THE ROLE OF NUCLEAR POWER IN DIVERSIFYING ELECTRICITY FUEL

BY

ARNAN JUFAIN ALQAHTANI

A Thesis Presented to the

DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

In

ELECTRICAL ENGINEERING DEPARTMENT

May, 2013

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN 31261, SAUDI ARABIA

DEANSHIP OF GRADUATES STUDIES

This thesis, written by **ARNAN JUFAIN ALQAHTANI** under the direction of his thesis advisor, and approved by all thesis committee, has been presented to and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING.

Thesis Committee:

Dr. Ibrahim M. El-Amin (Advisor)
Professor, EE Dept.

Dr. Ali A. Al-Shaikhi
EE Department Chairman

Dr. Mohammad A. Abido (Member)
Professor, EE Dept.

Dr. Salam A. Zummo
Dean of Graduate Studies

عمادة الدراسات العليا
DEANSHIP OF GRADUATE STUDIES

3/9/13

Date

Dr. Ibrahim O. Habiballah (Member)
Associate Professor, EE Dept.

بسم الله الرحمن الرحيم

وقل رب زدني علما

Dedicated To

My mother, my wife and my new born son "Sattam".

Acknowledgements

Foremost, all the praise is for Allah, the Lord of the world. I must thank God for giving me the ability to think and write. It would not have been possible to write this master thesis without the help and support from Allah.

Next, I would like to express my sincere gratitude to my advisor Prof. Ibrahim El-Amin for the continuous support of my thesis study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my thesis study.

Besides my advisor, I would like to thank the rest of my thesis committee: Dr. Mohamed Abido and Dr. Ibrahim Habiballah for their encouragement and insightful comments. I also thank all of teachers who taught me in the university.

My greatest appreciation and friendship goes to my closest friend, Ibrahim Al-Beshri, from AFIT University, for his continuous encouragement and providing me by valuable sources to my references. In addition, I would like to thank my two friends Fahad Al-Qahtani and Saleh Abu Salmeen for helping me in the software program (MATLAB).

Finally, I must thank my parents for supporting me throughout all my studies at University and supporting me spiritually throughout my life. I would like to thank all my brothers, especially Saeed “Abu Najd”, for his continuous support and praise. From my heart, I would like to thank my wife for her personal support and great patience at all times. Without whose love, support, and continued patience, my contribution to this thesis would not be possible.

Table of Contents

List of Figures

List of Tables

Nomenclature

M-V	Mean-Variance
MVP	Mean-variance portfolio
LDC	Load Duration Curve
SS	Study System
LCOE	Levelized Costs of Electricity
T	Economic life of the plant
r	Discount rate
C_t	Fixed capital investment (overnight & OM) expenditures in period t
$F_{\ t}$	Expenses for fuel in period t
OM_t	Expenses for operation and maintenance in period t
e_t	Electricity generated in period t
GHG	Greenhouse Gas
IEA	International Energy Agency ()
WNA	World Nuclear Association
SEC	Saudi Electric Company
HFO	Heavy Fuel Oil
NG	Natural Gas
LCR	Light Crude Oil
GWh	Giga Watt hour
MWh	Mega Watt hour
NPP	Nuclear Power Plant

CP	Capacity Factor
LF	Load Factor
σ_i	Standard deviation of fuel i.
σ_j	Standard deviation of fuel j.
σ_{ij}	Standard deviation of fuels i and j
r_{ij}	Correlation coefficient for fuels i and j
I	Technology Type
L	Load Type
F_{ni}	Fixed cost for technology I fuel
V_i	Variable fuel cost for technology I
LF_{il}	Load Factor for technology I and load type L
OM_i	Operation and Maintenance Cost for technology I
ye_{il}	Existing energy from technology I to supply load L
yn_{il}	The new energy from technology I to supply load L
σ_{ij}	Covariance between prices of I & J
U_i	Exiting capacity for technology I
D_L	Load Type L
β	Risk aversion. $\beta = 0 \rightarrow \infty$
V_{CO2}	Costs per unit resulted from carbon emission
SE_i	Costs per unit resulted from Safety Element for technology I
WF	Weighted Factor for safety

THESIS ABSTRACT (ENGLISH)

Name: ARNAN JUFAIN ALQAHTANNI

Title: THE ROLE OF NUCLEAR POWER IN DIVERSIFYING ELECTRICITY FUEL

Degree: MASTER OF SCIENCE

Major Field: ELECTRICAL ENGINEERING

Traditional electricity planning processes focus on finding the least-cost generating alternative. However, at current dynamic and uncertain environment, it is almost impossible to correctly identify the long term planning using the least cost options. To account for such issues, portfolio theory has found its way in numerous applications in optimizing the electricity generation mix. The portfolio model used is avoiding utilization of standard Mean-Variance (M-V) portfolio where load variation is discounted. The portfolio proposes mean-variance portfolio analysis using the decomposition of the load into various types and utilizing the load factors of each load type. This thesis uses an enhanced mathematical model that has ability to analyze portfolio method in diversifying fuel technologies for electricity generation in purpose of long term planning. The resulting fuel diversity mix may include nuclear energy as an option. It shows that including the nuclear energy into the fuel mix is desirable and gives betters results regarding costs and reliability.

MASTER OF SCIENCE DEGREE
KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS
Dhahran, Saudi Arabia
2013

ملخص الأطروحة (عربي)

الاسم: عرنان جفين جليغم القحطاني

عنوان الأطروحة: دور الطاقة النووية في تنوع الوقود لانتاج الكهرباء

الدرجة: ماجستير في العلوم الهندسية

التخصص: الهندسة الكهربائية

سنة التخرج: ٢٠١٣

تركز عمليات التخطيط التقليدية لانتاج الكهرباء على إيجاد الوقود البديل الأقل تكلفة توليد فقط دون اي اعتبارات اخرى. ولكن في بيئة ديناميكية وغير واضحة المعالم مستقبلا يكاد يكون من المستحيل تحديد التخطيط الدقيق على المدى الطويل بشكل صحيح باستخدام طرق الأقل تكلفة فقط. وللحصول على نتائج ادق في تخطيط الامد البعيد لانتاج الاحتياجات من الكهرباء، لقد وجدت نظرية المحفظة (تنوع الوقود) و اثبتت جدواها في العديد من التطبيقات في تحقيق الاستفادة المثلى من مزيج وقود انتاج الكهرباء. طريقة المحفظة (تنوع الوقود) المستخدمة في نتائج هذه الاطروحة قد تفادت عيوب طريقة المحفظة التقليدية حيث لا يوخذ اعتبارات اختلاف الاحمال. فلقد تم استخدام طريقة تحليل المحفظة المقترحة وتطبيقها على أنواع مختلفة من الاحمال. إذا هذه الأطروحة تعتمد في نتائجها على طريقة المحفظة (تنوع الوقود) المطورة واللتي لها القدرة على تحليلمزيج من وقود توليد الكهرباء في أغراض التخطيط على المدى الطويل مع الاخذ في الحسبان شكل الأحمال المختلفة والمتوقعة في المستقبل. أيضا في هذه الأطروحة سوف يتم ايضاح جدوى اضافة وقود الطاقة النووية لمزيج الوقود السابق ذكره. فقد اظهرت النتائج ان ادخال الطاقة النووية كعنصر في مزيج الوقود أمر ينصح به وذلك لانه يقدم نتائج أفضل فيما يتعلق بالتكاليف والدقة.

ماجستير في العلوم الهندسية

جامعة الملك فهد للبترول والمعادن

الظهران، المملكة العربية السعودية

٢٠١٣

CHAPTER 1

INTRODUCTION

1.1 Background

Electrical energy demand and consumption represent important problems at a global scale. Global demand for energy is growing dramatically. The International Energy Agency (IEA) estimated a continuous growth in the demand of energy. According to latest “World Energy Outlook” published by (IEA), the global demand would reach 11.5 terawatts, by 2030. Furthermore, IEA estimated an average annual growth rate of 1.6%. The (IEA) expects the global energy consumption will grow by about 70% in the coming 25 years. This requires 55% more energy generation than today. The increasing trend in world energy use can be attributed to two main reasons: a growing world population and developing industrial countries.

Nearly all power plants are fueled by fossil fuel. Today about 86% of world electricity is produced from highly carbon-intensive fossil fuels, namely coal, oil and gas. Fossil fuels will continue to dominate energy supplies, meeting more than 80% of the projected increase in primary energy demand. On the other hand, the fossil fuel is subject to significant price fluctuations, fuel scarcity, and recent high oil/gas prices; and also the pollution caused by fossil fuels. These lead to major concerns worldwide. The concerns are related to fuel availability and its volatility. These will impact the quantity of energy fuel technology and its cost.

Moreover, the pollution caused by fossil fuels is a major source of concern worldwide. Fossil fuels give off carbon dioxide when burned thereby causing a greenhouse effect. This is also the main contributory factor to the global warming experienced by the earth today. The increase in emissions of CO2 is projected to increase dramatically in the next 20 years if utilities continue to increase the production of energy through the burning of fossil fuels. For this reason, many initiatives are taken to reduce energy generation from fossil sources; such diversifying the energy portfolio, and reducing costs of energy supplies, with lower greenhouse gas emissions.

No individual fuel is capable of providing the energy to meet all of all electricity demands. That is because certain fuels in the electricity generation mix are better suited than others for particular applications. A variety of fuels is needed as a key to affordable and reliable electricity. A diverse fuel mix protects electric companies and consumers from contingencies such as fuel unavailability, price fluctuations, and changes in regulatory practices. Given high and rising energy fuel prices (i.e. fossil fuel); observers often point to improving fuel diversity as well as energy independence as a way to mitigate the impacts of recent price increases on consumers.

Fuel diversity is a critical component of the reliable and efficient operation of wholesale electricity systems. It identifies options to address fuel diversity that are both well and poorly aligned with electricity markets. Fuel diversity in electricity generation is critical to the success of a sustainable grid, and nuclear power can and should play a key role in producing clean, baseload energy for nations.

The uranium fuel for nuclear plants is abundant and readily available in many places over the world, and is low in cost. The fuel for a nuclear plant is a much smaller component of operating costs compared to that of coal-fired or natural gas-fired plants. Prices for milled uranium tend to have almost no volatility.

This Thesis is motivated by interest in using the technique of diversifying fuel portfolio in order to overcome inadequacies of fossil fuel. It also presents a high-level vision and framework for activities needed to keep the nuclear energy option viable in the near term and to expand its use in the decades ahead

1.2 Thesis Motivation

Just one case for global power demand growth mentioned above, electricity consumption rates in Saudi Arabia have been gradually on a rise over the past three decades. While the population of about 26 million is growing at a rate of 3%, the growth in total number of power utility customers is increasing at a higher rate of 5%. Between 2010 and 2011, the Saudi Electric Company, SEC reported an 11.9% growth in total peak loads, which reached 41.49 GW in 2010.

In order to supply this large demand needs, Saudi Arabia needs to expand its power capacity and networks. The total actual generation capacity reached 50 GW by the end of 2012. This power generation capacity needs fuel consumption of approximating 53 million Ton of Oil Equivalent (TOE). This is equivalent to an estimated consumption of 1.07 million barrels of oil per a day. In addition to the large oil consumption, gas consumption for power generation grew by 49% to reach 22,095 million cubic meters in 2011.

Studies show that power demand in Saudi Arabia is expected to continue its rapid increase to reach 120 GW over the coming 20 years. For this reason, Saudi government pays attention to renewable and nuclear energy to meet expected power demand in future. One step in this regards, it announced establishment of King Abdullah City for Atomic and Renewable Energy (KA_CARE) in April 2010.The main goal for KA_CARE is to make atomic and renewable energy an integral part of the energy mixes. As well, it aims to contribute to sustainable future for Saudi Arabia by developing an alternative energy capacity.

The primary focus of KA_CARE activities is the introduction of sustainable energy to Saudi Arabia's energy mix. Detailed studies were undertaken that indicate the most sustainable sources of renewable energy for the Kingdom are photovoltaic and concentrated solar power, geothermal, wind energy and substantial component of nuclear energy.

1.3 Thesis Objective

The main objective of this research is to develop and use an enhanced mathematical model that has the ability to formulate and analyze a portfolio of fuel technologies for electricity generation in the context of long term planning. The resulted fuel diversity mix includes Nuclear Energy as an option. The model used in this thesis will avoid utilization of standard Mean-Variance (M-V) portfolio where load variation is discounted. It accounts for the load variety by assigning load factor for each load type. Therefore, the goal is to dispatch a mix of fuel technologies to meet different load requirements. The overall objective of this thesis can be highlighted as follows:

i. To use the advanced Mean-Variance (M-V) portfolio method to determine the optimum fuel technology mix to serve different load types.
ii. To show the influence of nuclear energy on any generation fuel portfolio (mix).
iii. To test the model with an analysis for two (2) study systems data in the year 2020.

1.4 Problem Statement

This thesis is concerned on the utilization of M-V portfolio to analyze electricity generation fuel technology mix in order to meet future power demands. The approach used gives many generation mixes of fuel technology and load type. The optimum mix achieves a good balance between cost associated with production (mean cost) and cost associated with mix variation risk (variance cost). Depending on the availability of the fuel technology forms and all related costs factors balance, generating technology units are assigned to supply each load type separately. By this, the study aims to determine each technology type percentage (level) in the generation mix that assigned to meet each load type, provided the production and risk costs are minimized. By minimizing the mean and variance of costs related to each technology, the projected power demand is fully served by a generation from both existing and new units. Load diversification is taken into consideration in the analysis of estimating each unit of generation level; and in determining how each unit generation cost contributes to the total generation costs. Therefore, the technologies represent the generating units and related costs are given by how units are utilized over load profile. It is assumed that the existing units have only the operational costs, where the new units for planning have both fixed and variable costs. For this reason, production costs for exiting units reflect variable costs only. Thus, existing units generation is subject to a constraints of fixed generating capacity limit. The new units are assumed to be constructed as required even though this can be relaxed.

1.5 Thesis Organization

After this opening chapter, this thesis uses a mathematical model to analyze portfolio method in diversifying fuel technologies for electricity generation as a purpose for long-term planning. Chapter 2 summarizes related literature survey for the standard M-V portfolio study if used in long term power generation planning. It will also discuss the role for nuclear energy in the power generation planning.

Chapters 3 & 4 give a brief overview about the mean variance portfolio approach and nuclear energy, respectively, and its role in the long term power generation planning.

Chapter 5 presents the model used for analyzing proposed M-V portfolio in generation planning. In this model, the Load Duration Curve (LDC) is segmented to three (3) load types: base, cycling and peak using load factors.

Chapter 6 covers two main sections. In the first section, data is analyzed and manipulated for the first study system (SS01). The second Study System (SS02) data is analyzed in the second section.

Chapters 7 & 8 summarize the results for fuel diversification studies for study systems SS01 & SS02 respectively. Sequences of scenarios are presented to report possible situations of the future may expose. One scenario represents a normal situation. One more scenario will present the effect of adding nuclear energy technology to the generation mix. Another scenario reflects the effect of carbon dioxide emissions. The final scenario is when safety of power plants is taken into consideration.

Chapter 9 includes the conclusion and suggestions for future work. It will summarize the outcome from the model developed in this thesis.

CHAPTER 2

LITERATURE SURVEY

This chapter provides a brief literature review on subjects that are closely related to the thesis subject.

2.1 Electric Power Planning

Long-term generation planning is a key issue in the operation of an electricity generation company. Its results are used both for budgeting and planning fuel acquisitions and to provide a framework for short-term generation planning. The long-term problem is an optimization problem because several of its parameters are only known as probability distributions (for example: load, availability of thermal units, hydrogenation and generations from renewable sources in general) [1]. A long-term planning period (e.g., a year) is normally subdivided into shorter intervals (e.g., a week or a month), for which parameters (e.g., the load-duration curve) are known or predicted, and optimized variables, such as the expected energy productions of each generating unit must be found [2].

2.2 The Uncertainty of Fossil Fuel Prices

The experiences of the past years have shown how drastic fluctuations in oil and other fossil fuel prices are and how difficult it can be to forecast them. Not only an actual supply-demand situation but also the influence of assumption has been pointed out as a cause of price fluctuations [3]. This raised the level of risk in evaluating fuel needs.

The cost risk has an effect on the value of energy production assets and the relative competitiveness of the fuel type. For a choice between fuel types, rational investors must take this uncertainty into account [4]. The decision maker who wants to add a power station to the generation capacity must take into account the different degrees of uncertainties associated with fuels. The higher uncertainty of fossil fuel prices makes the introduction of nuclear power into generating planning a hedge against this uncertainty [4-5]. Even if nuclear power generation has become economical; will it be possible to fill in the fossil fuel gap?

2.3 Electricity Generation Costs

The investment in long-term generation planning is usually developed by an experienced organization usually owned by national governments. Numerous reasons may lead to significant changes in electricity prices across the geographical areas over the world. Long term generation planning is a development for identifying a production capacity mix that is sufficient to serve projected power demand requirements with trying to minimize generation costs and their variability. In long term planning for electricity generation proposals, the following costs are usually accounted [5-6].

1. Fixed costs:
    a. Capital fixed costs (overnight costs).
    b. Operation and maintenance (O&M) fixed costs.
2. Variable costs:
    a. Operation and maintenance (O&M) variable costs.
    b. Fuel variable costs.

The above cost components are dependent on a specific project, fuel technology used and site of the generating units. Future generation mix planning includes choosing desired technologies and estimating capacity investments. Making a decision in the generation planning process depends on several economic factors. Examples of these factors are environment issues, national security, and public opinion. Mainly, cost factors have the major impact on making decision for selecting the targeted fuel or technology type in electricity gentian investment [5]. The ideal generation mix is the one that is operating economically at fairly minimum fixed and variable costs and has mostly stable (no variation) fuel costs [4].

