 MW per year seems to be a success. Other DSM options were converting CRT TVs to LCD TVs and managing the use of refrigerators.

- India-Sri Lanka power link: The proposed interconnection expected to deliver electricity at a price ranging from 6.5 to 8 USCents/kWh according to a study conducted by NEXANT.

- Non-conventional renewable energy sources: According to ECA, RMA AND ERM (2010) NCRE technologies include small hydro, wind, biomass, agricultural and industrial waste, municipal waste and waste heat. It is expected to raise the NCRE contribution from 4% to 10% in 2015.

The energy security policy of any country would be targeting at reducing their dependency on imported energy. Sri Lanka in its early stages managed to generate bulk of its electricity requirement by hydro power but during last two decades there were more emphasis on crude oil based power generation. Looking at the long term generation expansion plans of CEB, one could clearly notice that the emphasis will broaden beyond oil to include coal. Access to supply and price stability are the main aspects of energy security.

Conventional regulatory mechanisms existing at the moment in Sri Lanka, electric utilities generally hold monopolies. Therefore, consumers are not given the opportunity to select between providers like in many developed nations. Further the utility rates are structured to achieve full cost recovery and fuel price pass through to end users. This study focused on determining the best mix with lesser price volatility (standard deviation) and lower levelised cost (expected cost). In Chapter IV, the optimal portfolios were further analysed for their GHG emissions. A compromised solution was arrived at considering the lower price risk, lower expected cost and less GHG emissions. This study aimed at plotting an efficient frontier comprising number of viable generating portfolios for Sri Lanka's power sector.

Next step was to find the optimal portfolio from above possibilities. Generally in finance the optimal point is found by plotting a tangent from the risk free point towards the efficient frontier. (Metron, 1972). Awerbuch(2003) had used same technique to determine the optimal portfolio considering that Wind gives zero risk. Although one could assume that wind has zero risk, it is highly unreasonable to assume the same for Sri Lanka since most of the plants being candidate plants with associated risk of capital outlays, interest during construction (IDC) etc and it is still not certain whether country could accommodate wind into its system because the system must be able to respond to varying wind speeds. Wind speeds are generally subjected to high level of fluctuations which imparting risk of entire system failure. So for a small country like Sri Lanka, it is not correct to assume wind at zero risk. The portfolio optimization in mean variance plane using utility curves or indifference curves was adopted to determine the optimal portfolio (Baron, 1977).

For this study, DSM and India-Sri Lank power link were excluded since the underlying objectives of the study was to determine the optimal electricity generating portfolio in the decision makers perspective and further extending to reduce the societal risk. The study envisaged that diversification will reduce the overall risk and inclusion of renewable sources will resulting in further reduction of price risk but the expected cost will rise since the investment cost of renewable are relatively higher. However, Abeygunawardana (2008) in his article "viability of coal and oil-fired power plants in Sri Lanka", states that in future the cost of renewable technologies will decline considerably.

6.2 OBJECTIVE 02: ESTIMATION OF ENVIRONMENTAL/SOCIETAL RISK

The second objective of this study was to establish a quantitative framework that determines the societal/environmental risk. In most literature this is being done by imposing a penalty schema for emissions. In other words, the emissions are considered as costs that will add to generating costs. It is important to discuss the impact of environmental risk along with the existing regulatory framework.

6.2.1 ENVIRONMENTAL REGULATIONS AND STANDARDS

The National Environment Act No. 47 (1980) is the primary piece of legislation for environmental management and protection in Sri Lanka. The Central Environment Authority was given the mandate to implement two main regulatory instruments Environmental Protection License for industries and Environmental Impact Assessment for major development projects including power projects. Sri Lanka introduced its ambient air quality regulations in 1994 and further strengthened in 2008. Still, the existing guidelines are less stringent than that of World Health Organization (WHO), especially in the areas of emission of the SO_2 and other matter.

Figure 6.1. National ambient air quality standards

Pollutant	*Maximum permissible concentration $\mu g/m^3$*	
	Sri Lanka	WHO
PM10 (Annual)	50	20
PM2.5 (Annual)	25	10
NO2 (24 Hours)	100	40 (Annual)
SO2 (24 Hours)	80	20
O_3	200 (1 hour)	-
CO	10,000 (8 hours)	10,000 (8 hours)

Source: ECA, RMA and ERM (2010)

Generally many developed countries have successfully controlled the conventional power plant emission by imposing rigorous regulations on SO_2 and NO_X emissions and cost of emissions abatement are generally accepted as a part of the cost of generation. Therefore, globally the focus has shifted to climate change and GHG emissions.

