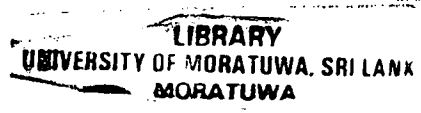


LB/DON/20/2012

# RISK BASED OPTIMAL ELECTRICITY GENERATION PLANNING USING MODERN PORTFOLIO THEORY



I. Mahakalanda

07/8501



University of Moratuwa, Sri Lanka.

Dissertation submitted in partial fulfilment of the requirements for the degree of  
Master of Science in Financial Mathematics

Department of Mathematics

University of Moratuwa  
Sri Lanka

October 2009

University of Moratuwa



102484

51"09"  
336:51(043)

TH

102484

102484


---

## 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.

### *UOM Verified Signature*

I Mahakalanda   
(07/8501)

30.09.2010

Date

We endorse the declaration by the candidate.

### *UOM Verified Signature*

.....  
Dr. P.D. Nimal  
(Supervisor)  
Senior Lecturer



University of Moratuwa, Sri Lanka  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

30.09.2010

Date

Department of Finance,  
Faculty of Management Studies and Commerce  
University of Sri Jayawardena pura

### *UOM Verified Signature*

.....  
Prof. R. A. Attalage  
(Co-supervisor)  
Department of Mechanical Engineering  
Faculty of Engineering  
University of Moratuwa

30.09.2010

Date

---

## 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.

---

## ACKNOWLEDGEMENT

---

The work of this nature would not realise with out the help and kindness of many individuals mentioned below. Appreciations to those who contributed in one way or the other to make my effort successful: my supervisor, Senior Lecturer, Department of Finance, University of Sri Jayawardenapura Dr. P D Nimal and co-supervisor, Prof. R A Attalage attached to Department of Mechanical Engineering, University of Moratuwa for their continuous guidance, commitment and for their valuable time. My gratitude goes to Dr. Chandana Perera for his time and efforts spent to finding a supervisor for my research.

I am grateful to Dr. Vathsala Wickramasinghe for all the guidance and support rendered. I greatly appreciate Dr. Thilak Siyambalapitiya for making available necessary data for my research and Mr. Darshana Mudalige for diligent support provided. I should also like to thank Mr. Rohana Dissanayaka, Mr. T M J Cooray for their support and guidance. I thank my examiners for providing constructive comments on my study.

Finally, I wish to express thanks to my wife who is my best friend for encouraging me and taking care of family matters and my parents for all their support throughout my life.



University of Moratuwa, Sri Lanka  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

## TABLE OF CONTENTS

DECLARATION.....	ii
ABSTRACT.....	iii
ACKNOWLEDGEMENT.....	iv
TABLE OF CONTENTS .....	vi
LIST OF TABLES.....	vi
LIST OF FIGURES.....	v
LIST OF EQUATIONS.....	vi
LIST OF ACRONYMS.....	vi
LIST OF SYMBOLS.....	vi
INTRODUCTION.....	1
1.1 BACKGROUND.....	1
1.3 CONTEXT OF THE PROBLEM AND OBJECTIVES.....	5
1.4 METHODOLOGY.....	6
1.5 SCOPE AND LIMITATIONS.....	6
1.6 SIGNIFICANCE.....	7
1.7 CHAPTER OUTLINE.....	8
LITERATURE REVIEW.....	9
2.1 INTRODUCTION.....	9
2.2 FUNDAMENTALS OF PORTFOLIO THEORY: THE EFFICIENT PORTFOLIO SET WHEN ALL SECURITIES ARE RISKY. ....	10
2.3 INTERPRETING CORRELATION COEFFICIENT.....	14
2.4 PORTFOLIO THEORY AND ENERGY.....	18
2.6 MODEL DESCRIPTION: MEAN VARIANCE PORTFOLIO FRAMEWORK FOR POWER SYSTEM PLANNING.....	19
2.7 PORTFOLIO FRAMEWORK FOR POWER SYSTEM PLANNING.....	21
2.8 ASSUMPTIONS AND LIMITATIONS.....	22
2.9 DETERMINATION OF CONSTRUCTS AND VARIABLES.....	22
2.10 PORTFOLIO CHOICE.....	26
2.11 ENVIRONMENTAL RISK AND SOCIETAL RISK.....	34
2.12 CHAPTER SUMMARY.....	35
SECTOR HIGHLIGHTS - SRI LANKA ELECTRICITY GENERATION.....	37
3.0 INTRODUCTION.....	37
3.1 SECTOR REVIEW - FROM 1990 TO 2008.....	38
3.2 GENERATION EXPANSION PLANNING.....	40
3.4 SRI LANKAS' RENEWABLE ENERGY POLICY.....	44
3.5 CHAPTER SUMMARY.....	45
METHODOLOGY.....	46
4.1 INTRODUCTION.....	46
4.2 CONCEPTUAL FRAMEWORK.....	46
4.3 METHODS OF DATA COLLECTION.....	50
4.4 METHODS OF EVALUATING VALIDITY AND RELIABILITY OF DATA.....	52
4.5 METHODS OF DATA ANALYSIS.....	53
4.6 CHAPTER SUMMARY.....	54
DATA ANALYSIS AND SCENARIO DESIGN.....	55
5.0 INTRODUCTION.....	55
5.1 PORTFOLIO RISK ESTIMATION FOR SRI LANKA ELECTRICITY GENERATING MIXES .....	55