Fixed capital costs, sometimes called “overnight costs" are acquired while the power plant is still in the construction period. Estimation of fixed costs per electricity generation unit needs assumptions about plant life, discount rate, and capacity factor [6]. The capital and overnight costs both include expenses on equipment technology, engineering and civil work, and labor. However, overnight costs exclude financing costs, such as interest, incurred during construction and other marginal costs such as land purchase and development [4-6]. Fixed O&M costs are associated to major and periodic maintenance of the plant equipment, building or site and safety programs, and are usually charged as annual fixed expenses on the capital costs [6-8]. In this thesis the expression `fixed cost' represents fixed capital and fixed O&M costs combined.

Variable costs of O&M are expenses on maintenance because of unscheduled plant outages and other costs incurred by hourly plant operations. Fuel costs directly vary with plant output and can change considerably through time [4-8].

The fuel costs constitute a considerable portion of the production total cost, specifically in case of using conventional thermal units such as coal, natural gas, and oil. For this reason, fuel costs play an important part on the variations of the generation unit's cost. Because of variations between fuel types used and technologies, approximations of factors such as fuel cost, heat rate, and the heat content of each unit fuel, are needed to estimate variable costs per unit of electricity.

Base loads are generally satisfied by new and higher efficiency units that have fairly high fixed costs and low variable costs. Such plants are coal fired or nuclear-powered [4,7]. On the other hand, the peak load is served by older and lower efficient units having lower fixed costs and higher variable costs, such as those run on combustion turbine units.

The levelized cost and standard M-V portfolio methods, do not adequately account for all full set of economic benefits and concerns such as the load variety. For this reason, this thesis aims to use an improved M-V portfolio analysis because it is more applicable for planning electricity generation mixes [4-6].

2.4 Levelized Costs of Electricity (LCOE)

The levelized cost of electricity (LCOE) is a process for converting the present value of the total cost of constructing, operating and maintenance costs over its economic lifetime to a constant of annual payment. [6]. The main goal for levelized cost is to compare between different technologies based on generation costs for each technology unit; the lower cost is better. It does not account for any criteria other than the production cost. It can be calculated by computing all capital and variable costs on a uniform annual basis over the entire plant life time and then adding it to annual fixed O&M and fuel costs [6, 7].

Different papers show levelized cost for different technologies and they provide comparison among them by plants [6-8]. All papers used the approach to evaluate the levelized cost considering investment, fuel and operation and maintenance costs, making expectations for the energy market, and taking into consideration the fuel prices projections.

In the case of new nuclear energy plants, it is essential to pay special attention to the financial strategy that will be applied, time of construction, investment cost, and the discount and return rate. The levelized cost counts the unit cost of the electricity (kWh) generated during the lifetime of the nuclear power stations. Then it is compared with the cost of other alternative technologies cost [7-8].

2.5 The Economics of Nuclear Power

Nuclear energy is, in many places, competitive with fossil fuel for electricity generation, despite relatively high capital costs and the need to consider waste disposal and decommissioning costs. If the social, health and environmental costs of fossil fuels are also taken into account, nuclear is outstanding [3].Fuel costs for nuclear plants are a minor proportion of total generating costs, though capital costs are greater than those for coal-fired plants [4-5].

2.6 Regulatory Risk

Kessides, etal [5], addressed regulatory risk and showed that it must be cited as an inherent characteristic that greatly determines the economics of nuclear power generation. It is hoped that regulatory risk can be decreased by rational and scientific judgment. Nuclear power generation safety regulations should be carefully applied due to the enormous potential hazard that it can represent [5].

2.7 Nuclear Power Generation as Cost Benefits Analysis under Uncertainty

Kessides, etal [5] identified the fundamental elements and critical research tasks of a comprehensive analysis of the costs and benefits of nuclear power relative to investments in alternative base load technologies. These would call for the valuation of the following:

- Environmental benefits: reduced Greenhouse Gas (GHG) emissions to be gained from adding nuclear rather than coal or gas fired generating capacity.
- Fuel mix diversification value of nuclear power as a hedge against uncertain fossil fuel and carbon prices.
- Costs of radioactive waste disposal;
- Risks associated with radioactivity release from all fuel cycle activity;
- Risks of proliferation from the nuclear fuel cycle.
- Financial liabilities arising from the back-end activities of the nuclear fuel cycle e.g. decommissioning and waste management.

2.8 Fuel Diversity

Susan, etal [9] defined the fuel diversity: is adding variety to a power system's fuel and technology mix in order to enable the system to withstand fuel price volatility, fuel supply or delivery disruptions, or technical disturbances on the system.

2.9 Portfolio Theory

Originally, portfolio theory was developed for financial purposes to find optimum portfolios that have maximum expected return at every level of expected portfolio risk [10]. An important point to note is that in electricity generating portfolios, it is more suitable to minimize portfolio generating costs as opposite to portfolio returns as described by Awerbuch [11].

Effective portfolios are defined by the following property:

- They minimize the expected cost (maximize return) for any given level of risk while minimizing expected risk for every level of expected cost (return) [10].

The application of portfolio theory to evaluate and to select risky projects, such as power technology projects, has attracted substantial interest among both academicians and practitioners. There are many papers which are based on the portfolio theory to determine the optimal generating technology portfolio. Awerbuch and Berger [11] apply portfolio theory to identify Europe's best fuel mix at the macro-economic level.

Abdelhamid [3] discussed the application of portfolio theory to the Tunisian electricity generating mix into presence of renewable energy. Jean-Michel, etal used Monte Carlo simulations of gas, coal and nuclear plant investment returns as inputs of a Mean–Variance Portfolio optimization to identify optimal base load generation portfolios for large electricity generators in liberalized electricity markets [12]. The authors studied the impact of fuel, electricity, and CO2 price risks and their degree of correlation on optimal plant portfolios. In presence of high degrees of correlation between gas and electricity prices, it reduces gas plant risk and makes portfolios dominated by gas plant [11].

2.10 Portfolio Theory Based On a Load Factor for Fuel Diversification

Fuel diversification implies the selection of a mix of generation technologies for long-term electricity generation. The goal is to strike a good balance between reduced costs and reduced risk. The method of analysis that has been advocated and adopted for such studies is the mean-variance portfolio analysis [13-14].

The standard mean-variance methodology, does not account for the ability of various fuels/technologies to adapt to varying loads. Such analysis often provides results that are easily dismissed by regulators and practitioners as unacceptable, since load cycles play critical roles in fuel selection. To account for such issues and still retain the convenience and elegance of the mean-variance approach, a variant of the mean-variance analysis using the decomposition of the load into various types and utilizing the load factors of each load type is proposed [11,14].

Shimon Awerbuch [14] compared portfolio approach with the classical method “Least cost” in order to provide the electricity generation planning. For the last decades, least-cost planning is the basic to decide expansion of electricity generating capacity in most countries. Decision makers in generation planning were confident if they add the “least-cost” alternatives, they could expand the system at the lowest cost [14]. In other side, today’s planners face diverse range of technological and institutional options for generating electricity and a future that is highly dynamic, complex, and uncertain. For this reason, attempting to identify the least-cost alternative in this environment is difficult. Thus, more powerful techniques are required if we are to develop generating strategies that remain economical under a variety of uncertain future outcomes [3, 14].

Given the rapidly changing environment, it makes sense to shift electricity planning from its current emphasis of evaluating alternative technologies, to evaluating alternative generating portfolios and strategies. Mean-variance portfolio (MVP) theory is highly suited to the problem of planning and evaluating a nation’s electricity portfolios and strategies [10-14]. Financial investors are used to deal with uncertainty. They have learned that a portfolio of assets provides the best means of hedging future risk. Investors would not conceive of investing all their funds in a single stock on the basis of 30-year performance forecasts.

MVP principles require that planners evaluate the cost of conventional and renewable alternatives not on the basis of their stand-alone cost, but on the basis of their portfolio cost i.e. their contribution to overall portfolio generating cost relative to their contribution to the cost risks of a portfolio of generating resources.

The following chapter discusses the issues related to fuel diversity and application of Mean-Variance Portfolio Theory.

CHAPTER 3

FUEL DIVERSITY

3.1 Background

The concept of managing risk through fuel diversity in the electricity sector has recently gained the attention in many countries [5]. Fuel diversification involves the selection of a mix of electric generation technologies so that a balance is struck between reduced cost and reduced risk in fuel prices. The fuel diversification problem can be addressed in short and long term perspectives [10]. In a short-term perspective, the decision maker is limited to selecting power sources from existing alternatives [13]. The construction of new generation plants and the associated fixed costs are justifiably ignored. The short-term problem translates in most instances to a scheduling problem. On the other hand, the long-term perspective on fuel diversity seeks insights that can help decision-making involved in the selection of new power plants and technology. The long-term problem can be thought of as a resource-planning problem. The focus is on the long-term perspective [14].

Fuel diversity is a critical component of the reliable and efficient operation of wholesale electricity systems. There will be an attempt to explore the significance of fuel diversity and its impact on electricity market. It identifies options to address fuel diversity that are both well aligned and poorly aligned with electricity markets. Then, a plan to address the impact of fuel diversity on electricity generation market is developed.

The mean-variance portfolio optimization approach considers variance as the measure of risk. One first begins with an estimate of the mean, variance and covariance of per unit generation costs incurred in using various technology/fuel combinations. The fixed costs and deterministic operating expenses of setting up the generation unit contribute to the expected cost [9]. The fuel costs and operating costs that are not deterministic affect the mean costs as well as the variance. An optimization problem that seeks a combination of technology/fuel types (including nuclear fuel) is set up to minimize total variance for a given expected cost. The solution of this optimization problem can be traced as a frontier in a mean-variance plot, for various values of expected cost [14]. A rational choice of fuel mix would then be the solution corresponding to any point on this frontier, called the efficient frontier. The exact point depends on the decision maker's risk preference.

Portfolio theory was developed in financial theory where it locates portfolios with maximum expected returns at every level of expected portfolio risks [10]. In the case of electricity planning, the mean variance (MPV) portfolio analysis methodology allows for a broad view of the plant portfolio in terms of risk and cost. Thus the efficient generating portfolios are defined by the property: minimizing the expected cost for any given level of risk while minimizing risk for every level of the expected cost [9-11]. However, we can consider the cost as opposed to return.

Nuclear energy is an important element of the diverse energy portfolio required to accomplish our objectives [12]. Here there is a try to identify opportunities and challenges associated with continued and increased use of fission energy to enhance our nation's prosperity, security, and environmental quality; and present a strategy and analysis to guide the Nuclear Energy scientific and technical agenda.

3.2 Defining Fuel Diversity

Fuel diversity is having a variety of energy sources available. Power generators can spread risk and opportunity across a wide variety of fuels, taking advantage of emerging technologies from price swings for any one particular fuel type [9-12].

From customer point of view, enhancing "fuel diversity" means adding variety to a power system's fuel and technology mix in order to enable the system to withstand fuel price volatility, fuel supply or delivery disruptions, or technical disturbances on the system. Proponents of policies aim to increase fuel diversity because they note that having a variety of fuel sources available for energy needs including electricity, transportation, heating and other uses provides numerous benefits [9-12], such:

- Competition among different fuels to provide the least-cost energy to consumers, resulting in lower overall prices.
- Preventing significant price increases for any particular fuel type.
- An energy system that is less subject to exchange rate fluctuations and geopolitical uncertainties often associated with imported fuels.
- Encouraging the use of original fuels as part of the energy mix, often with significant positive economic and environmental benefits.

3.3 Uncertainty and the Risk

Decisions on capacity expansion are a function of multiple factors. On the demand side, consideration must be given to demand forecasts for total and peak usage which are a function of population projections, the location of projected population growth, and projected economic activity [3]. Unfortunately, forecasts are never perfectly accurate, and deviations may have major risk implications for shareholders and consumers who could bear some of the cost in the long term for a utility's excess or insufficient capacity and for regulators whose appointments are politically determined.

The choice of fuel and generating technology combinations are a function of several factors [3, 5]:

- Projected peak and base load demand growth.
- Fuel price.
- Availability forecasts,
- Expected environmental compliance costs.
- Technology reliability.
- The potential for energy efficiency.

With respect to fuel prices and availability, oil and natural gas have become increasingly volatile in recent years relative to the other competing fossil fuel.

The dominance of gas and oil has led to calls for fuel diversification: coal, nuclear power, renewable energy … etc. However, with respect to potential environmental compliance costs from potential climate change policy, some diversification strategies may appear better than others.

3.4 Efficient Electricity Generating Portfolios

3.4.1 Least-cost Versus Portfolio-based Approaches in Generation Planning

Traditional energy planning focuses on finding the least-cost generating alternative. This approach worked sufficiently well in stable energy prices. However, today's electricity planner faces a broadly diverse range of resource options and a dynamic, complex, and uncertain future. Attempting to identify least-cost alternatives in this uncertain environment is virtually impossible [10]. As a result, more appropriate techniques are required to find strategies that remain economical under a variety of uncertain future outcomes. Levelized cost of energy (LCOE) is given by the following formula [5-6]:

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{T} \frac{C_t + OM_t + F_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{e_t}{(1+r)^t}} \tag{3.1}$$

r = Discount rate	T = Economic life of the plant
C_t = Fixed capital investment (overnight & OM) expenditures in period t	OM_t = Expenses for operation and maintenance in period t,
F_t= Expenses for fuel in period t	e_t= Electricity generated in period t.

From equation (3.1), it is noted that the LCOE method needs estimation of the plant's capacity factor for e_t . This means that the plant is operated with a pre-specified load factor.

Given the uncertain environment, it makes sense to shift electricity planning from its current emphasis on evaluating alternative technologies to evaluating alternative electricity generating portfolios and strategies. The techniques for doing this are rooted in modern finance theory, in particular mean-variance portfolio theory.

Portfolio analysis is widely used by financial investors to create low risk, high return portfolios under various economic conditions. In essence, investors have learned that an efficient portfolio takes no unnecessary risk to its expected return. In short, these investors define efficient portfolios as those that maximize the expected return for any given level of risk, while minimizing risk for every level of expected return.

Portfolio theory is highly suited to the problem of planning and evaluating electricity portfolios and strategies because energy planning is not unlike investing in financial securities where financial portfolios are widely used by investors to manage risk and to maximize performance under a variety of unpredictable outcomes. Similarly, it is important to consider electricity generation not in terms of the cost of a particular technology today, but in terms of its portfolio cost. At any given time, some alternatives in the portfolio may have high costs while others have lower costs, yet over time, an intelligent combination of alternatives can serve to minimize overall generation cost relative to the risk.

In sum, when portfolio theory is applied to electricity generation planning, conventional and renewable alternatives are not evaluated on the basis of their stand-alone cost, but on the basis of their portfolio cost, that is: their contribution to overall portfolio generating cost relative to their contribution to overall portfolio risk.

Portfolio-based electricity planning techniques suggested ways to develop diversified generating portfolios with known risk levels that are commensurate with their overall electricity generating costs. Simply, these techniques help identify generating portfolios that can minimize a society's energy cost and the energy price risk it faces [11].

3.5 Electricity Generating Costs, Risks, and Correlations

3.5.1 Electricity Generating Cost and Returns

Portfolio theory was initially conceived in the context of financial portfolios, where it relates expected portfolio return to expected portfolio risk, defined as the year-to-year variation of portfolio returns. This section illustrates portfolio theory as it applies to a two-asset generating portfolio, where the generating cost is the relevant measure. Generating cost ($/kWh) is the inverse of a return (kWh/$), that is, a return in terms of physical output per unit of monetary input.

3.5.2 Expected Portfolio Cost

Expected portfolio cost is the weighted average of the individual expected generating costs for the two technologies [10]:

$$\text{Expected portfolio cost} = X_1 E\,(C_1) + X_2\,E\,(C_2), \tag{3.2}$$

Where X_1 and X_2 are the fractional shares of the two technologies in the mix, and E (C_1) and E (C_2) are their expected levelized generating costs per kWh.

3.5.3 Expected Portfolio Risk

Expected portfolio risk, $E(\sigma_p)$, is the expected year-to-year variation in generating cost. It is also a weighted average of the individual technology cost variances, as tempered by their covariances [10]:

$$Expected\ portfolio\ risk = E(\sigma_p) = \sqrt{X_1^2\sigma_1^2 + X_2^2\sigma_2^2 + 2X_1X_2\rho_{12}\sigma_1\sigma_2)} \quad (3.3)$$

Where: X_1 and X_2 are the fractional shares of the two technologies in the mix; σ_1 and σ_2 are the standard deviations of the holding period returns of the annual costs of technologies 1 and 2; and ρ_{12} is their correlation coefficient.

3.5.4 Correlation, Diversity, and Risk

The correlation coefficient, ρ, is a measure of diversity. Lower ρ among portfolio components creates greater diversity, which reduces portfolio risk σ_p. More generally, portfolio risk falls with increasing diversity, as measured by an absence of correlation between portfolio components. Adding a fuel-less (that is fixed-cost, riskless) technology to a risky generating mix lowers expected portfolio cost at any level of risk, even if this technology costs more [4]. A pure fuel-less, fixed-cost technology, has σ_i = 0 or nearly so. This lowers, σ_p. Since two of the three terms in equation (3.3) reduce to zero. This, in turn, allows higher-risk/lower-cost technologies into the optimal mix. Finally, it is easy to see that σ_p declines as $\rho_{i,j}$ falls below 1. In the case of fuel-less renewable technologies, fuel risk is zero and its correlation with fossil fuel costs is zero too.