6.2.2 PROPOSED EMISSION REGULATIONS

According ECA, RMA AND ERM (2010) the source specific atmospheric emissions are in draft form which will be formally issued by CEA. The liquefied natural gas (LNG) is preferred by many countries mainly due to lowest emission of NO_X and smoke. Further LNG is regarded as highly efficient source as shown in Table 6.1.

Table 6.1. Proposed emission standards for larger plants

Fuel type	*Capacity (MWe)*	*Pollutant*	*Maximum emission level, mg/Nm^3*
Oil	≥ 100	SO_X	850
		NO_X	450
Coal	≥ 50	SO_X	800
		NO_X	650
		PM	100
		Smoke	10% opacity
Natural gas	≥ 50	NO_X	75
		PM	300
		Smoke	75

In its draft issue, Sri Lanka: Environmental Issues in Power Sector by ECA, RMA and ERM (2010) point out two issues in carbon accounting. GHG emissions from hydro reservoirs and the second is whether to consider combustion related emissions only or whether to consider GHG emissions from a power plant for its entire life span and fuels including the extraction and the processing of the fuels. Per capita GHG emission in Sri Lanka is well below when compared with other countries which have a similar per capita income. Further it is 50% less than India according to the table below.

Table 6.2. GHG emissions per capita

Country Name	*1970*	*1980*	*1990*	*2000*	*2005*
World	4.06	4.41	4.29	4.07	4.53
EU	8.26	9.26	8.39	7.95	8.07
USA	20.57	20.26	19.22	20.01	19.52
Singapore	8.77	12.47	13.76	12.89	13.19
India	0.35	0.51	0.80	1.14	1.28
Sri Lanka	0.29	0.22	0.22	0.54	0.56

Source: World Bank World Development Indicators Database

However in this study, the amount of carbon emissions of each portfolio was separately determined and used as an orthogonal construct to mean-variance plane and lowest emitting portfolio was selected as the least risky portfolio.

Entire study was evolving mainly with two parameters expected/levelised cost and standard deviation/risk. Therefore, the parameter that could be used to predict the future portfolios shall be either expected cost or standard deviation. The standard deviation was selected as the predictor variable instead of expected cost which is not time variant (Bhattacharyya, 2009). It is extremely important to check the accuracy and reliability of the model that developed under the first two objectives. This was discussed separately below.

6.2.3 DETERMINATION OF MODEL VALIDITY (CRITERION VALIDITY)

Generally, the commonly accepted method to measure the diversity of a generating mix is the Herfindhal Index (H Index), which is adopted from finance theory. Lower the value of H index is greater the fuel diversity. But in this measure all crude oil base generation technologies were considered as a single source due to their high correlation. The value of H index was used as a validation technique where the standard deviation obtained in the study was compared with the value of H index (ECA, RMA and ERM , 2010).

Table 6.3. Capacity shares, H index and Variance

	Installed capacity, MW (Capacity shares)					
	1980	1990	2000	2007	2012+ coal	2012+ renewables
H Index	0.52	0.60	0.65	0.51	0.45	0.33
Variance	0.1533	0.1555	0.1605	0.1562	0.1538	0.1413

Source: ECA, RMA and ERM (2010)

Table 6.3 compares diversity index, H determined by industry experts and Variance calculated in this study. Figure 6.2 shows how standard deviation of different generation mixes in given years behave against the H index. It is clear that H index is positively correlated with the Standard deviation or in other words risk (Correlation coefficient is 0.913062).