5.2	SCENARIO DESIGN: PORTFOLIO ANALYSIS AND INTERPRETATION OF GRAPHICAL OUTPUT .....	66
5.3	ELECTRICITY GENERATION PORTFOLIO OPTIMIZATION USING INDIFFERENCE CURVES FOR SRI LANKA.....	72
5.4	SOCIETAL RISKS AND ENVIRONMENTAL RISKS.....	75
5.7	CHAPTER SUMMARY .....	79
	SUMMARY OF FINDINGS AND DISCUSSION .....	80
6.0	INTRODUCTION: INTERPRETATION OF FINDINGS VERSUS OBJECTIVES .....	80
6.1	OBJECTIVE 01: DETERMINATION OF EFFICIENT ELECTRICITY GENERATION PORTFOLIO .....	80
6.2	OBJECTIVE 02: ESTIMATION OF ENVIRONMENTAL/SOCIETAL RISK .....	82
6.3	OBJECTIVE 03: TO EVALUATE THE SENSITIVITY OF RISK AND EXPECTED COST WHEN DECIDING TO INCORPORATE NEW POWER GENERATING TECHNOLOGY TO EXISTING PORTFOLIO .....	86
	CONCLUSIONS AND FURTHER RESEARCH.....	87
7.0	INTRODUCTION.....	87
7.1	CONTRIBUTIONS OF THE STUDY .....	87
7.2	CONCLUSIONS .....	87
7.3	IMPLICATIONS .....	88
7.4	FURTHER RESEARCH.....	89
	REFERENCES .....	90
	APPENDIX A1: ELECTRICITY GENERATING PORTFOLIO.....	92



University of Moratuwa, Sri Lanka.  
 Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