3.6 M-V Portfolio Optimization Basics Applied To Electricity Sector Planning

Expected portfolio generating cost is the weighted average of the individual technology costs. The expected risk of an electricity portfolio – that is, the expected year-to-year fluctuation in portfolio generating cost – is a weighted average of the risks of the individual technology costs, tempered by their correlations or covariances. Each technology, in itself, is characterized by a portfolio of cost streams, comprising capital outlays, fuel expenditures, operating and maintenance (O&M) expenditure, and CO_2 costs. It follows that for each technology, risk is the standard deviation of the year-to-year changes of these cost inputs.

Portfolio theory improves decision making in the following way. First, since the investor only needs to consider the portfolios on the so-called efficient frontier, rather than the entire universe of possible portfolios, it simplifies the portfolio selection problem. Second, it quantifies the notion that diversification reduces risk. For electricity planning, portfolio optimization exploits the interrelationships (i.e., correlations) among the various technology generating cost components.

Take for example fossil fuel prices. Because they are correlated with each other, a fossil-dominated portfolio is undiversified and exposed to fuel price risk. Conversely, renewables, nuclear, and other non-fossil options diversify the mix and reduce its expected risk because their costs are not correlated with fossil prices.

3.6.1 Illustrative Example [11]:

The portfolio diversification effect is illustrated in Figure 3.1, which shows the costs and risks for various possible two-technology portfolios. Technology A is representative of a generating alternative with higher cost and lower risk. It has an expected (illustrative) cost of around €0.10 per kWh with an expected year-to-year risk of 8 percent. Technology B is a lower cost/ higher-risk alternative, such as gas-fired generation. Its expected cost and risk are about € 0.055 per kWh and 12 percent, respectively. The correlation factor between the total cost streams of the two technologies is assumed to be zero. This is a simplification since, in reality, the capital and variable cost of Present Value (PV) will exhibit some non-zero correlation with the capital and variable cost of gas generation.

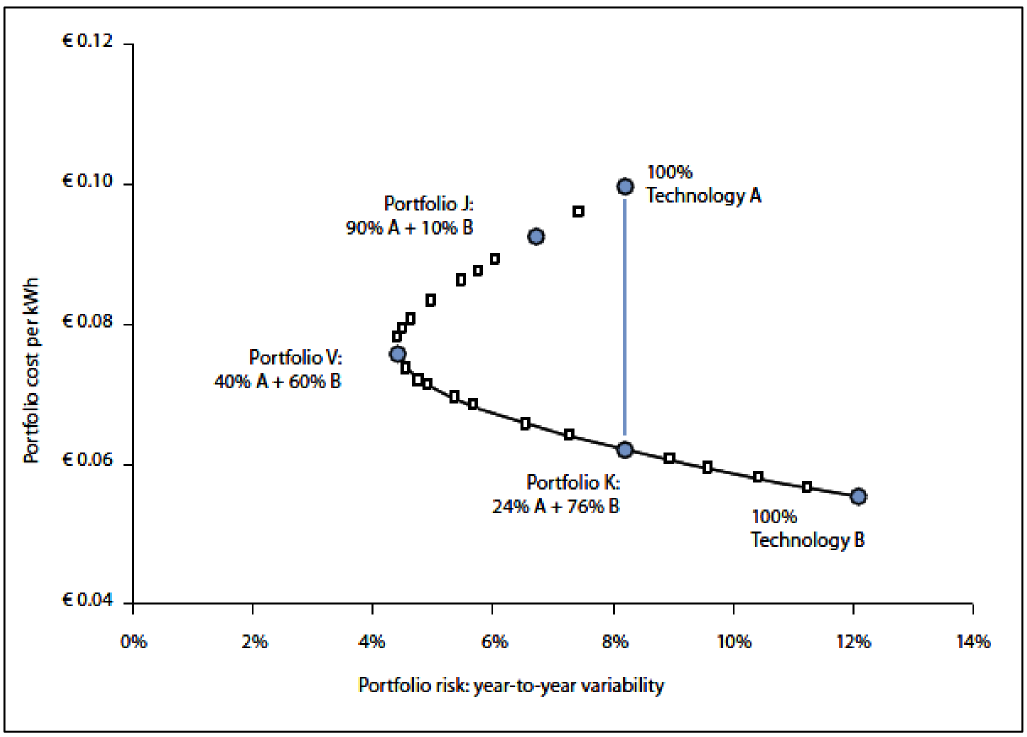

Figure 3.1: Portfolio effect for illustrative two technologies A & B [11]

As a consequence of the portfolio effect, total portfolio risk decreases when the riskier technology B is added to a portfolio consisting of 100 percent A. For example, portfolio J, which comprises 90 percent of technology A plus 10 percent B, exhibits a lower expected risk than a portfolio comprising 100 percent A. This is counter-intuitive since technology B is riskier than A. Portfolio V, the minimum variance portfolio, has a risk of around 4 percent, which is half of the risk of A and one-third of the risk of B. This, however, illustrates the point of diversification.

Investors would not hold any mix above portfolio V because mixes exhibiting the equivalent risk can be obtained at lower cost on the solid portion of the line. Portfolio K is therefore superior to 100 percent A. It has the same risk, but lower expected cost. Investors would not hold a portfolio consisting only of technology A, but rather would hold the mix represented by K. Taken on a standalone basis, technology A is more costly, yet properly combined with B, as in portfolio K, it has attractive cost and risk properties. Not only is the mix K superior to 100 percent A, most investors would also consider it superior to 100 percent technology B. Compared to B, mix K reduces risk by one-third while increasing cost by just 10 percent (€0.005 per kWh), which gives it a higher share ratio than other mixes. Mix K illustrates that astute portfolio combinations of diversified alternatives produce efficient results, which cannot be measured using stand-alone cost concepts.

To summarize, portfolio optimization locates minimum-cost generating portfolios at every level of portfolio risk, represented by the solid part of the line (efficient frontier) in Figure 3.1, that is, the stretch between V and B.

The following chapter gives a brief review of nuclear power and the associated issues of cost and safety.

CHAPTER 4

NUCLEAR ENERGY IN ELECTRICITY GENERATION

This chapter is added for completeness of the topic and to highlight all related nuclear issues.

4.1 Background

Nuclear power is energy which is produced with the use of a controlled nuclear reaction. Many nations use nuclear power plants to generate electricity for both civilian and military use, and some nations also utilize nuclear power to run parts of their naval fleets, especially submarines. Some people favor an expansion of nuclear power plants because this form of energy is considered cleaner than fossil fuels such as coal, although nuclear power comes with a number of problems which must be addressed, including the safe disposal of radioactive waste products [2, 6].

The process of generation nuclear power starts with the mining and processing of uranium and other radioactive elements. These elements are used to feed the reactor of a nuclear power plant, generating a reaction known as fission which creates intense heat, turning water in the plant into steam. The steam powers steam turbines, which generate electricity and feed the electricity into the electrical grid [2].

Many nuclear power plants have extensive automated systems which help to identify potential trouble spots, and these systems can also re-route power, turn off parts of the plant, and perform other tasks which make the plant safer and cleaner.

Around the world, nuclear energy is once again being regarded as a viable source of electricity due to its dependability, affordability, and efficiency to meet rising energy demand. Additionally, in today's carbon constrained world, governments and power companies are turning to nuclear energy as a key source of zero emissions electricity.

4.2 Worldwide Status

While America and Europe dither over nuclear power, Asia is going full steam ahead. According to a report by the International Atomic Energy Agency, 65 percent of nuclear plants, currently under construction, are in Asia, with China and India leading the pack; both know that the only way to continue economic growth is through nuclear power. The two countries alone are preparing to build as many nuclear power plants in the coming decade as the rest of the world combined [15, 17].

4.2.1 Some Statistical

Table 4.1 lists the current nuclear plants over the world that is in operation or under construction as end of 2012,

Table 4.1: Nuclear Power Plants Statistic over the World

Country	In operation		Under Construction		Country	In operation		Under construction	
	No.	MW	No.	MW		No.	MW	No.	MW
Argentina	2	935	1	692	Mexico	2	1300	-	-
Armenia	1	375	-	-	Netherlands	1	482	-	-
Belgium	7	5,927	-	-	Pakistan	3	725	2	630
Brazil	2	1,884	1	1,245	Romania	2	1,300	-	-
Bulgaria	2	1,906	-	-	Russian	33	23,643	11	9,927
Canada	19	13,665	-	-	Slovakian	4	1,816	2	782
China	23	17,834	31	31,353	Slovenia	1	688	-	-
Czech	6	3,766	-	-	South Africa	2	1,830	-	-
Finland	4	2,736	1	1,600	Spain	8	7,560	-	-
France	58	63,130	1	1,600	Sweden	10	9,325	-	-
Germany	9	12,068	-	-	Switzerland	5	3,263	-	-
Hungary	4	1,889	-	-	Ukraine	15	13,107	2	1,900
India	20	4,391	7	4,824	UAE	-	-	1	1,345
Iran	1	915	-	-	UK	16	9,246	-	-
Japan	50	44,215	3	3,993	USA	104	101,465	1	1,165
Korea	23	20,754	3	3,640	**Total**	**437**	**372,210**	**68**	**65,406**

Source: European Nuclear Society (ENC), [15]

4.2.2 Global Nuclear Facts [15-19]

- 437 nuclear plants operating in 30 countries with an installed electric net capacity of about 372 GW [15-16].
- 14 percent of the world's electricity provided by nuclear power [16-18].
- 68 new nuclear plants under construction in 14 countries with an installed electric net capacity of about 65 GW [15-18].
- 156 new nuclear plants on order or planned, with an additional 350 proposed [15-18].

According to the World Nuclear Association [20], China has 23 nuclear power reactors in operation, and more than 30 already under construction, but only provide just 3 percent of its electricity. The country plans to build 10 new nuclear plants each year. India has 20 nuclear plants [15, 20].

- France, Russia, Japan, the U.K., Canada and South Korea are actively seeking to play a big part in China and India's ambitious nuclear plans [15, 20].
- Russia is the latest country to strike a civil nuclear deal with energy-hungry India [15].
- America is a significant player and Westinghouse Electric is building four nuclear reactors in China [20].

4.2.3 The Interest in Nuclear Energy in the Middle East and North Africa

Although most attention has been focused on the progress of Iran in its nuclear program, six other countries in the region have signed agreements to proceed with nuclear power development and another ten have expressed interest or conducted studies related to nuclear power. The United Arab Emirates is set to be the first Arab country to build a nuclear power plant after approval from the country's nuclear regulator and securing a supply of uranium [20-22]. Table 4.2 shows summary of nuclear powers programs in the Middle East and North Africa.

Table 4.2: The Interest in Nuclear Energy in the Middle East and North Africa

<table>
<tr><th colspan="2">UAE</th></tr>
<tr><td colspan="2">• Programme to build a fleet of 14 nuclear power plants (NPPs)
• Contracted with KEPCO for first four NPPs
• First NPP to be operational by May 2017
• Emirates Nuclear Energy Corporation is state government-owned development corporation
• Federal nuclear Regulatory Authority was establish</td></tr>
<tr><th colspan="2">SAUDI ARABIA</th></tr>
<tr><td colspan="2">• Established the kA_CAR in 2010.
• City objectives include developing national polices and implementation plans.
• Technical consultant appointed to develop national nuclear and renewable strategy</td></tr>
<tr><th colspan="2">KUWAIT</th></tr>
<tr><td colspan="2">• Established the Kuwait National Nuclear Energy Committee
• Seeking to build four 1000MW NPP, the first to be completed in 2020
• Technical consultant preparing a road map for the introduction of a nuclear power programme
• Pledged $10M to IAEA fuel Bank</td></tr>
<tr><th>QATAR</th><th>BAHRAIN</th></tr>
<tr><td>• Considering nuclear energy option
• Technical consultant appointed to undertake a preliminary and site feasibility study</td><td>• Established the National Committee on the Peaceful Use of Nuclear Energy
• Considering nuclear energy option</td></tr>
<tr><th>OMAN</th><th>GCC</th></tr>
<tr><td>• Established a preparatory committee
• Considering nuclear energy option
• Part of the Global Nuclear Energy partnership</td><td>• Joint programme to build an NPP
• IAEA feasibility study concluded in 2007 and formally endorsed by the GCC</td></tr>
<tr><th colspan="2">EGYPT</th></tr>
<tr><td colspan="2">• Nuclear power programme being developed since 1950s;government decree to proceed with plans in 2007
• Has a nuclear research reactor
• National Nuclear Law of 2010 established Nuclear and Radiation Control Authority
• Egyptian Nuclear Power plants Authority is the development corporation
• Currently in discussions with reactor suppliers</td></tr>
<tr><th colspan="2">JORDAN</th></tr>
<tr><td colspan="2">• Tendering for first NPP
• Short list of three reactor suppliers; Atmea, AECl and Atomstroy export
• Research reactor under construction by Korea Atomic energy Research institute and Daewoo Engineering
• Jordan Atomic energy commission is the development corporation
• Jordan Nuclear Regulatory Authority established pursuant to Nuclear Safely and Security Radiation protection Law No .43 of 2007</td></tr>
<tr><th>TURKEY</th><th>LIBYA</th></tr>
<tr><td>• Akkuyu plant to be developed pursuant to inter govemmental agreement with Russia
• Under discussions for Sinop plant reactor supplier
• Proposals to build 10-12 reactors by 2020</td><td>• Established Libyan Atomic Energy Establishment
• Tendered in 2010 for consulting services for feasibility study and site study</td></tr>
<tr><th>MOROCCO</th><th>ALGERIA</th></tr>
<tr><td>• Plans to build first NPP by 2020
• Has commenced revising legislative framework</td><td>• Plans to build first NPP by 2020
• Proposal to build a new unit every five years</td></tr>
</table>

Source: KA_CARE, etal [20-22].

4.3 Challenges for Nuclear Expansion

The prospects for growth and expansion of nuclear power depend on several challenges being met, including [15-22]:

- Continued diligence in achieving safety and reliability of nuclear plants.
- Improving economic competitiveness.
- Achieving and retaining public confidence in nuclear power.
- Continuing successful management of spent fuel and radioactive waste.
- Management and acceptance of the transport of nuclear fuel.
- Establishing acceptable infrastructure in countries introducing nuclear power.
- Achieving proven reactor designs that is appropriate to specific countries.
- Achieving, for the long term, effective and sustainable use of resources.
- The capital cost of new large plants is high and can challenge the ability of electric utilities to deploy new nuclear power plants.
- There is currently no integrated and permanent solution to high-level nuclear waste management.
- International expansion of the use of nuclear energy raises concerns about the proliferation of nuclear weapons stemming from potential access to special nuclear materials and technologies.

4.4 Safety

Nuclear power is safe and even though there have been two old serious accidents in Pennsylvania (Three Mile Island, 1979) and Chernobyl (1986), but these are irregular incidents when compared to the rate of accidents which occur in fossil fuel industries, coal mines and gas pipelines which have a history of eruption [15-18]. The following is a summary of events that took place at Fukushima Daiichi Nuclear Power Plant in Japan March 2011.

In March 2011 eleven operating nuclear power plants shut down automatically during the major earthquake. Three of these subsequently caused an International Nuclear Event Scale (INES) level 7 Accident due to loss of power leading to loss of cooling and subsequent radioactive releases [19].

4.5 Disadvantages of Nuclear Energy

The disadvantages of nuclear power include [15-22]:

1. Radioactive minerals are unevenly distributed around them.
2. Nuclear waste from nuclear power plant creates thermal (heat) pollution which may damage the environment. A large amount of nuclear waste is also created and disposal of this waste is a major problem.
3. The danger of accidental discharge of radio activity also exists.
4. Building a nuclear plant requires huge capital investment and advanced technology.
5. Nuclear plants are opposed on moral grounds, by many groups, because of their close linkage with development of nuclear weapons.
6. There are number of restrictions on the export or import of nuclear technology, fuels etc.
7. Safety issues associated with nuclear power are hard to be overlooked; aftermaths of Chernobyl (1986) and Fukushima nuclear earthquake (2011) cannot be forgotten easily.
8. Nuclear power is not a renewable source of energy. Uranium is a metal that is mined from the ground in much the same way as coal is mined. It is a scarce metal and the supply of uranium will one day run out making all the nuclear power plants obsolete.

4.6 Summary

The primary purpose here is to address nuclear power in fuel mix diversity as a resource capable of meeting energy demand, environmental and security needs by resolving technical, cost, safety, security, and proliferation resistance, through the mean-variance portfolio analysis for fuel diversification.

If nuclear power is included to the fuel mix, it has the potential to advance several socially desirable calls for [15-22]:

1. **Lower long-term prices:**

   The biggest nuclear power advantages are that it is relatively cheap, unless you count the bills from disasters.

2. **Lower price risk:**

The availability of nuclear power is competitive compared to other sources of power like oil and gas. The cost of the nuclear fuel is a small part of the total reaction and therefore even if there is a slight fluctuation in the market the entire reaction need not be affected.

3. **Scarcity:**

The source of nuclear power is uranium and this is available in abundance in the crust of the Earth.

4. **Higher power reliability:**

One of the main benefits of nuclear power is that it is an extremely reliable source of power because most nuclear reactors have a life cycle of 40 years which can be easily extended further for 20 more years.

5. **Cleaner environment:**

The main benefits of nuclear power are that it is environment friendly. This is because it almost emits no carbon dioxide during the electricity generation.

CHAPTER 5

SYSTEM MODELING

This Chapter delivers basics related to the proposed M-V portfolio model based on load diversification in order to be used in the electricity generation planning. It starts by introductory section to discuss principal concepts of load duration curve, capacity factor, load factor, and multi objective optimization.