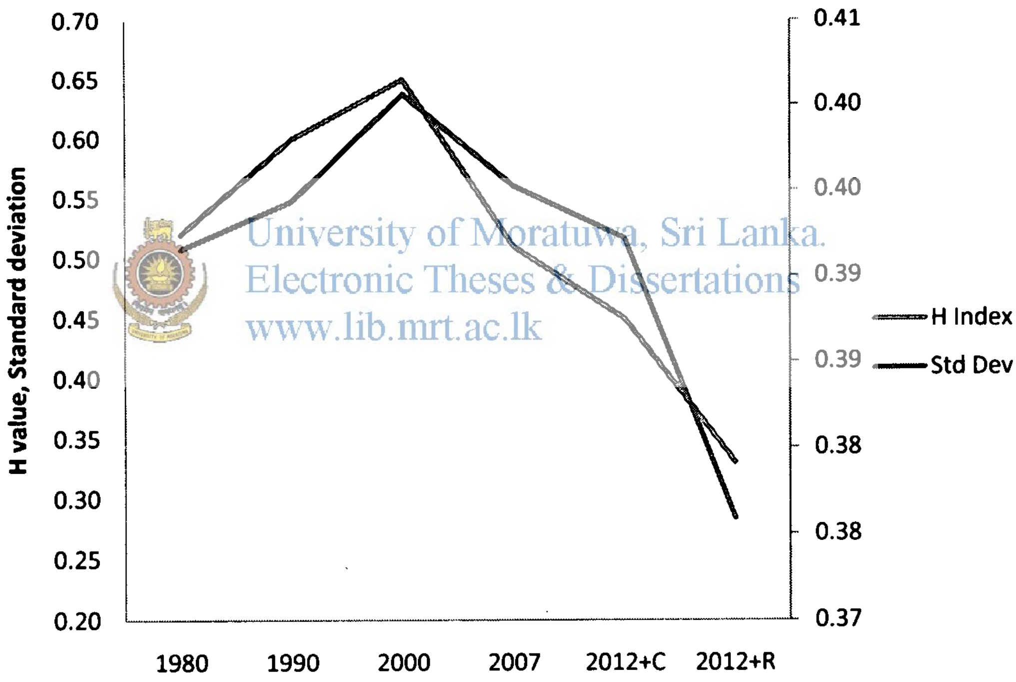

Figure 6.2. Behaviour of H value against Standard Deviation
Source: Author derived data

The important point is that the standard deviation was determined considering all existing generating technologies inclusive of their investment cost, fuel cost, variable O&M cost and Fixed O&M cost. Therefore, standard deviation determined in this study gives more complete picture when it comes to evaluation of the level of risk showing similar trends that shown by the diversity index H.

6.3 OBJECTIVE 03: TO EVALUATE THE SENSITIVITY OF RISK AND EXPECTED COST WHEN DECIDING TO INCORPORATE NEW POWER GENERATING TECHNOLOGY TO EXISTING PORTFOLIO

It is important to conduct a sensitivity analysis to investigate the behaviour of optimal portfolio when a source is added to cater increasing demand. This would provide much better picture to the decision maker because it considers risk aspect in addition to the cost aspect which is used in conventional decision making (Awerbuch & Berger, 2003) . Figure 6.3 gives a what-if analysis for the generating portfolios. The sensitivity is observed by increasing 20% of respective sources from the optimal portfolio "Mix T" determined in the Chapter IV. The prospective candidate plants considered at this occasion are wind, heavy fuel and coal. It is unlikely that Sri Lanka will have the opportunity to increase its capacity through hydro power in future. Liquid natural gas may be still viable but it seems that CEB's focus is more on coal.