## LIST OF TABLES

<b>Table 2.1 Correlation coefficients for different technologies</b>	<b>26</b>
<b>Table 2.2. Variance-covariance matrix</b>	<b>26</b>
<b>Table 3.1 Capacity shares</b>	<b>39</b>
<b>Table 3.2. Generation expansion plan 2008 -capacity additions</b>	<b>43</b>
<b>Table 3.3. NCRE Parameters</b>	<b>44</b>
<b>Table 3.4. Generating technologies and their state of maturity</b>	<b>44</b>
<b>Table 3.5. Energy share of each generation technology</b>	<b>45</b>
<b>Table 4.1. Secondary data sources and description of data acquired</b>	<b>51</b>
<b>Table 5.1. Cost of fuel types used for different plants</b>	<b>56</b>
<b>Table 5.2. Historic fuel prices</b>	<b>56</b>
<b>Table 5.3. Holding period return for different fuel types</b>	<b>57</b>
<b>Table 5.4. Covariance-variance matrix of different fuel types</b>	<b>60</b>
<b>Table 5.5. Estimated fuel correlation matrix</b>	<b>61</b>
<b>Table 5.6. Economic attributes of existing generation plants</b>	<b>63</b>
<b>Table 5.7. Estimated economic costs of candidate plants</b>	<b>63</b>
<b>Table 5.8. Covariance - Variance matrix for generating technologies</b>	<b>64</b>
<b>Table 5.9. Present and future generation mix</b>	<b>65</b>
<b>Table 5.10. Resource Limitations</b>	<b>66</b>
<b>Table 5.11. Possible generating portfolios</b>	<b>69</b>
<b>Table 5.12. Feasible, 2008 and 2019 electricity generating portfolios</b>	<b>71</b>
<b>Table 5.13. Expected cost, standard deviation and b</b>	<b>72</b>
<b>Table 5.14. Life cycle emission for different generating mixes</b>	<b>77</b>
<b>Table 6.1. Proposed emission standards for larger plants</b>	<b>83</b>
<b>Table 6.2. GHG emissions per capita</b>	<b>84</b>
<b>Table 6.3. Capacity shares, H index and Variance</b>	<b>85</b>

## LIST OF FIGURES

Figure 2.1 The principle of diversification	9
Figure 2.2. Mean-standard deviation portfolio frontier: risky assets only	13
Figure 2.3. Perfectly positively and negative correlated returns	14
Figure 2.4. Risk and return for two-asset portfolio given different correlation coefficients	16
Figure 2.5. Possible risk-cost impacts    Figure 2.6. Portfolio combinations for available m-assets	16
Figure 2.7. An illustration of a revenue efficient frontier	17
Figure 2.8. Markowitz efficient frontier	17
Figure 2.9. Risk-return diagram	18
Figure 2.10. An illustration of a cost efficient frontier	20
Figure 2.11. Cost-risk diagram	20
Figure 2.12. Variables of the study	23
Figure 2.13. Wealth and utility	28
Figure 2.14. Characteristics of the functions with different risk-aversion coefficients	28
Figure 2.15. Indifference curves for a risk-averse investor	29
Figure 2.16. Indifference curves for different type and risk averse investors	30
Figure 2.17. Optimal portfolio selection	30
Figure 2.18. Mean and variance of four alternatives	31
Figure 2.19. Energy portfolio choice	34
Figure 2.20. Life Cycle CO <sub>2</sub> emissions	35
Figure 3.1. Growth rates of GDP and Electricity sales	37
Figure 3.2. Gross electricity generation	38
Figure 3.3. Energy generation by source (GWh) – 2002 and 2003	40
Figure 4.1. Conceptual Model developed for the study	47
Figure 4.2. Electricity generating portfolios	48
Figure 4.3. Efficient electricity generating portfolios	48
Figure 4.4 Determination of optimal portfolio	49
Figure 4.5. Optimal electricity generating portfolio	49
Figure 4.6. Sensitivity analysis	50
Figure 5.1. NAPHTHA price trends	57
Figure 5.2. Holding period returns for NAPHTHA	58
Figure 5.3. GAS Oil price trend	58
Figure 5.4. Holding period returns for GAS Oil	58
Figure 5.5. HFO trend	59
Figure 5.6. Holding period returns for HFO	59
Figure 5.7. Holding period returns for Coal	60



<b>Figure 5.8. Fuel use for electricity generation</b>	<b>61</b>
<b>Figure 5.9. Gross generation by fuel type</b>	<b>62</b>
<b>Figure 5.10. Coal price trend</b>	<b>65</b>
<b>Figure 5.11. Expected cost versus standard deviation for 3 technologies</b>	<b>67</b>
<b>Figure 5.12. MATLAB window - Constructing efficient frontier</b>	<b>67</b>
<b>Figure 5.13. MATLAB window - Efficient portfolios</b>	<b>68</b>
<b>Figure 5.14. MS Excel Solver output</b>	<b>70</b>
<b>Figure 5.15. Combinations of electricity generating technologies</b>	<b>71</b>
<b>Figure 5.16. Indifference curves in mean variance plane</b>	<b>74</b>
<b>Figure 5.17. Life Cycle CO<sub>2</sub> emissions</b>	<b>76</b>
<b>Figure 5.18. CO<sub>2</sub> emissions for different portfolios</b>	<b>77</b>
<b>Figure 5.19. Portfolio CO<sub>2</sub> emissions, Expected cost and Risk</b>	<b>78</b>
<b>Figure 6.1. National ambient air quality standards</b>	<b>83</b>
<b>Figure 6.2. Behaviour of H value against Standard Deviation</b>	<b>85</b>
<b>Figure 6.3. Sensitivity analysis</b>	<b>86</b>