5.1 Load Duration Curve, Load Factors and Capacity Factors

The Load Duration Curve (LDC) is the most sensible way to represent the load of a future interval. The LDC demonstrates the distribution of power demand by plotting it in decreasing level from the highest (peak) to the lowest (base). The power demand is plotted versus time. It is representing the amount of power requirements, plotted on the vertical axis, for amount of time, plotted on the horizontal axis. A typical LDC is shown in Figure 5.1. The curve is regularly divided into three areas corresponding to peak periods of very high demand for short amounts of times, cycling periods with reasonable demands for longer periods, and base periods of low demand that always exists. Anyone can consider any number of period types even though it is very common that three types of period are considered. Usually the LDC is approximated using a non-increasing step function as shown in Figure 5.2. The different load regions under such an approximation become rectangles.

It is common to use the capacity factor (CF) to measure the plant's utilization whereas the entire system's utilization is measured by the load factor (LF). Capacity Factor (CF) is defined as the ratio of the electrical energy produced by a generating unit in a given period to the electrical energy that could have been produced at full power operation. On the other hand, the Load Factor (LF) is defined as the ratio of the average load on the entire generating system (with one or more generating units) in a certain period to the maximum load on the system during that period [5]. By defining CF and LF, both take values from 0 to 1 [0:1].

$$\boldsymbol{Capcty\ Factor\ (CF)} = \frac{\textbf{Energy produced in a given period}}{\textbf{capacity}*\textbf{time period}}, \qquad \mathbf{0} < CF < 1 \tag{5.1}$$

$$\boldsymbol{Load\ Factor\ (LF)} = \frac{\textbf{Energy produced in a given period}}{\textbf{peak load}*\textbf{time period}} \qquad \mathbf{0} < LF < 1 \tag{5.2}$$

5.1.1 Illustrative Example [23]

Consider three different load types (peak, cycle, and base) and two generation units (generators 1 and 2) each with capacity 150 MW. The load duration curve is approximated as shown in Figure 5.2. The three load factors are 1.00 for base, 0.90 for cycling load and 0.25 for peaking load. If generator 1 is always used before generator 2, then the capacity factors are 0.97 for generator 1 and 0.47 for generator 2. The following examples show how capacity and load factors are calculated.

Example 1: Capacity factor calculations for generators 1 and 2.

$$\boldsymbol{CF = \frac{Energy\ Produced}{Capacity \times time\ period}} \tag{5.3}$$

$$\mathbf{CF_1} \frac{(\mathbf{100 \times T + (150 - 100) \times 0.9T})}{\mathbf{150 \times T}}$$

$$= 0.9667$$

$$\mathbf{CF_2} = \frac{(\mathbf{200 - 150) \times 0.9T + (300 - 200) \times 0.25T})}{\mathbf{150 \times T}}$$

$$= \mathbf{0.4667}$$

Example 2: Load factor calculations for load types 1, 2 and 3, for base, cycling, and peaking respectively.

$$\boldsymbol{CF = \frac{Energy\ Produced}{Peak\ Load \times time\ period}} \tag{5.4}$$

$$\boldsymbol{LF_1} = \frac{\mathbf{100 \times T}}{\mathbf{100 \times T}} = \mathbf{1}$$

$$\boldsymbol{LF_2} = \frac{\mathbf{100 \times 0.9T}}{\mathbf{100 \times T}} = \mathbf{0.9}$$

$$\boldsymbol{LF_3} = \frac{\mathbf{100 \times 0.25T}}{\mathbf{100 \times T}} = \mathbf{0.25}$$

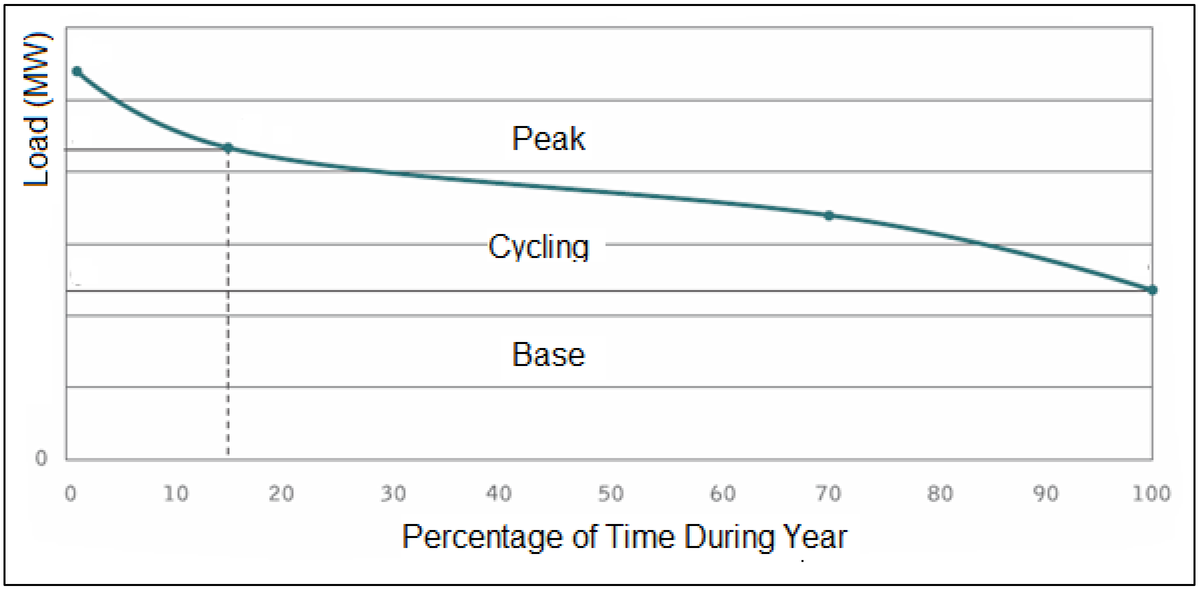

Figure 5.1: Typical Load Duration Curve (LDC) [15]

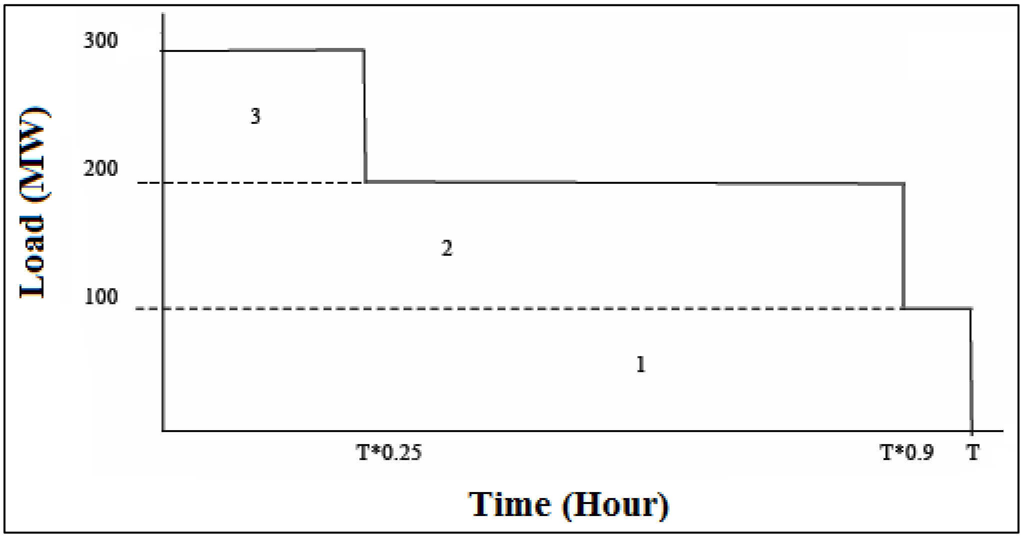

Figure 5.2: Load duration Curve using a non-increasing step function [23]

5.2 Fuel Cost Covariance Matrix:

The covariance is the degree to which two variables are correlated. That is, covariance is the measure of how much two variables are related to one another. It is important in security (risky) analysis to determine how much or how little price movements in two industries are related. So, the covariance is a measure of dependence between two variables (technology fuel price in this study).

The covariance matrix is required in the portfolio optimization module. It is obtained from levlized cost of energy for each fuel expectation and standard deviation for each individual plant type. The covariance between possible prices for fuel i and j, is obtained as follows [7]:

$$\mathrm{\sigma_{ij}} = \mathrm{r_{ij}\sigma_i\sigma_k} \tag{5.5}$$

Where:

σ_{ij} = The standard deviation of fuels i and j.

r_{ij} = The correlation coefficient for fuels i and j.

σ_i = The standard deviation of fuel i.

σ_j = The standard deviation of fuel j.

5.3 Model formulation

Let the number of different technologies available for electricity generation be I. Each technology has a specific fuel source. The load duration curve is segmented into L load types with load factors given as $LF_1 > LF_2 > LF_3$. For each technology, the existing generation capacity is given by U_i expressed in GWh for $i = 1, \dots, I$. The vector F, formed by ith component, represents the total fixed cost for each technology, expressed in $\$/GWh$. The variable cost of fuel for technology i is V_i and is expressed in $\$/GWh$. The mean and variance of V_i are estimated from available data and taken as (μ_i, σ_i^2). Covariance obviously exists between different fuels and σ_{ij} will denote the covariance between fuel i and fuel j. The variable operations and maintenance costs for technology i are denoted by OM_i.

5.3.1 Normal Scenario

For the sake of long-term planning, apart from the question of how much energy existing technologies should produce, there is an interest in direction on the building of new plants. Up this level, there is a need to differentiate between energy generated from both existing and new generating units. The demand requirements for power is split into various load types D_n expressed in GWh. Note that $D_n = LF_n * L_{max}$ where L_{max} is the maximum load. The energy (GWh), generated by existing units based on technology i to meet demand type L , is denoted by ye_{il}. Similarly, yn_{il} denotes the energy from new units to meet D_l . The objective is to hit a good balance between low expected production costs (mean) and low risk cost (variance) by selecting the optimal ye_{il} and yn_{il} . There is also, need to define the sets $Ye = \{ye_1, \dots, ye_L\}$ and $Yn = \{yn_1, \dots, yn_L\}$.

The multi-objective formulation is used with the parameter beta, $\beta \in (0, \infty)$ taking the risk against mean cost. The parameter β can also be taken as a degree of risk aversion. The larger β the greater is the aversion from risk.

So, the objective is to:

Minimize

$$\left[\sum_{i=1}^{I}\sum_{l=1}^{L}\left(\frac{F_{n_i}}{LF_{il}} yn_{il} + (OM_i + V_i)(ye_{il} + yn_{il})\right)\right] + \beta\left[\sum_{i=1}^{I}\sum_{j=1}^{I}\sum_{l=1}^{L}\left(\sigma_{ij}(ye_{il} + yn_{il})(ye_{jl} + yn_{jl})\right)\right] \tag{5.6}$$

Subject to constraints:

1. Existing capacity limit:

$$\sum \frac{ye_{il}}{LF_{il}} \le U_i \tag{5.6 a}$$

2. Demand satisfaction,

$$\sum ye_{il} + yn_{il} \le D_L \tag{5.6 b}$$

3. Non-negativity,

$$ye_{il} \ge 0$$

$$yn_{il} \ge 0$$

Where:

I: Technology Type	L: Load Type
F_{ni}: The fixed cost for technology I fuel	V_i: Variable fuel cost for technology I
LF_{il}: Load Factor for technology I and load type L	OM_i: Operation and Maintenance Cost for technology I
ye_{il}: The existing energy from technology I to supply load L	yn_{il}: The new energy from technology I to supply load L
σ_{ij}: The covariance between prices of I & J	β: Risk aversion. $\beta = 0 \to \infty$
U_i: The exiting capacity for technology I	D_L: Load Type L

The first term in equation (5.6) represents the levelized cost (cost resulted from production) of the optimization model, where the second term represents risk cost (cost resulted from fuel price variation) in the fuel diversity. The diversity is expressed is terms of covariance matrix of fuel prices and the risk aversion factor β.

The decision variables, ye_{il} and yn_{il}, denote the amount of energy production from existing and new plants respectively. Both reflect how generating units of different technologies are scheduled to meet load based on clear concern of the different load types. For load type l, LF_l is used in the proposed model to decide whether technology i will be involved in the optimal generation mix and how much its generation amount will be. A technology i with high investment costs F_i will not unpredictably opted out from the optimizing program as it also depends on how F_i is evaluated by LF_l of such load type. A small LF_l will result in levelized fixed costs for any technologies per unit of generation to proportionately increase, which lead to making them less economical to be selected in the optimal plan. A large F_i when joined with a large LF_l may lead to keep technology i in the optimal plan; but that also is dependent on how much corresponding variable costs contribute to the total production costs, which are to be minimized. A small F_i divided by a large LF_l may result in a relatively small number per unit of generation, which may lead to allowing the technology to enter the optimal mix. A technology with small F_i could also leave the plan in the case when dividing by LF_l results in to be an uneconomical choice.

The Efficient Frontier

The efficient frontier is the figure resulting from plotting the mean and variance along the vertical and horizontal axes respectively. The proposed portfolio model is a type of multi-objective formulations. The solution to the optimization problem can be located for different values of β. This gives a set of solutions that are best visualized by efficient frontier as shown in Figure 5.3. The optimum choice for any decision maker lies on this frontier and the exact selection depends on β selected by the decision maker. Inefficient choices lie above or to the right of the frontier.

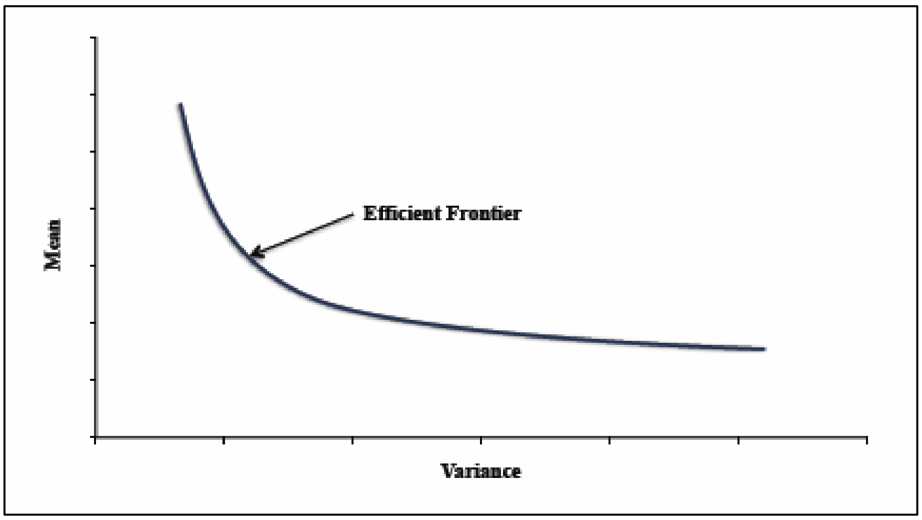

Figure 5.3: Mean-Variance Efficient Frontier

5.3.2 Environment Constraint (Effect of Carbon Emission)

An alternate scenario in which the emission of carbon dioxide is considered as a penalty is now considered. In this scenario, fuel costs are increased proportionally to their CO2 emissions. Each fuel is given a carbon dioxide cost adder. It affects the different fuels independently. Thus, different fuels have varying carbon contents and different net heat rates for separate technologies. Like what has been done for fixed and variable costs, carbon emission costs are added to O&M costs components and are treated as costs per unit of energy generated. The model proposed is given below:

Minimize

$$\left[\sum_{i=1}^{I}\sum_{l=1}^{L}\left(\frac{F_{n_i}}{LF_{il}}yn_{il} + (OM_i + V_i + V_{CO2})(ye_{il} + yn_{il})\right)\right] + \beta\left[\sum_{i=1}^{I}\ \sum_{j=1}^{I}\ \sum\nolimits_{l=1}^{L}\left(\sigma_{ij}(ye_{il} + yn_{il})(ye_{jl} + yn_{jl})\right)\right]$$

5.7)

Subject to a constraint:

1. Existing capacity limit:

$$\sum \frac{\mathrm{ye_{il}}}{\mathrm{LF_{il}}} \leq \mathrm{U_i} \qquad (5.7\text{ a})$$

2. Demand satisfaction,

$$\sum \mathrm{ye_{il}} + \mathrm{yn_{il}} \leq \mathrm{D_L} \qquad (5.7\text{ b})$$

3. Non-negativity,

$$ye_{il} \geq 0$$
$$yn_{il} \geq 0$$

Where V_{CO2} is the costs per unit resulted from carbon emission.

5.3.3 Safety Consideration

Environmental and health consequences are usually seen as external costs which are quantifiable but do not appear in the utility's accounts. Production of electricity from any form of primary energy has some environmental effect, and some risks. A balanced assessment of nuclear power requires comparison of its environmental effects with those of the principal alternative, coal-fired electricity generation, as well as with other options.