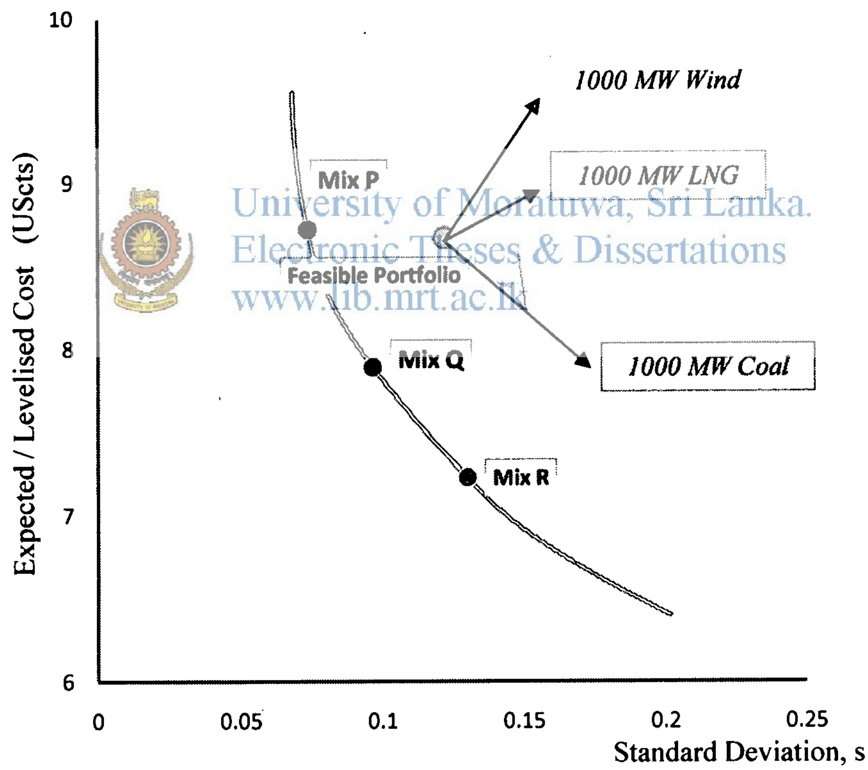

Figure 6.3. Sensitivity analysis

Increase in 20% demand catered by wind will have lesser impact on volatility with respect to heavy fuel or coal as shown in the figure above. However, coal at the moment provides lower levelised cost which has greater possibility of showing fluctuations similar to crude oil in future and with higher GHG emissions. Therefore, CEB's intentions in pilling up coal power plants might not be prudent in the long run considering the societal risk that it could impart.

CHAPTER VII

CONCLUSIONS AND FURTHER RESEARCH

7.0 INTRODUCTION

The Chapter VII highlights the empirical and theoretical contribution of the dissertation to the areas of electricity generation expansion planning in Sri Lanka. Next the conclusion to the study is made and followed by the implications. Finally, the study explores the future research possibilities when the system becomes more complex and demanding.

7.1 CONTRIBUTIONS OF THE STUDY

The importance of asset-liability management framework in electricity generation planning for Sri Lankan is becoming profound in the context of present challenges faced by energy sector. Similar studies were done in developed countries having liberalised electricity markets. Therefore, traditional MPT techniques were easily applied. On the other hand, application of MPT for monopolised market was not straight forward.

Determining most efficient generation portfolio out of all portfolios on the efficient frontier was performed using iso-variance curves plotted in the mean-variance plane which was again not a very popular technique used in traditional finance theory. The societal risk was subsumed to the model as a separate orthogonal axis to the mean-variance plane. Further, the accuracy of model was established by comparing the correlation between standard deviation derived for portfolios in each decade and Hefindhal (H) index used in the electricity industry.

7.2 CONCLUSIONS

Portfolio based generation planning is used to analyse the portfolio performance not only by cost basis but more importantly by risk basis as well. Markowitz's Portfolio theory (MPT) is well established, proven and robust model used in finance to determine the optimal the portfolios of financial assets. The analysis for electricity generating technologies based on modern portfolio theory (MPT) lays out a consistent framework to gain better view into the portfolio cost and risk, inherent to alternative technologies. One argument against MPT approach is that the power producers generally evaluate their own direct cost and risk at the time of making the investment decision.

They may generally prefer to bear the risk offered by low capital intensive non-renewable generation technologies since the investors in most countries allowed passing the fuel risk to the consumer though the regulatory mechanisms in operation. As a result, there exist under investments in most of the renewable technologies due to the requirement of high initial capital requirements and associated uncertainties. The records show that since 1990s there is an accretion in thermal power generation in Sri Lanka.

To establish the first objective, the analysis finds an efficient portfolio based on expected cost and risk for Sri Lanka which is useful for a rational investor and policy makers. Second, it incorporates emissions into the picture by determining the quantity of carbon dioxide emitted by each portfolio derived to satisfy the next objective. Therefore the less emitting portfolio was selected. A sensitivity analysis incorporated herewith would provide the planner the direction that the existing portfolio moves in terms of expected cost and risk when adding a new generating source to the system where the planner could assuage price and environment risk satisfying the third objective. In addition, the analysis illustrated that standard deviation could be used as a predictor variable when deciding to acquire new generating technologies.

Modern portfolio framework together with inclusion of environmental adders is useful in determining the optimal electricity generation portfolio for Sri Lanka in year 2020 and its sensitivity towards incoming technology into the optimal portfolio attained. Therefore it provides a systematic guide to the policy makers and investors for electricity generation expansion planning.