## LIST OF EQUATIONS

Equation 2.1	$\min \omega^T \Omega \omega$ .....	11
Equation 2.2	$L = \omega^T \Omega \omega + \delta_1(\mu_p - \omega^T \mu) + \delta_2(1 - \omega^T \mathbf{1})$ .....	11
Equation 2.3	$2\Omega \omega - \delta_1 \mu - \delta_2 \mathbf{1} = \mathbf{0}$ .....	11
Equation 2.4	$\omega_p = \mathbf{g} + \mathbf{h} \mu_p$ .....	11
Equation 2.5	$\sigma^2 = \frac{C\mu^2 - 2A\mu + B}{D}$ .....	12
Equation 2.6	$\frac{d^2 \sigma^2}{d\mu^2} = \frac{2C}{D} > 0$ .....	12
Equation 2.7	$\sigma = \sqrt{\frac{C\mu^2 - 2A\mu + B}{D}}$ .....	12
Equation 2.8	$\mu = \bar{\mu} + \frac{1}{C} \sqrt{DC(\sigma^2 - \bar{\sigma}^2)}$ .....	12
Equation 2.9	$\text{Cov}(R_p, R_r) = \frac{C}{D} \left( \mu_p - \frac{A}{C} \right) \left( \mu_r - \frac{A}{C} \right) + \frac{1}{C}$ .....	13
Equation 2.10	Holding period return, $r_t = \frac{EV_t - BV_t - CF_t}{BV_t}$ .....	21
Equation 2.11	$\sigma_k^2 = (\omega_k^C \sigma_k^C)^2 + (\omega_k^F \sigma_k^F)^2 + (\omega_k^{O\&M} \sigma_k^{O\&M})^2$ .....	21
Equation 2.12	.....	22
Equation 2.13	Levelised cost calculation.....	24
Equation 2.14	Single index portfolio selection.....	27
Equation 2.15	Cut-off rate.....	27
Equation 2.16	Percentage of investment in each security.....	27
Equation 2.17	Expected utility.....	31
Equation 2.18	Mean of mix strategy $a_Q$ .....	32
Equation 2.19	Variance of mix strategy $a_Q$ .....	32
Equation 2.20	$U = \mu - b_0 \sigma^2 + b_1 M_3 - b_2 M_4 + b_3 M_5 - \dots$ .....	33
Equation 2.21	$M_n = \frac{n!}{2^n \left( \frac{n}{2} \right)!} \sigma^n$ .....	33
Equation 2.22	$U = E(x) - f(\sigma^2)$ .....	33
Equation 3.1	$B_j = \sum_{t=1}^T (\overline{I_{j,t}} - \overline{S_{j,t}} + \overline{F_{j,t}} + \overline{L_{j,t}} + \overline{M_{j,t}} + \overline{O_{j,t}})$ .....	42
Equation 3.2	Minimum $B_j$ among all $j$ .....	42
Equation 3.3	Calculation of Capital investment costs and salvage value.....	42
Equation 3.4	Fuel cost calculations.....	43
Equation 3.5	Fuel inventory cost.....	43
Equation 3.6	Operations and maintenance costs.....	43
Equation 4.1	$\min \omega^T \Omega \omega$ .....	48

**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**

$\mu$	Expected cost, mean
$\sigma$	Standard deviation
$\omega$	Weights
$\Omega$	Covariance matrix
$EV_t$	Previous value
$BV_t$	Current value
$\delta$	Lagrange multipliers