The last scenario here is which the safety is taken into consideration. In this scenario, each fuel safety is reflected into the model as a cost element, named Safety Element (SE) cost. The safety element costs are added to O&M costs components and treated as costs per unit of energy generated. So, we are treating safety as cost parameter in the model proposed below:

Minimize

$$\left[\sum_{i=1}^{I}\sum_{l=1}^{L}\left(\frac{F_{n_i}}{LF_{il}}yn_{il}+(OM_i+V_i+V_{CO2}+SE_i)(ye_{il}+yn_{il})\right)\right]+\beta\left[\sum_{i=1}^{I}\sum_{j=1}^{I}\sum_{l=1}^{L}\left(\sigma_{ij}(ye_{il}+yn_{il})(ye_{jl}+yn_{jl})\right)\right] \tag{5.8}$$

Subject to a constraint:

1. Existing capacity limit:

$$\sum\frac{\mathrm{ye_{il}}}{\mathrm{LF_{il}}}\leq \mathrm{U_i} \tag{5.8 a}$$

2. Demand satisfaction:

$$\sum \mathrm{ye_{il}}+\mathrm{yn_{il}}\leq \mathrm{D_L} \tag{5.8 b}$$

3. Non-negativity:

$$ye_{il}\geq 0$$

$$yn_{il}\geq 0$$

Where SE_i is the costs per unit resulted from Safety Element.

As nuclear power is exposed as the most hazardous, because of the possibility of radiation from waste storage, the safety must be taken into consideration. Also, the safety issues related to nuclear plants always are more than those of non-nuclear technology.

As no accurate figures of the safety cost for any fuel, the safety is considered by using a weighting factor called "Weighted Factor (WF) for Safety". It depends on the decision maker in generation planning how safety is estimated during the planning period. In this thesis, two (2) alternatives are assumed. One is low consideration for safety with WF equals 10. The second is the higher consideration for safety and WF is given a value of 100. The safety element (SE) for nuclear plant is equal to the SE for non-nuclear multiplied by the weighted factor (WF). This because nuclear has substantially more safety issues to the world than non-nuclear energy, that is:

$$SE_{Nuclar} = WF \times SE_{Non-Nuclear} \tag{5.9}$$

Where:

SE: Safety Element

WF: Weighted Factor for safety = $\begin{cases} WF = 10 & Low\ Safety\ Penalty \\ WF = 100 & High\ Safety\ Penalty \end{cases}$

5.4 Thesis Methodology

This section is discussing the research methodology and the use of the model to achieve the main objectives of this thesis. The main objective is to use the portfolio model to analyze the energy fuel diversification in long term planning of electricity generation. The study attempts to determine if a multiple fuel approach can be desirable in selecting the optimal energy source to produce electricity.

5.4.1 Methodology Formulation

The research study was done based on three (3) scenarios. One scenario represents a normal scenario where the exiting situation for the study system is characterized. The second scenario presents the effect of carbon dioxide emissions on the proposed model. The third scenario studies the effect when safety of power plants is taken into consideration.

5.4.2 Methodology and Case Study

The study is to determine the optimal fuel mixt for electricity generation by analyzing the portfolio approach. The analysis is designed as a comparative case study between two (2) cases. One case is when the nuclear energy is an option in the energy fuel mix; and the other is when nuclear is not an option. To achieve this result, data for two (2) Study Systems (SS01 & SS 02) is used in this thesis to solve the problem of fuel diversity.

5.4.3 Methodology Steps

The study is conducted in the following phase:

Phase 1: Data collection,

Phase 2: Modeling,

Phase 3: Simulation.

1) **Phase 1: Data collection**

a. **Cost factors data**

Cost factors are calculated for selecting the optimal generation plan for meeting future demand requirements. Each fuel approximate heat rates in Btu per kWh were used to calculate approximate average fuel prices in dollars. Fixed capacity costs and variable $O\&M$ for each generating units powered by each fuel were also given as determined by the Energy Information Administration (EIA). The variances between each two (2) fuel prices were provided to have the covariance matrix of fuel price for each study system.

b. **Existing Generating Unit Capacity**

Each study system has existing generating units with a generating capacity limit for each technology. This capacity limit is one constant in the proposed model.

c. **Future Demand in 2020**

The estimated load was derived by increasing the actual hourly electricity demand for any study system in a year using expected growth rates which was obtained from historical data. From this increasing load data, the load duration curve (LDC) was obtained for the historical demand. The LDC is then divided into three areas: base load, cycling load and peak load. Each load type is given a load factor (LF).

2) Phase 2: Methodology and Modeling

For proposed long-term planning, the electricity is generated from both existing and new generating units. In addition, the demand requirements for power are split into various load types. The proposed model gives the optimal generated energy contribution between existing and new units in order to supply the required load type. This will result in a good balance between low expected production costs and low risk cost. The proposed model is given by equation 5.6, 5.7 & 5.8.

3) Phase 3: Simulation

The model is executed in the MATLAB software using the “fmincon” minimization function. The fmincon function is a non-linearly constrained optimization solver. It has each constraint with equal weighting. The optimized solution is constrained by limiting the existing capacity and in the same time the required demand needs to be met by both existing and new generating units. It gave the iteration for each value of β from value of zero up to infinity (∞). At each value of β, the model gave the contribution of exiting ad new generation energy at which the production cost and risk cost are minimized. This gave a set of solutions that were best visualized by plotting the mean versus the variance. This plot is called the efficient frontier where the optimum choice lies on this frontier.

CHAPTER 6

STUDY SYSTEMS DATA

This Chapter provides details on data that are used in this thesis and solve the problem of fuel diversity for two (2) Study Systems (SS01 & SS 02). Cost factors and hourly load data for both systems are obtained differently. Different scenarios are used to report possible circumstances that indefinite future may be exposed to. The first scenario characterizes a normal situation where existing and new generating units are considered to serve future demand. Another scenario will reflect the effect of adding nuclear power plant. One more scenario will present effect of the carbon dioxide emissions. Final scenario reflects additions to generation costs that are proportional to safety element. This is important as nuclear power is being considered. In this chapter, there will be detailed analysis for the both systems, because some data was obtained after some of manipulation steps.

6.1 First Study System (SS01) Data (ref. to [23])

SS01 uses four (4) fuel technologies coal, oil, natural gas and nuclear power. The data needed to run the software program in order to test the model proposed in this thesis is of three types:

i. Cost factors related to each technology, including fuel prices and associated variation,
ii. Existing generation capacity, and
iii. Electricity requirements i.e. total demand and the load duration curve.

Particularly, this section discusses data and parameter estimates that are used to demonstrate the implementation of the proposed model using data for SS01.

6.1.1 Cost data

Since the model proposed in this thesis deals with cost minimization, cost factors are important in the economics decision to select the optimal generation plan for meeting future demand requirements. Cost factors vary significantly between different technology types because of several reasons, e.g. regulatory environments. SS01 fuel prices for coal, oil and natural gas in dollars per million Btu and approximate heat rates in Btu per kWh are used to calculate approximate fuel prices in dollars per MWh. As determined by the Energy Information Administration (EIA) [23], average fuel costs for generating units powered by coal, oil and natural gas are shown in Table 6.1. Fuel cost for nuclear power, according to the World Nuclear Association, is shown in Table 6.2. Table 6.3 shows all fuel cost and annual fixed costs (F_i), and variable $O\&M$ costs ($O\&M_{i,}$). Fixed capacity costs have been converted to dollars per unit of energy($\$/GWh$), by dividing by the number of hours in a year, 8760, while variable $O\&M$ and fuel costs are already expressed per unit of energy.

Table 6.1: Coal, Oil & Natural Gas Fuel Average Cost in 2012 [23]

Fuel	Coal	Oil	Natural Gas
$/ million Btu	1.54	7.12	8.2
$/ MWh	15.77114	72.91592	83.9762

Source Energy Information Administration (EIA)

<u>Calculation Sample:</u>

$$\boldsymbol{Coal\ fuel\ cost} = 1.54 * 10241 * 10^{-3} = 14.77114\ \$/GWh$$

Using the following relations: MWh = $10241 * 10^{-3}$ million Btu

Table 6.2: Nuclear Fixed, Fuel Average and O&M Cost in 2012 [23]

Total Fixed Costs (Million $/MW)	Variable O&M ($/MWh)	Fuel Cost ($/MWh)
2.01400	12.700	5.20

Table 6.3: SS01 Technologies Fixed and Variable Costs for electricity generation [23]

Technology	Fixed Costs Fi		Variable O&M OM_i		Fuel Cost V_i	
	million $/MW	million $/GWh	$/MWh	million $/GWh	$/MWh	million $/GWh
Coal	1.24900	0.14258	4.18000	0.00418	15.77	0.01577
Oil	0.58400	0.06667	1.88000	0.00188	72.92	0.07292
Natural Gas	0.38500	0.04395	2.89000	0.00289	83.98	0.08398
Nuclear	2.01400	0.22991	12.700	0.01270	5.20	0.00520

6.1.2 Covariance Matrix of the Fuel Costs

As introduced in Section 5.2, the quantity σij is the covariance between possible prices for fuels i and j. The covariance matrix of fuel price for SS01 electric system is given in Table 6.4.

The nuclear fuel price is very stable over the past years. One reason for that is that nuclear fuel price variance is very small. The only risk related to nuclear generation cost is the one associated with the need for large capital expenses.

The variance related to maintenance expenditures are not correlated between different units consuming the same fuel. The opposite is true in fuel price case that is variance of fuel price should be correlated between different units consuming the same fuel. That is, if natural gas price increases, it will have a similar effect on all natural gas fired units. Also, the need to replace a steam generator at one nuclear unit is unlikely to have a corresponding cost risk at another nuclear unit.

Table 6.4: SS01 Fuel price covariance (million$/GWh) [23]

	Coal	Oil	Gas	Nuclear
Coal	$\mathbf{1.877226 \times 10^{-6}}$	6.815061×10^{-6}	4.736821×10^{-6}	6.530220×10^{-6}
Oil	6.815061×10^{-6}	$\mathbf{3.729910 \times 10^{-6}}$	2.156534×10^{-6}	2.063233×10^{-6}
Gas	4.736821×10^{-6}	$2.156534 \times \mathbf{10^{-6}}$	$\mathbf{1.843646 \times 10^{-6}}$	1.697626×10^{-6}
Nuclear	6.530220×10^{-6}	2.063233×10^{-6}	1.697626×10^{-6}	$\mathbf{3.635170 \times 10^{-6}}$

The covariance terms for both existing and new nuclear with the other fuels are the same as those shown in Table 6.4. The covariance term between existing nuclear and new nuclear is simply the nuclear fuel price variance (3.633517×10^{-6}) in Table 6.4.

6.1.3 Existing Generating Unit Capacity

SS01 generating units use four (4) technologies for energy fuels: coal, oil, natural gas and nuclear; and each exiting unit has a generating capacity limit. Table 6.5 shows the generating capacity limit for each technology.

Table 6.5: SS01 Existing Generation Capacity

Energy Fuel	Total Capacity (MW)	Production Capacity (GWh)
Coal	16005.4	140207.304
Oil	481.6	4218.816
Gas	4559.7	39942.972
Nuclear	1674.4	14667.744

6.1.4 SS01 Future Demand in 2020

The study system is analyzed using an estimated load for the year 2020. The estimated load was derived by increasing the actual hourly SS01 electricity demand in 2003 using expected growth rates obtained from historical data [23]. By analyzing the load duration curve for the historical demand, the load was then assigned to each of the three types mentioned previously.

By scaling up hourly load in 2003 by a multiplicative constant that makes total load equal to the projected total load for 2020, a new load duration curve can be developed. This results in a total energy requirement of 158,450 GWh.

Table 6.6 shows the total energy requirements for each load type: baseload, cycling and peak, in the target year 2020. The resulting load factors for each load type are shown in Table 6.7. The model will determine the optimal fuel sources for the different load types for each level of risk aversion.

Table 6.6: Total energy requirements for each load type for SS01

	Forecast Requirements (GWh)			
Projected Year	Baseload	Cycling	Peaking	Total
2020	142,953.4594	8,311.1096	7,185.0004	15,8450

Table 6.7: Load Factor for each load type

Load Year	Baseload	Cycling	Peaking
2003	0.9594	0.4276	0.0811

6.2 The Second Study System (SS02) Data

This section discusses data and parameter estimates for SS02, where it represents a Middle Eastern Utility. SS02 data is used to demonstrate the implementation of the proposed optimization model in equation (5.6). SS02 uses three (3) exiting fuel technologies Heavy Fuel Oil (HFO), Light Crude Oil (LCR), and Natural Gas (NG). The technology cost factors, existing generation capacity, and electricity requirements are detailed below.

6.2.1 Cost Data

Since the model proposed in this thesis deals with the cost minimization system, cost factors are important in the economics decision to select the optimal generation plan for meeting future demand requirements.

SS02 fuel prices for Heavy Fuel Oil, Light Crude Oil and Natural Gas in dollars per million Btu and approximate heat rates in Btu per kWh are used to calculate approximate fuel prices in dollars per GWh as shown in Appendix A. Average fuel costs for generating units powered by HFO, LCR and natural gas are shown in Table 6.8. Table 6.9 shows SS02 technologies fixed and variable costs for electricity generation. Table 6.10 shows all fuel cost and annual fixed costs (F_i), and variable $O\&M$ costs ($O\&M_{i,}$). Fixed capacity costs have been converted to dollars per unit of energy $\$/GWh$, by dividing by the number of hours in a year, 8760, while variable $O\&M$ and fuel costs are already expressed per unit of energy. The fuel data for nuclear power is as given in Table 6.2.

Table 6.8: HFO, LCR & Natural Gas Fuel Average Cost in 2012

Technology	SR/MMBTU	SR/MWh	$/MWh	Fuel Cost Vi million $ /GWh
HFO	7.09	24.19817	6.452845	0.00645
LCR	10.89	37.16757	9.911352	0.00991
Natural Gas	12.26	41.84338	11.15823	0.01116

<u>Calculation Sample:</u>

$$\boldsymbol{LCR\ Fuel\ Cost = \ 10.89 * \frac{3.413}{3.75 * 1000} = 0.00991\ million\ \$/GWh}$$

Using relations:

$1\ MWh = 3.413\ MMBTU$

Exchange rate of $\$1.0 = SR\ 3.75$

Table 6.9: SS02 Technologies Fixed and Variable Costs for electricity generation

Technology	Capital Cost SR/KW	Fixed O&M (SR/KW-yr)	Fixed Cost (SR/KW)	Variable O&M Cost (SR/MWh)	Fixed Cost million $/GWh	Variable O&M Cost million $/GWh
HFO	7600	37.5	7637.5	5.7	0.23250	0.00152
LCR	5000	45	5045	16.5	0.15358	0.00440
Natural Gas	6500	37.5	6537.5	10.2	0.19901	0.00272

Calculation Sample:

$$\boldsymbol{HFO\ Fixd\ Cost} = \frac{(7600 + 37.5)}{3.75 * 8760} = 0.23250\ \ million\ \$/GWh$$

$$\boldsymbol{NG\ Variable\ O}\&M\ Cost = \frac{10.2}{3.75 * 1000} = 0.00272\ million\ \$/GWh$$

Table 6.10 summarizes cost data for fixed and variable O&M, as well as fuel costs for SS02.

Table 6.10: SS02 Technologies Fixed and Variable Costs for electricity generation

Technology	Fixed Costs Fi		Variable O&M OM_i		Fuel Cost V_i	
	million $/MW	million $/GWh	$/MWh	million $/GWh	$/MWh	million $/GWh
HFO	2.0367	0.23250	1.5200	0.00152	6.452845	0.00645
LCR	1.345361	0.15358	4.4000	0.00440	9.911352	0.00991
Natural Gas	1.743328	0.19901	2.7200	0.00272	11.15823	0.01116
Nuclear	2.01400	0.22991	12.700	0.01270	5.20	0.00520

6.2.2 Fuel Cost Covariance Estimates

Because of lack of data, SS01 covariance is used to test SS02 data. The difference will be that HFO is replacing coal data and LCR is replacing oil data. Table 6.11 shows the covariance matric for SS02.

Table 6.11: SS02 Fuel price covariance (million$/GWh)

	HFO	Light Crude Oil	Natural Gas
HFO	$\mathbf{1.877226 \times 10^{-6}}$	6.815061×10^{-6}	4.736821×10^{-6}
LCR	6.815061×10^{-6}	$\mathbf{3.729910 \times 10^{-6}}$	2.156534×10^{-6}
Natural Gas	4.736821×10^{-6}	$2.156534 \times \mathbf{10^{-6}}$	$\mathbf{1.843646 \times 10^{-6}}$

6.2.3 Existing Capacity

SS02 generating units have three (3) technologies for energy fuels: HFO, LCR, natural gas and nuclear; and each exiting unit has a generating capacity limit. Table 6.12 shows the generating capacity limit for each technology.

Table 6.12: SS02 Existing Generation Capacity

Energy Fuel	Total Capacity (MW)	Production capacity (GWh)
HFO	0	0
LCR	3640	31,886.4
Natural Gas	11,772.01	103,122.8076

6.2.4 SS02 Future Demand in 2020

The study analysis is performed using an estimated load for the year 2020 for SS02. The estimated load was derived by increasing the actual hourly SS02 electricity demand in 2008. By analyzing the load duration curve for the historical demand Figure 6.1, the load was then assigned to each of the three types mentioned previously.

By scaling up hourly load in 2008 by a multiplicative constant that makes total load equal to the projected total load for 2020, a new load duration curve can be developed. This results in a total energy requirement of 123,902 GWh.

Table 6.13 shows the total energy requirements for each load type: baseload, cycling and peak, in the model year 2020. The resulting load factors for each load type are shown in Table 6.14. The model will determine the optimal fuel sources for the different load types for each level of risk aversion.