7.3 IMPLICATIONS

Risk based electricity generation portfolio optimization techniques provide the decision makers a better platform to select the power generating options considering not only the least cost but risk involved with at the capital outlays, fixed and variable O&M and also fuel price changes over the life span of the plant. It is important to strike a balance between energy risk, cost and sustainability. The pressure on the governments for less carbon intensive is mounting day by day but these options are at higher initial cost. Still the study points out the importance of embedding fuel price volatility into decision making criteria which provides more complete picture.

This study further rejects CEB's intentions on pilling up coal power plants of which CEB expect to cater more than 50% of future demand. If coal prices start to show high volatility, there will be hardly any difference to what it is found at the moment with crude crisis.

Conceptually, the need for risk based power system planning model is timely considering the issues faced by many economies globally. Risk has become more important and more discussed topic at present. Then why not risk is not embedded to a critical area such as energy?

The first objective of the study is to find out the efficient electricity generating portfolios gives less expected cost and less risk to a rational investor. It further revealed that carbon intensive generating technologies could be replaced by renewable technologies which are less risky. With reference to the second objective, carbon emission accounted portfolios are considered to reduce societal risk giving more flexibility to the governments who are increasingly pressurised to decarbonising electricity generation and concern on nations' energy security, sustainability, affordability and issues faced by climate change.

Incidentally a rational planner could also utilise the standard deviation as a variable that linked with diversity of the generating technologies. Therefore, this research strikes a balance between the expected cost and the risk for sustainability.

7.4 FURTHER RESEARCH

This study highlights the importance of adding renewable power generation sources into existing mixes. However, when wind is added the scenario will become probabilistic due to stochastic nature of variations taking place both in supply and demand sides. When the power is purchased and or sold (transfer) beyond geographical boundaries (expected when India –Sri Lanka power link establishes) it will further require more complex analysis. The models will have to be developed for optimizing of country's energy markets and their interactions focusing how the regional energy transfer should take place giving priority to renewable energy production. These models will be deduced from existing global climate models having deduced to country level. Further, robust stochastic models that could tackle with outliers need to be formulated after a thorough investigation of data collected from energy markets and carefully studying the available models within different forecasting frameworks.

Formulating models to estimate the optimal investment in power systems securing mentioned transfers will be required. These investment decisions are frequently made under technical and market uncertainties. When it comes to power generation industry, some technical uncertainties may decrease with the time. Still emerging technologies may have significant levels of risk.

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APPENDIX A1: ELECTRICITY GENERATING PORTFOLIO

ENERGY PRICE ESCALATIONS AND HOLDING PERIOD RETURNS

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
DIESEL (US$/bbl)	32.58	28.54	26.58	24.13	21.08	20.89	22.48	23.88	16.30	20.20	31.04	52.64	26.83	33.70	46.49	61.08	72.02
Holding period returns	-0.12	-0.07	-0.09	-0.13	-0.01	0.08	0.06	-0.32	0.24	0.54	0.70	-0.49	0.26	0.38	0.31	0.18	0.13
LNG			1.15	1.12	1.23	1.05	1.10	1.13	1.22	1.34	0.90	1.19	1.08	0.85	0.82	0.67	0.61
Holding period returns			-0.03	0.10	-0.15	0.05	0.03	0.08	0.10	-0.33	0.32	-0.09	-0.21	-0.04	-0.18	-0.09	0.02
NAPHTHA (US$/bbl)	23.72	22.62	20.27	17.22	16.34	17.61	20.22	21.91	14.83	19.37	28.26	23.78	24.89	30.44	41.23	50.74	61.81
Holding period returns	-0.05	-0.10	-0.15	-0.05	0.08	0.15	0.08	-0.32	0.31	0.46	-0.16	0.05	0.22	0.35	0.23	0.22	0.29
GAS OIL 1.0% S (US$/bbl)	29.32	28.25	25.13	23.79	20.65	21.54	26.98	24.18	15.46	19.07	32.20	27.20	27.32	32.31	32.31	67.45	67.45
Holding period returns	-0.04	-0.11	-0.05	-0.13	0.04	0.25	-0.10	-0.36	0.23	0.69	-0.16	0.00	0.18		1.09		
FO 380CST (US$/mt)	103.21	88.26	79.97	71.03	79.76	92.96	102.77	97.52	65.34	97.70	152.30	128.75	144.55	165.97	180.41	254.10	329.03
Holding period returns	-0.14	-0.09	-0.11	0.12	0.17	0.11	-0.05	-0.33	0.50	0.56	-0.15	0.12	0.15	0.09	0.41	0.29	0.15
Coal	28.48	31.48	30.35	27.98	25.67	21.64	25.09	28.06	26.47	30.14	33.19	35.28	28	25.00	40.00	46.00	40.00
Holding period returns	0.11	-0.04	-0.08	-0.08	-0.16	0.16	0.12	-0.06	0.14	0.10	0.06	-0.21	-0.11	0.60	0.15	-0.13	0.35