Table 6.13: Total energy requirements for each load type for SS02

	Forecast Requirements (GWh)			
Projected Year	Baseload	Cycling	Peaking	Total
2020	97,157.753	22,773.1876	3,968.58106	123,902

Table 6.14: Load factor for each load type for SS02

Load Year	Baseload	Cycling	Peaking
2008	0.78415	0.1838	0.03203

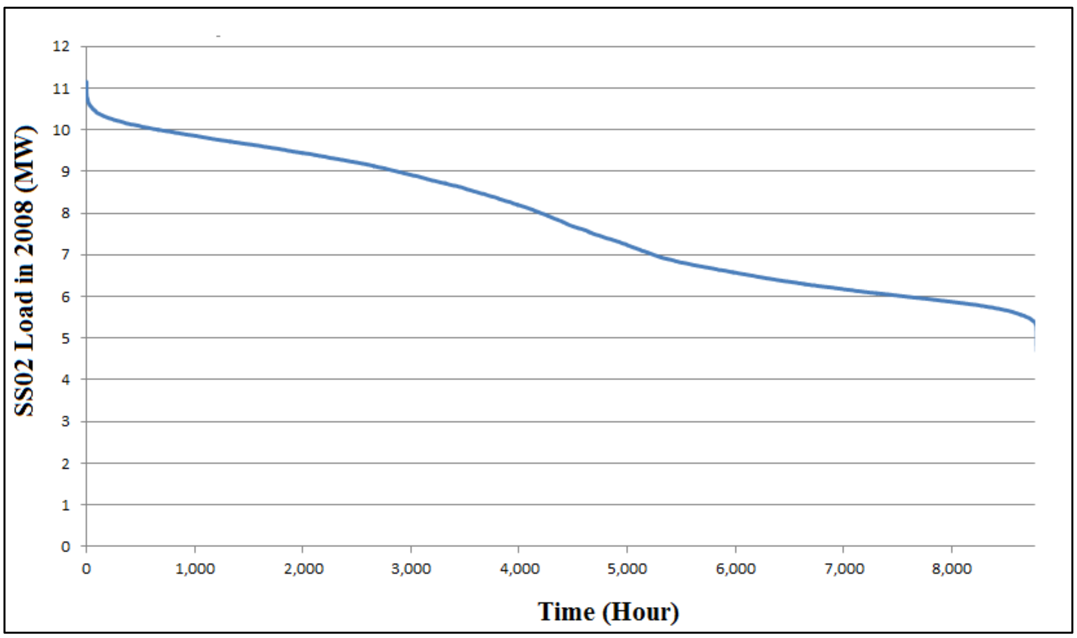

Figure 6.1: Load Duration Curve for the historical demand for SS02

6.3 Effect of Carbon Dioxide Emission Costs

As stated before, the model is supplemented to show the carbon emission impact on the proposed portfolio model. A scenario is presented in which the emission of carbon dioxide is penalized. It will demonstrate the capability for each fuel to absorb the cost related to carbon emission. In the carbon cost scenario, each fuel is given a carbon dioxide cost adder. It affects the different fuels independently. Thus, different fuels have varying carbon contents and different net heat rates for separate technologies.

Table 6.15 shows emission factors, net heat rates and carbon costs, which are used to derive carbon emission costs, by technology. For carbon emission cost factor, coal & HFO and oil & LCR are interchangeable. Nuclear energy emits no carbon dioxide, so it has no carbon cost adder. The carbon price is assumed to be € 25/ton CO2 [25]. Carbon cost for coal (or HFO) , oil (or LCR) and natural gas in dollars per ton and approximate heat rates in Btu per kWh is used to calculate approximate emission prices in dollars per GWh. Table 6.16 shows carbon emission costs by technology.

Table 6.15: Emission factors, net heat rates and derived carbon emission costs by technology

Technology	Emission Factor, lb.CO2/MMBtu	Net Heat Rate, Btu HHV/kWh	Carbon Cost, $/ton CO2
Coal (or HFO)	205.300	10,128	32.5
Oil (or LCR)	161.386	13,637	32.5
Natural Gas	117.080	9,923	32.5

Sources: Table A3. Carbon Dioxide Uncontrolled Emission Factors [26] & Table 8.1. Average Operating Heat Rate for Selected Energy Sources [APPENDIX]

Table 6.16: Emission factors, net heat rates and derived carbon emission costs by technology

Technology	Coal (or HFO)	Oil (or LCR)	Natural Gas
Emission Cost, $/GWh	0.030661	0.032453	0.019973

<u>Calculation Sample:</u>

$$\boldsymbol{Emission\ cost\ for\ Coal} = \frac{205.3 * 10{,}128 * 32.5}{10^6 * 2204.63} = 0.030661\ \$/GWh$$

Using the following relations:

- $1\ ton = 2{,}204\ pound$
- $MMBTU = 10^6 * Btu$
- Exchange rate €1 = $1.30

6.4 Safety Consideration

6.4.1 Low Safety Penalty

As there are no accurate figures of the safety cost for any fuel, the normal safety consideration is given when the weighted factor for safety is given value of 10. So, the safety for nuclear is charged 10-times the non-nuclear technology, that is:

$$SE_{Nuclar} = 10 \times SE_{Non-Nuclear}$$

Table 6.17: Low Safety Penalty Factor costs by technology

	Non-Nuclear	Nuclear
Safety Cost (million $/GWh)	0.0001	0.001

The normal safety considering is used in our planning for 2020 because it is the most reasonable situation.

6.4.2 High Safety Penalty

Higher consideration for safety is considered to see at which risk aversion the nuclear will be available in the fuel mix for generation planning. The higher safety consideration is assumed when the weighted factor for safety is given value of 100. So, the safety for nuclear is charged 100-times the non-nuclear technology, that is:

$$SE_{Nuclar} = 100 \times SE_{Non-Nuclear}$$

Table 6.18: High Safety Penalty Factor costs by technology

	Non-Nuclear	Nuclear
Safety Cost (million $/GWh)	0.0001	0.01

CHAPTER 7

IMPLEMENTATION AND RESULTS (STUDY SYSTEM SS01)

In this chapter, results related to study system (SS01) are provided for a normal and a number of other scenarios in order to test the proposed model implementation.

7.1 Nuclear Energy Scenario

This case presents SS01 normal scenario where the existing units are fueled by coal, oil, natural gas and nuclear. The efficient frontier for this scenario is shown in Figure 7.1. The variance (risk cost) is on the horizontal axis and the production cost is on the vertical axis. The risk aversion factor β is a weighting parameter to balance expected production cost against the risk cost (fuel price variance). When β ranges from near zero to a very large number, the efficient frontier shown in Figure 7.1 is obtained as a result of the optimizing proposed model for the fuel diversification given previously in equation (5.6). Any point lying on the efficient frontier represents an optimal fuel mix corresponding to level of risk aversion (value of β). So, the value of β points the importance of risk reduction.

Table 7.1 presents predicted energy production by technology in 2020 at selective values of β. Table 7.2 presents the total cost per unit for each technology.

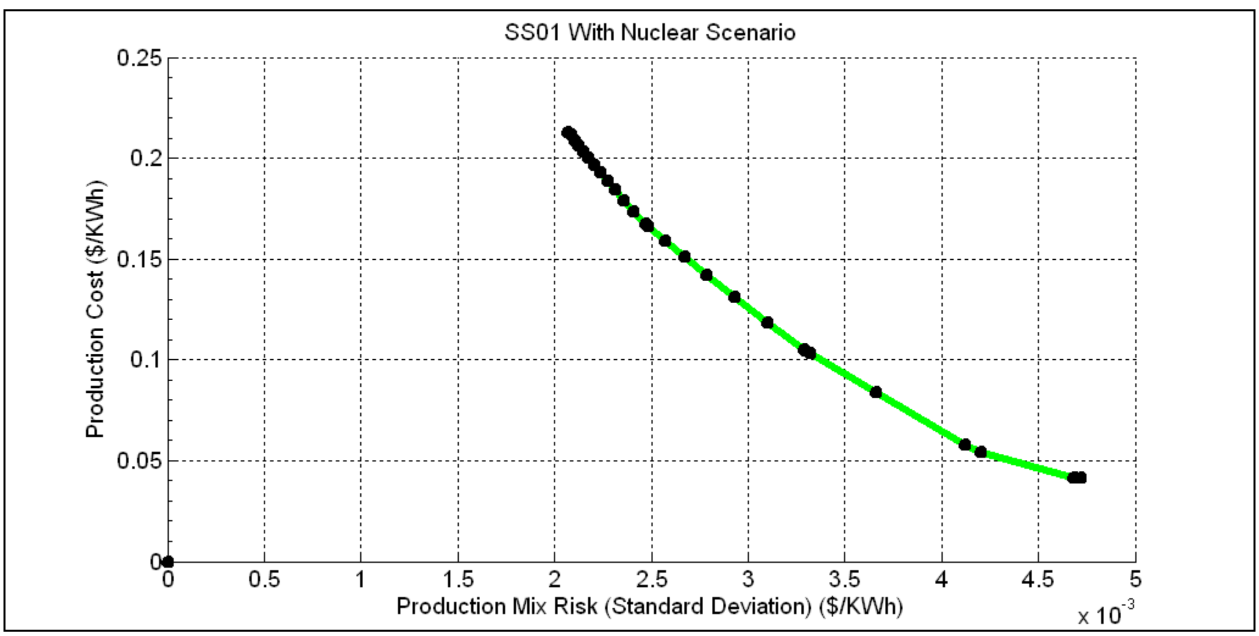

Figure 7.1: SS01 (Production-Risk) Cost Efficient Frontier for (With-Nuclear) Scenario

Figure 7.1 shows that at mid-levels of β the efficient frontier starts to converge indicating that at these levels of risk aversion the asymptotic mean and standard deviation are quite close.

Table 7.1: SS01 Energy Production Percentage by Technology at Selected Values of β in 2020 for (With-Nuclear) Scenario

	Risk Aversion (β)				
Technology	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Coal	82.30%	82.92%	82.92%	78.56%	53.56%
Oil	1.13	1.14%	0.63%	0.22%	0.20%
Natural Gas	7.06%	7.06%	7.57%	4.47%	2.04%
Nuclear	8.88%	8.88%	8.88%	16.75%	44.20%

Starting at low levels of risk aversion (β = 0 or near zero), coal is the dominant fuel of generation energy (supplying 82 percent). The nuclear units supply 9 percent of the energy, while natural gas and oil supply 7 percent and 1 percent, respectively. Some new natural gas-fired units are added for peaking loads. For high level of risk aversion (β = 0.1), the coal is about (54 percent), oil (1 percent) & natural gas (2 percent) are used, while more energy is supplied by nuclear (44 percent).

Table 7.2: SS01 Generation Total Cost in cent $/KWh for (With-Nuclear) Scenario

	Risk Aversion (β)				
Per unit cost (cent $/KWh)	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Production cost	4.1187	4.1200	4.1262	5.4058	5.5161
Mix risk cost	0.4791	0.4722	0.4699	0.4201	0.3287
Total cost	4.5978	4.5922	4.5962	5.8259	5.8448

As seen in Table 7.2, the model further diversifies fuel to reduce variance at the expense of expected cost as the level of risk aversion (β) increases. When β is near zero cost is minimized and risk is given minimal consideration, while a very large value of β indicates that risk is minimized and expected cost is given minimal consideration. Therefore, higher values of β mean greater risk aversion, with a willingness to pay a higher cost.

Results shown in table 7.2 seem to coincide with what is observed in Figure 7.1 in the sense that the expected total production cost per unit of energy ($/kWh) gradually increases as the majority of the mix diversifies away from coal to nuclear, which generally costs more to produce due to a larger fixed cost. Regardless of the level of risk aversion, coal is the dominant source of energy providing over 53 to 82 percent.

7.2 SS01 Without-Nuclear Energy Scenario

In previous generation portfolio, SS01 has nuclear energy as an option into the fuel mix. In this section, a scenario when nuclear power is excluded from SS01 fuel mix is considered. This can be done simply by running a program similar to the first scenario except that nuclear technology is no longer available. Energy demand is to be filled by power generated only from coal, oil and natural gas. Table 7.3 presents the predicted energy production by technology in 2020 at selective values of β. Table 7.4 presents the total cost per unit for each technology when nuclear is no longer an option in SS01 plan.

Table 7.3: SS01 Energy Production Percentage by Technology at Selected Values of β in 2020 for (Without-Nuclear) Scenario

	Risk Aversion (β)				
Technology	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Coal	84.89%	90.22%	90.22%	90.22%	92.08%
Oil	2.55%	1.14%	0.52%	0.22%	0.22%
Natural Gas	12.55%	8.64%	9.26%	9.56%	7.70%

When nuclear is not an option, for low values of β, the electricity that would have been supplied by nuclear power is primarily produced from natural gas. That is, natural gas contribution increases (from 7 to 12.5 percent), where coal mostly supplies the total load with 85 percent. For high risk aversion ($\beta = 0.1$), coal is used to replace the nuclear powered electricity. This result is shown in the efficient frontier indicates that have higher values of both cost and variance as in Figure 7.2.

Table 7.4: SS01 Generation Total Cost in cent $/KWh for (Without-Nuclear) Scenario

	Risk Aversion (β)				
Per unit cost (cent $/KWh)	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Production cost	4.990458	5.19878	5.206452	5.209943	5.515085
Mix risk cost	0.450454	0.402742	0.402307	0.402158	0.399287
Total cost	5.440912	5.601521	5.608759	5.612101	5.914372

As seen in Table 7.4, when β increases, the model further diversifies to reduce variance at the expense of expected cost. When β is near zero, cost is minimized and fuel risk is given minimal consideration, while a very large value of β indicates that risk is minimized and expected cost is given minimal consideration. Therefore, higher values of β mean greater risk aversion, with a willingness to pay a higher cost.

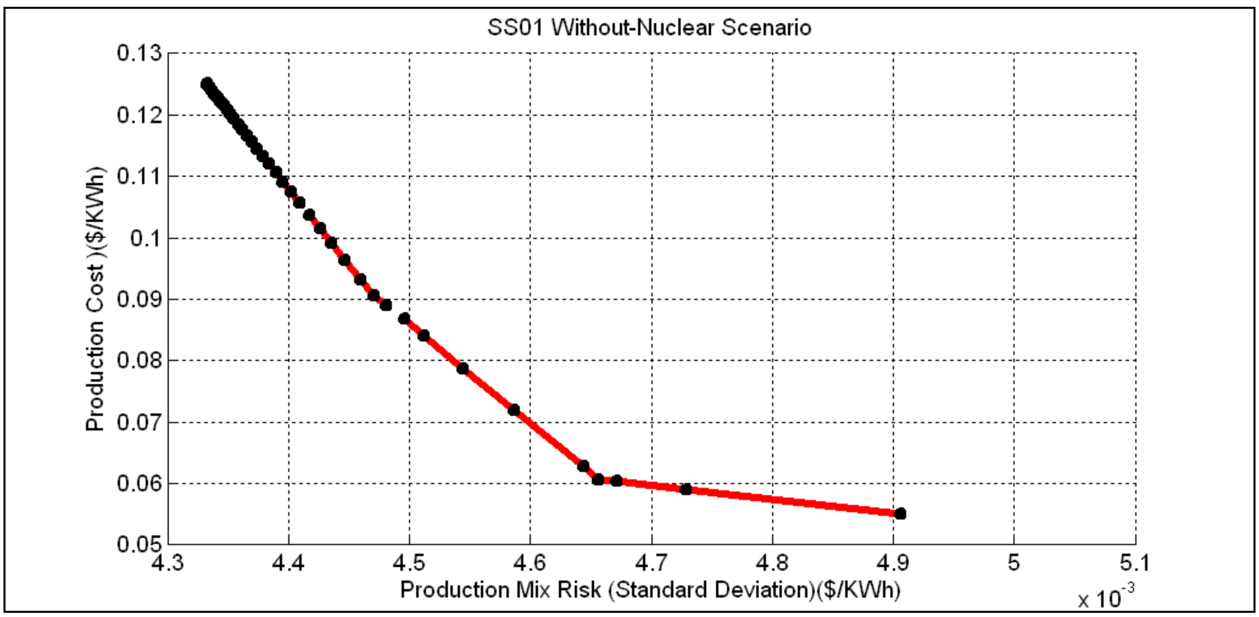

Figure 7.2: SS01 (Production-Risk) Cost Efficient Frontier for (Without-Nuclear) Scenario

Results in Figure 7.2 are consistent with what is seen in Table 7.4 for the selected levels of β. The mix has higher values of both cost and variance.

7.2.1 Comparison between With & Without Nuclear Scenarios

Figure 7.3 combines Figures 7.1 & 7.2. It shows the efficient frontiers for with and without nuclear cases at selective values of β. It is clear that the Without-Nuclear scenario presents a different set of results when compared to the With-Nuclear case. In Figure 7.3, the efficient frontier points that for Without-Nuclear scenario, the mix has higher both production cost and risk cost (variance).

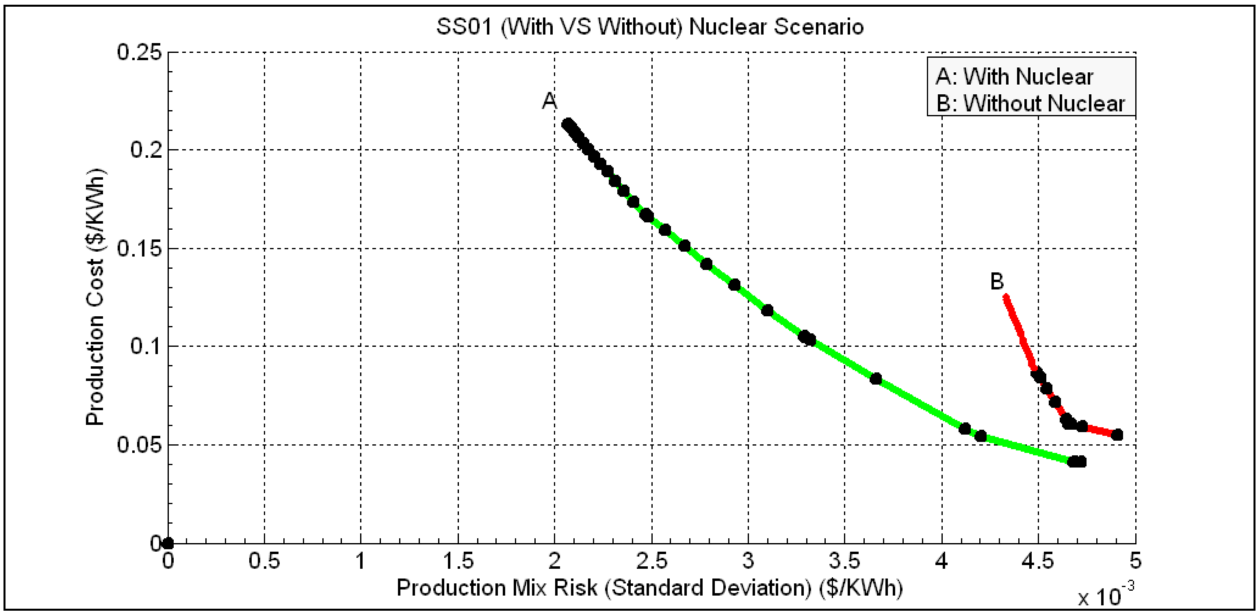

Figure 7.3: SS01 (With VS. No) Nuclear Scenarios Comparison

As seen in Figure 7.3, the graph for the Without-Nuclear scenario lies above and to the right of the With-Nuclear scenario. This indicates that Without-Nuclear has higher expected total cost per unit of energy for all the optimal mixes.

Furthermore, it can be seen from Figure 7.3 that at low level of β (no risk aversion), the production cost is (4.1187 cent $/ kWh), while the standard deviation is (0.4791 cent $/ kWh). This is a result of the model using less of the high variance coal and toward higher cost alternatives. At the opposite end of the spectrum (high level of β), the production cost is (5.6161 cent $/ kWh), while the standard deviation is (0.3287 cent $/ kWh). This result could be expected as the model looks to mitigate risk at any cost. Both the final cost (5.5151 cents per kWh) and standard deviation (0.3993) are lower than in the Without-Nuclear scenario. So, the efficient frontier indicates that With-Nuclear scenario has a lower cost and variance than the equivalent points from the Without-Nuclear scenario.

Table 7.5 gives comparison between with and without nuclear scenarios for the total cost per unit of energy. It shows the total cost increases from With-Nuclear scenario to Without-Nuclear scenario.

Table 7.5: SS01 Total cost for Comparison between With & Without Nuclear Scenarios

		Risk Aversion (β)				
		0	**0.007**	**0.017**	**0.05**	**0.1**
Production Cost (cent $/KWh)	With Nuclear	4.1187	4.1200	4.1262	5.4058	5.6161
	Without Nuclear	4.9905	5.1988	5.2065	5.2099	5.5151
Mix Risk Cost (cent $/KWh)	With Nuclear	0.4791	0.4722	0.4699	0.4201	0.3287
	Without Nuclear	0.4505	0.4027	0.4023	0.4022	0.3993
Total Cost (cent $/KWh)	With Nuclear	4.5978	4.5922	4.5962	5.8259	5.8448
	Without Nuclear	5.4409	5.6015	5.6088	5.6121	5.9144

For low risk aversion $(\beta = 0)$, the mean price (production cost) is increased from 4.1187 to 4.9905 cent $/KWh [21 percent increase]; and little decrease in the variance price (mix risk cost) from 0.4791 to 0.4505 cent $/KWh [6 percent decrease]. The total cost is the summation between production and mix risk costs. It is clear that the total cost increased from 4.5978 cent $/KWh (in With-Nuclear scenario) to 5.4409 cent $/KWh (in Without-Nuclear scenario) [18 percent increase].

For high risk aversion $(\beta = 0.1)$, the mean price (production cost) is slightly decreased from 5.6161 to 5.5151 cent $/KWh [2 percent decrease]; but large increase in the variance price (mix risk cost) from 0.3993 to 0.3287 cent $/KWh [18 percent increase]. It is clear that the total cost increased slightly from 5.8448 cent $/KWh (in With-Nuclear scenario) to 5.9144 cent $/KWh (in Without-Nuclear scenario) [1 percent increase].

7.3 Effect of Carbon Dioxide Emission Costs in SS01

As stated before, the model is tested to show the impact of carbon emission on the proposed portfolio. A scenario is presented in which the emission of carbon dioxide is penalized. In the carbon cost scenario, each fuel is given a carbon dioxide cost adder.

All fuel costs and variances as described previously in section 6.1, are applied to the problem model equation (5.7). In this scenario, fuel costs are increased proportionately to their CO2 emission.

7.3.1 Effect of Carbon Dioxide Emission on With-Nuclear Scenario

The With-Nuclear scenario for SS01 is represented in order to display the effect of CO2 emission on this scenario. This can be done by using all fuel costs factors and price variances as marked earlier in sections 6.1 & 6.3 and applied it to the model equation (5.7) in order to demonstrate the capability for each technology to absorb the cost related to carbon emission.

The efficient frontier shown in Figure 7.4 is obtained as a result of the optimizing proposed model for the fuel diversification given previously in equation (5.7) by changing β from near zero to a very large number.

Table 7.6 presents the predicted energy production by technology in 2020 at selective values of β under the effect of CO2 emissions. Correspondingly, Table 7.7 presents the total cost per unit for each technology.

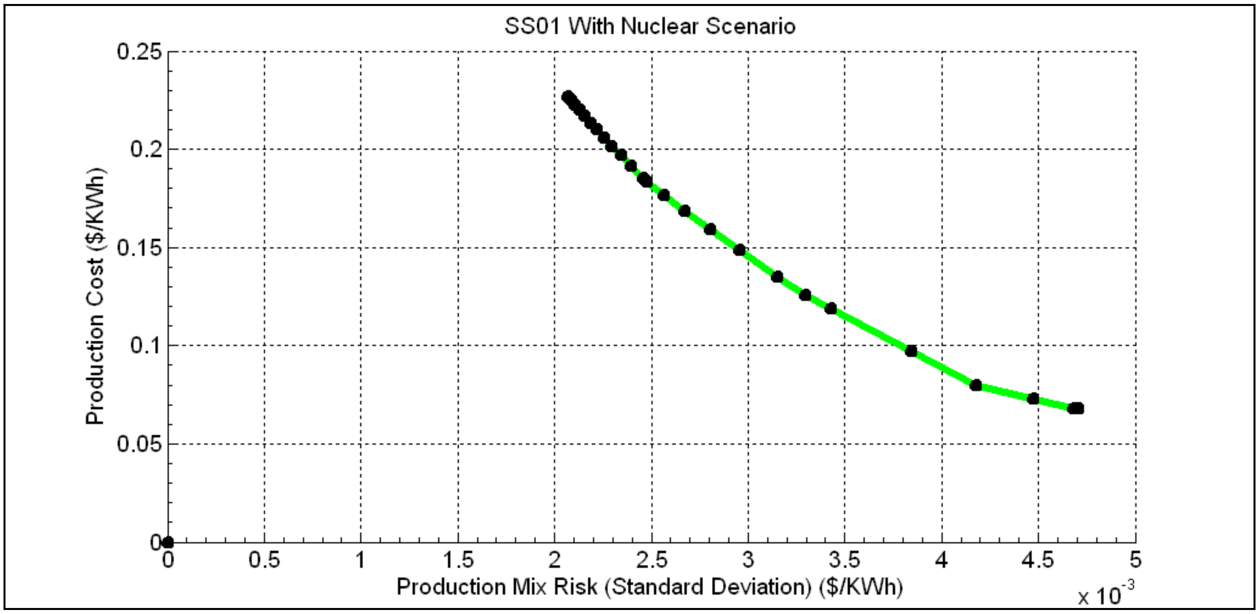

Figure 7.4: SS01 (Production-Risk) Cost Efficient Frontier for (With-Nuclear) Scenario - Effect of Carbon Emission

Table 7.6: SS01 Energy Production Percentage by Technology for (With-Nuclear) Scenario - Effect of Carbon Emission

	Risk Aversion (β)				
Technology	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Coal	82.92%	82.92%	82.92%	78.37%	46.37%
Oil	1.14%	1.14%	0.23%	0.22%	0.00%
Natural Gas	7.06%	7.06%	7.97%	4.32%	1.58%
Nuclear	8.88%	8.88%	8.88%	17.10%	52.05%

Table 7.7: SS01 Generation Total Cost in cent $/KWh for (With-Nuclear) Scenario - Effect of Carbon Emission

	Risk Aversion (β)				
Per unit cost (cent $/KWh)	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Production cost	6.6792	6.6790	6.6864	7.7967	7.8858
Mix risk cost	0.3759	0.3759	0.3753	0.3495	0.3144
Total cost	7.0550	7.0549	7.0617	8.1462	8.2002

The carbon dioxide cost adder impacts the various fuels differently, since different fuels have different carbon contents. The highest carbon content fuel, coal, experiences the greatest impact, followed by oil and natural gas. Nuclear energy has no cost adder since it emits no carbon dioxide. The primary effect of the carbon dioxide emission cost is to increase the cost while having little impact on variance.

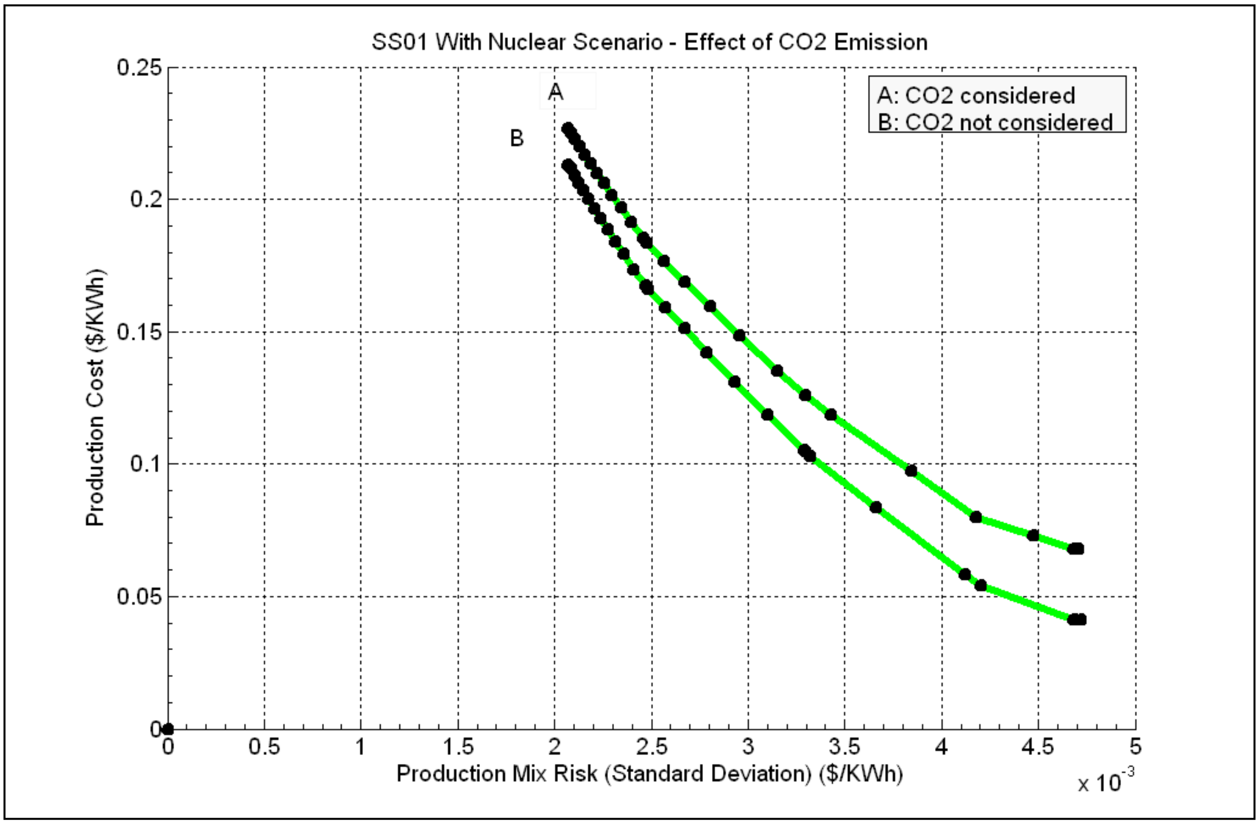

Figure 7.5: SS01 (Production-Risk) Cost Efficient Frontier for carbon emission Effect- With-Nuclear Scenario

Figure 7.5 combines Figures 7.1 & 7.4. It shows that the efficient frontier when CO2 emission is considered lies above the normal curve (if CO2 not considered). This happens because the main impact of the carbon dioxide emission cost is to increase the production cost, whereas having a slight effect on the risk cost (variance). For all values of β, the portfolio with carbon cost is dominated by one in the normal case (when CO_2 not considered). This is not surprising because for any portfolio the variance is the same in the two cases though the carbon costs are added to the expected production cost of all technologies.

7.3.2 Effect of Carbon Dioxide Emission on (Without-Nuclear) Scenario

When nuclear is not an option in the technology fuel portfolio, Figure 7.6 shows the efficient frontier of the optimizing problem model equation (5.7) for fuel diversification, by changing β from near zero to a very large number.

Table 7.8 presents the predicted energy production by technology in 2020 at selective values of β. Table 7.9 presents the total cost per unit for each technology.

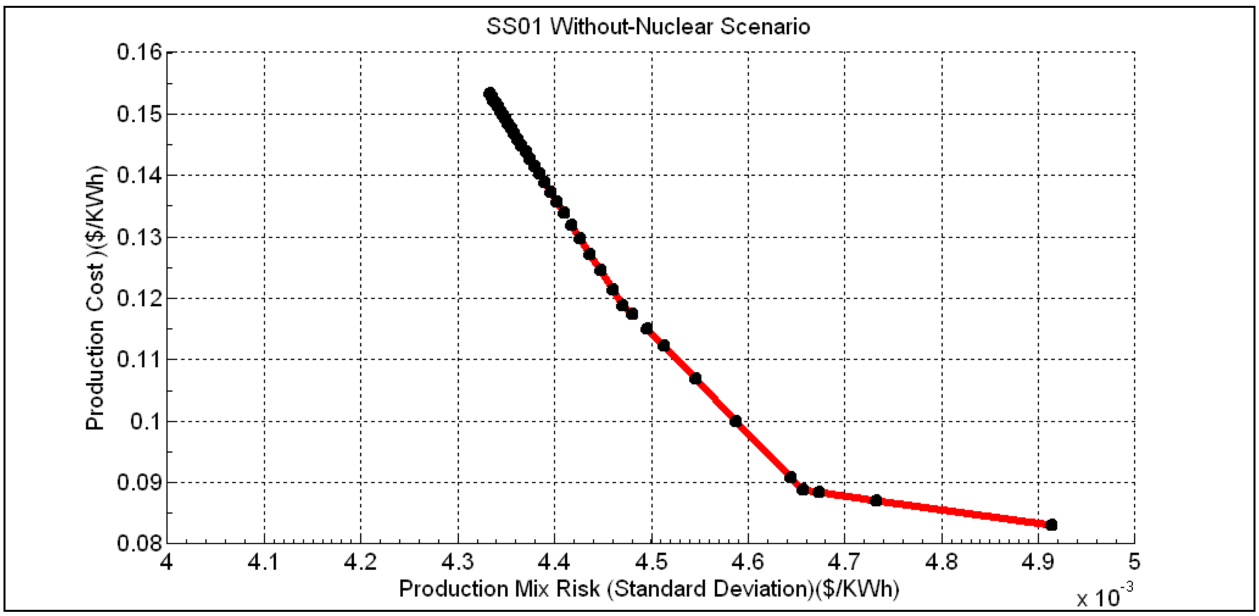

Figure 7.6: SS01 (Production-Risk) Cost Efficient Frontier for (Without-Nuclear) Scenario - Effect of Carbon Emission

Table 7.8: SS01 Energy Production Percentage by Technology for (Without-Nuclear) Scenario - Effect of Carbon Emission

	Risk Aversion (β)				
Technology	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Coal	90.02%	90.22%	90.22%	90.22%	91.01%
Oil	1.38%	1.14%	0.22%	0.22%	0.22%
Natural Gas	8.60%	8.64%	9.56%	9.56%	8.78%

When nuclear is not an option, the carbon dioxide cost adder impacts the different fuels (Coal, Oil & natural gas) differently. For this reason, there is no noticeable influence for the carbon emission effect in generation percentage by technology. For example, there is slight increase in the percentage of high carbon cost power derived from natural gas (from 7.70 to 8.78 percent), with a corresponding slight drop in electricity from coal from (92.08 to 91.01 percent). This happens because coal has relatively higher carbon cost adders than natural gas. The coal has the highest carbon content, so it experiences the greatest impact, followed by oil and natural gas.

Table 7.9: SS01 Generation Total Cost in cent $/KWh for (Without-Nuclear) Scenario - Effect of Carbon Emission

	Risk Aversion (β)				
Per unit cost (cent $/KWh)	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Production cost	8.0002	8.0042	8.0112	8.0114	8.3067
Mix risk cost	0.4030	0.4027	0.4022	0.4022	0.3994
Total cost	8.4032	8.4069	8.4134	8.4136	8.7061

Figure 7.7 combines Figures 7.2 & 7.6. It includes the efficient frontiers for the (Without-Nuclear) scenario with and without carbon cost cases determined by the model problem (5.7) in order to show the effect of carbon emission on the without nuclear scenario.