APPENDIX A1

GENERATING TECHNOLOGY COMBINATIONS

	Mean	Standard deviation	Correlation	Weights	Portfolio - mean	Portfolio -standard deviation
Diesel & Heavy Fuel	14.08 11.15	0.43 0.33	0.93	0%	11.15	0.32
				20.00%	11.74	0.34
				40.00%	12.32	0.36
				60.00%	12.91	0.38
				80.00%	13.49	0.40
				100.00%	14.08	0.42
Diesel & Coal	14.08 6.40	0.43 0.29	0.78	0%	6.40	0.26
				20.00%	7.94	0.28
				40.00%	9.47	0.31
				60.00%	11.01	0.33
				80.00%	12.54	0.36
				100.00%	14.08	0.38
Diesel & Hydro	14.08 8.47	0.43 0.20	-0.09	0%	8.47	0.20
				20.00%	9.59	0.17
				40.00%	10.71	0.20
				60.00%	11.84	0.26
				80.00%	12.96	0.34
				100.00%	14.08	0.43
Diesel & Naphtha	14.08 8.73	0.43 0.30	0.94	0%	8.73	0.30
				20.00%	9.80	0.32
				40.00%	10.87	0.35
				60.00%	11.94	0.37
				80.00%	13.01	0.40
				100.00%	14.08	0.43

Appendix A1

Diesel &	14.08	0.43	-0.09	0%	13.31	0.20
Wind	13.31	0.20		20.00%	13.46	0.17
				40.00%	13.62	0.20
				60.00%	13.77	0.26
				80.00%	13.93	0.34
				100.00%	14.08	0.43
Diesel &	14.08	0.43	-0.91	0%	8.67	0.45
LNG	8.67	0.45		20.00%	13.46	0.28
				40.00%	13.62	0.13
				60.00%	13.77	0.12
				80.00%	13.93	0.27
				100.00%	14.08	0.43
Heavy &	11.15	0.33	0.86	0%	6.40	0.29
Fuel	6.40	0.29		20.00%	13.46	0.29
Coal				40.00%	13.62	0.30
				60.00%	13.77	0.30
				80.00%	13.93	0.32
				100.00%	14.08	0.33
Heavy	11.15	0.33	-0.36		8.47	0.20
Fuel &	8.47	0.20		20.00%	9.01	0.15
Hydro				40.00%	9.54	0.14
				60.00%	10.08	0.19
				80.00%	10.61	0.25
				100.00%	11.15	0.33
Heavy &	11.15	0.33	0.99		8.73	0.30
Fuel	8.73	0.30		20.00%	9.21	0.31
Naphtha				40.00%	9.70	0.31
				60.00%	10.18	0.32
				80.00%	10.67	0.32
				100.00%	11.15	0.33

Heavy Fuel & Wind	11.15	0.33	-0.36		13.31	0.20
	13.31	0.20		20.00%	12.88	0.15
				40.00%	12.45	0.14
				60.00%	12.01	0.19
				80.00%	11.58	0.25
				100.00%	11.15	0.33
Coal & Hydro	6.40	0.29	-0.19		8.47	0.20
	8.47	0.20		20.00%	8.06	0.16
				40.00%	7.64	0.15
				60.00%	7.23	0.18
				80.00%	6.81	0.23
				100.00%	6.40	0.29
Coal & Naphtha	6.40	0.29	-0.90		8.73	0.30
	8.73	0.30		20.00%	8.26	0.30
				40.00%	7.80	0.29
				60.00%	7.33	0.29
				80.00%	6.87	0.29
				100.00%	6.40	0.29
Coal & Wind	6.40	0.29	-0.19		13.31	0.20
	13.31	0.20		20.00%	11.93	0.16
				40.00%	10.55	0.15
				60.00%	9.16	0.18
				80.00%	7.78	0.23
				100.00%	6.40	0.29