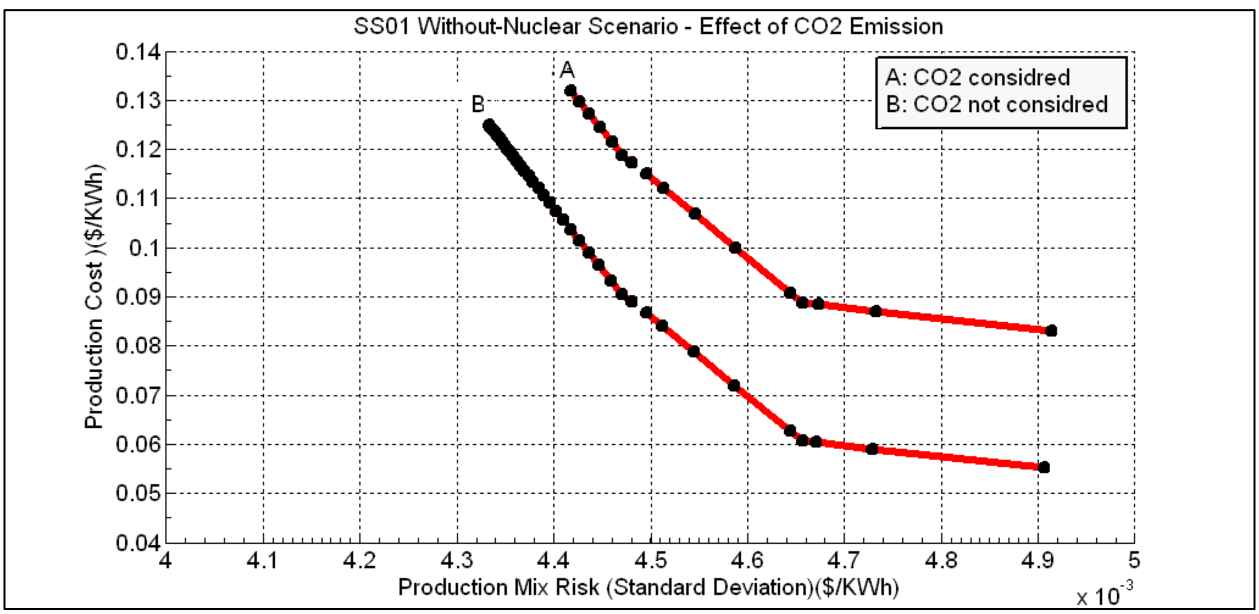

Figure 7.7: SS01 (Production-Risk) Cost Efficient Frontier for (Without-Nuclear) Scenario – Effect of Carbon Emission

The curve labeled "CO2 considered" in Figure 7.7 assumes a cost adder of $32.5/ton for emitting carbon dioxide. The efficient frontier when CO2 emission is considered lies above the normal curve (if CO2 not considered). This happens because the main impact of the carbon dioxide emission cost is to increase the production cost, whereas having a slight effect on the risk cost (variance).

7.3.3 Comparison between With & Without Nuclear Scenarios with Effect of CO2 Emission

The nuclear scenario provides a different and better set of results when compared to the (Without-Nuclear) scenario. Starting with the low values of β, the efficient frontier points have a lower cost and lower variance than the equivalent points from the (Without-Nuclear) scenario.

Table 7.10 gives comparison between with and without nuclear scenarios for the total cost per unit of energy in case of the effect of carbon emission. It shows the total cost increases from With-Nuclear scenario to Without-Nuclear scenario.

Table 7.10: SS01 Total Cost for Comparison between With & Without Nuclear Scenario- Effect CO2 Emission

		Risk Aversion (β)				
		0	**0.007**	**0.017**	**0.05**	**0.1**
Production Cost (cent $/KWh)	With Nuclear	6.6792	6.6790	6.6864	7.7967	7.8858
	Without Nuclear	8.0002	8.0042	8.0112	8.0114	8.3067
Mix Risk Cost (cent $/KWh)	With Nuclear	0.3759	0.3759	0.3753	0.3495	0.3144
	Without Nuclear	0.4030	0.4027	0.4022	0.4022	0.3994
Total Cost (cent $/KWh)	With Nuclear	7.0550	7.0549	7.0617	8.1462	8.2002
	Without Nuclear	8.4032	8.4069	8.4134	8.4136	8.7061

For low level of risk aversion (β equal to near zero), the production cost is (8.0002 & 6.6792 cent $/ kWh), while the risk cost (standard deviation) is (0.4030 & 0.3759 cent $/ kWh) for without and with nuclear respectively. At the opposite end of the spectrum (high level of risk aversion), the production cost is (8.3067 & 7.8858 cent $/ kWh), while the standard deviation cost is (0.3994 & 0.3144 cent $/ kWh) for without and with nuclear respectively. This indicates that the system is using less of the high variance (coal & natural gas) and toward loses lower cost alternatives such as nuclear. This result expected as the model looks to mitigate risk at any cost. Furthermore, Table 7.10 shows that the total cost (production cost and risk cost summation) increases from 8.2002 cent $/ kWh (With-Nuclear) scenario to 8.7061 cent $/ kWh (Without-Nuclear) scenario [6 percent increase]. This result gives a major advantage for using nuclear energy scenario.

Figure 7.8 shows the efficient frontiers for with and without nuclear cases at selective values of β for the effect of carbon emission.

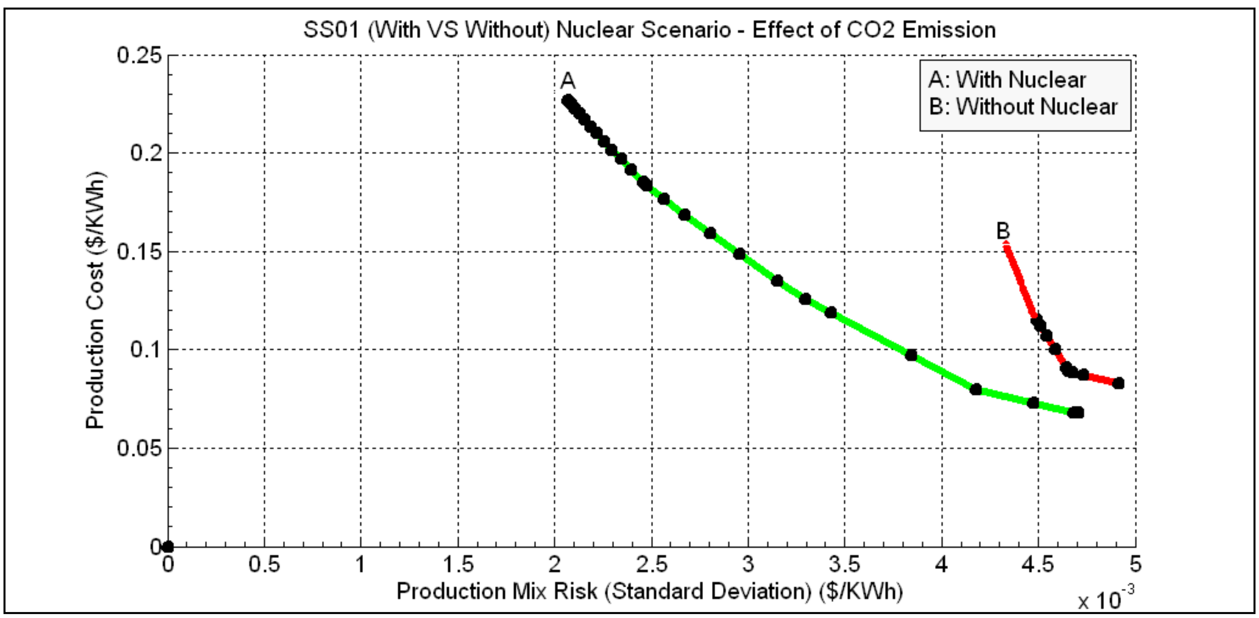

Figure 7.8: SS01 (With VS. No) Nuclear Scenarios Comparison - Effect of Carbon Emission

Figure 7.8 combines Figures 7.4 & 7.6. As seen in Figure 7.8, the frontier for the (With-Nuclear) scenario lies below and to the left of the (Without-Nuclear) scenario, indicating less expected production (mean) and risk (variance) costs per unit of energy for all the optimal mixes.

It is clear that the total cost increased slightly from 8.2 cent $/KWh (in With-Nuclear scenario) to 8.7 cent $/KWh (in Without-Nuclear scenario).

To conclude, the with-nuclear option gives better results than without nuclear both if carbon dioxide emission is considered. So, it is recommended to go with nuclear as an option in the fuel mix plan. The following section will limit the use of nuclear based on the safety issues related.

7.4 Analysis When Safety is taken into consideration for SS01

The model is tested on the use of nuclear power where safety issues are considered. Additional scenario is considered in which the safety of nuclear plant is penalized as a cost adder. This can be done by using all fuel costs factors and price variances as marked earlier in sections 6.1, 6.3 & 6.4.1 and applied it to the model equation (5.8) in order to demonstrate the effect of safety on the last result where carbon emission effect is emphasized. It is clear from the data given in section 6.4 that the nuclear energy is the technology that will be mostly affected by safety element. In this scenario, fuel cost for nuclear only is increased proportionately to its safety element. The objective in this section is to determine how much the proposed model will be affected when safety is taken into consideration.

The efficient frontier shown in Figure 7.9 is obtained as a result of solving proposed model for the fuel diversification given previously in equation (5.8) by changing β from near zero to a very large number. Table 7.11 presents the predicted energy production by technology in 2020 at selective values of β under the effect of safety of nuclear energy. Table 7.12 presents the total cost per unit for each technology.

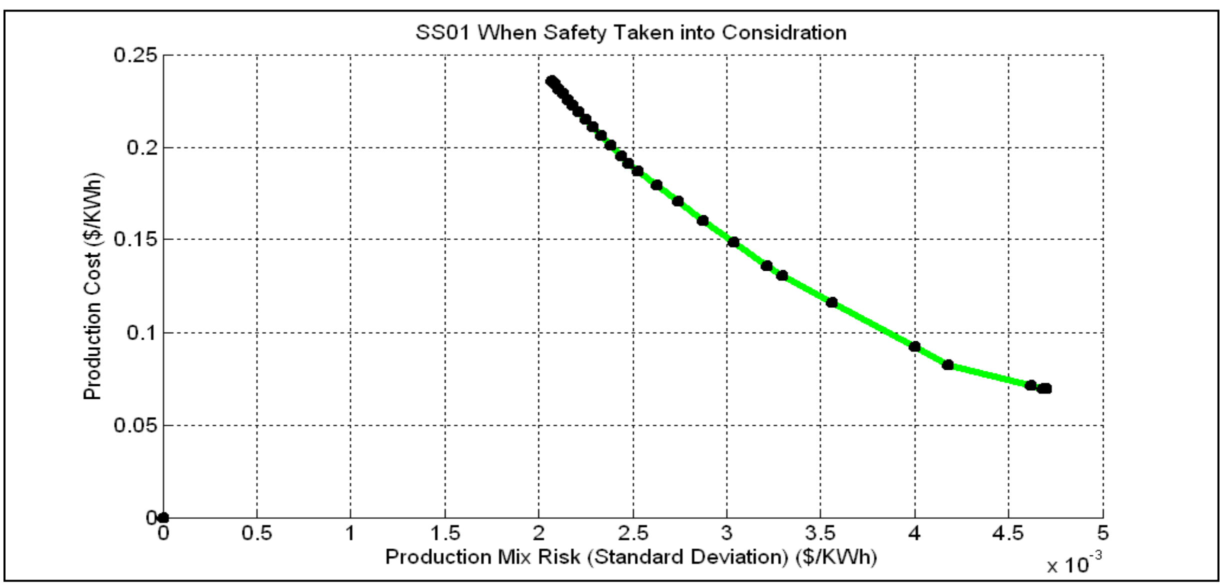

Figure 7.9: SS01 (Production-Risk) Cost Efficient Frontier for (With-Nuclear) Scenario – If safety is taken into consideration

Table 7.11: SS01 Energy Production Percentage by Technology for With-Nuclear Scenario- If safety is taken into consideration

	Risk Aversion (β)				
Technology	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Coal	80.24	82.92%	82.92%	78.37%	51.67%
Oil	2.20%	1.09%	0.22%	0.22%	0.02%
Natural Gas	9.47%	7.11%	7.98%	4.32%	2.04%
Nuclear	8.09%	8.88%	8.88%	17.09%	46.26%

Table 7.12: SS01 Generation Total Cost in cent $/KWh for With-Nuclear Scenario – If safety is taken into consideration

	Risk Aversion (β)				
Per unit cost (cent $/KWh)	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Production cost	6.9589	6.9602	6.9667	8.2524	13.5860
Mix risk cost	0.3801	0.3758	0.3753	0.3495	0.2693
Total cost	7.3390	7.3360	7.3420	8.6019	13.8553

In this scenario, the Safety Element cost adder impacts nuclear and non-nuclear fuels differently. Nuclear fuel has the highest impact. The effect of the safety cost is to increase the cost while having little impact on variance.

To conclude, it is clear that the With-Nuclear gives better result than without from cost point of view. We can notice this conclusion even the safety for nuclear is penalized as a cost.

7.5 Final Results: SS01 Power Generation Planning in 2020

Three cases were discussed for three different scenarios. The first is the SS01 With-Nuclear scenario that is based on normal plan relative to 2003 in SS01. The second scenario is when carbon emission is considered. The third is taking the safety issues in the consideration. For SS01 power generation planning in 2020, the third scenario “with nuclear” is used in the projected energy generation planning. The planning is developed based on the model that takes both CO_2 emission and safety in the normal consideration in all obtained results.

Table 7.13 provides the detailed portfolios for each of five (5) selected values of the risk aversion factor (β). They are grouped by fuel type (coal, oil, natural gas, and nuclear), within technology by existing versus new energy. For each energy fuel/technology, existing and new energy production, expected production standard deviations of cost are all indicated.

Table 7.13: 2020 Predicted Energy Production by Technology (GWh) for SS01

		Risk Aversion (β)				
Technology		**0**	**0.007**	**0.017**	**0.05**	**0.1**
Coal	Existing	131392	131392	131392	124178	81870
	New	0	0	0	0	0
	Total Coal	131392	131392	131392	124178	81870
Oil	Existing	1804	1721	342	342	39
	New	0	0	0	0	0
	Total Oil	1804	1721	342	342	39
Natural Gas	Existing	4048	4240	4872	3239	3239
	New	7133	7023	7771	3603	0
	Total Gas	11181	11263	12643	6842	3239
Nuclear	Existing	14072	14072	14072	14072	14072
	New	0	0	0	13014	59229
	Total Nuclear	14072	14072	14072	27086	73301
Expected Production cost (million $)		11028.34	11028.48	11038.72	13075.93	21526.96
Variance of cost (million $2)		354690.57	354603.77	353605.83	306656.28	182076.62
S.D. of cost (million $)		595.56	595.49	594.65	553.77	426.70
Expected unit cost ($/kWh)		0.0696	0.0696	0.0697	0.0825	0.1359
Unit S.D. of cost ($/kWh)		0.0038	0.0038	0.0038	0.0035	0.0027
Total Cost ($/kWh)		**0.0734**	**0.0734**	**0.0735**	**0.0860**	**0.1386**

To begin with, consider the lower level of risk aversion ($\beta = 0.007$). The existing coal is used to generate 131,392 GWh of energy. No new coal energy is added. The existing oil of 1,721 GWh is used, reflecting the usefulness of this existing capacity for serving extreme peak loads despite its high variable cost. No new oil-fired capacity is installed. Existing natural gas energy of 4,240 GWh is used. New natural gas energy of about 7,023 GWh is added. The addition of natural gas highlights the value of that technology for serving peak load due to its low capital cost. Finally for SS01, the existing nuclear energy of 14,072 GWh is fully utilized. No new nuclear capacity is added. The expected production cost is about $11.03 billion; the standard deviation of costs due to variations in fuel prices is about $595.5 million. On a per kWh basis, the expected cost of generation is $0.070, with a standard deviation of $0.004.

Moving across the columns of Table 7.11, as the aversion to risk rises, the total energy fueled by coal drops substantially with the gap being filled primarily by nuclear generation. While no new nuclear capacity is installed, with low risk aversion, nuclear capacity roughly triples and quadruples as the risk aversion β increases from 0.007 to 0.017 to 0.05 to 0. 1. The full existing coal capacity is used in the intermediate risk aversion case. The other changes in capacity and utilization are relatively minor. The minor amount of oil capacity is fully utilized in the base case, but delayed in the cases with higher risk aversion. There is also a modest decline in natural gas-fired capacity. The expected costs increase by about $2 billion as risk aversion moves from 0.007 to 0.05. The standard deviation of costs due to variations in fuel prices decrease by about $41.72 million. On a per kWh basis, the expected cost of generation increases from $0.070 to $0.083 to $0.135, while the standard deviation of cost decreases from $0.0038 to $0.0035 to $0.0027.

7.6 Effect of High Safety Penalty

This section attempts to answer the question "is nuclear still proposed if safety weighting factor (WF) assigned with too high value, that is higher consideration for safety?" To answer this question, WF is assigned a value of 100. Then the model equation (5.8) is solved in order to demonstrate the effect of higher consideration for nuclear safety.

The efficient frontier shown in Figure 7.10 is obtained as a result of the optimizing proposed model for the fuel diversification given previously in equation (5.8) by changing β from near zero to a very large number. Table 7.14 presents the predicted energy production by technology in 2020 at selective values of β under the effect higher consideration of safety for nuclear energy.

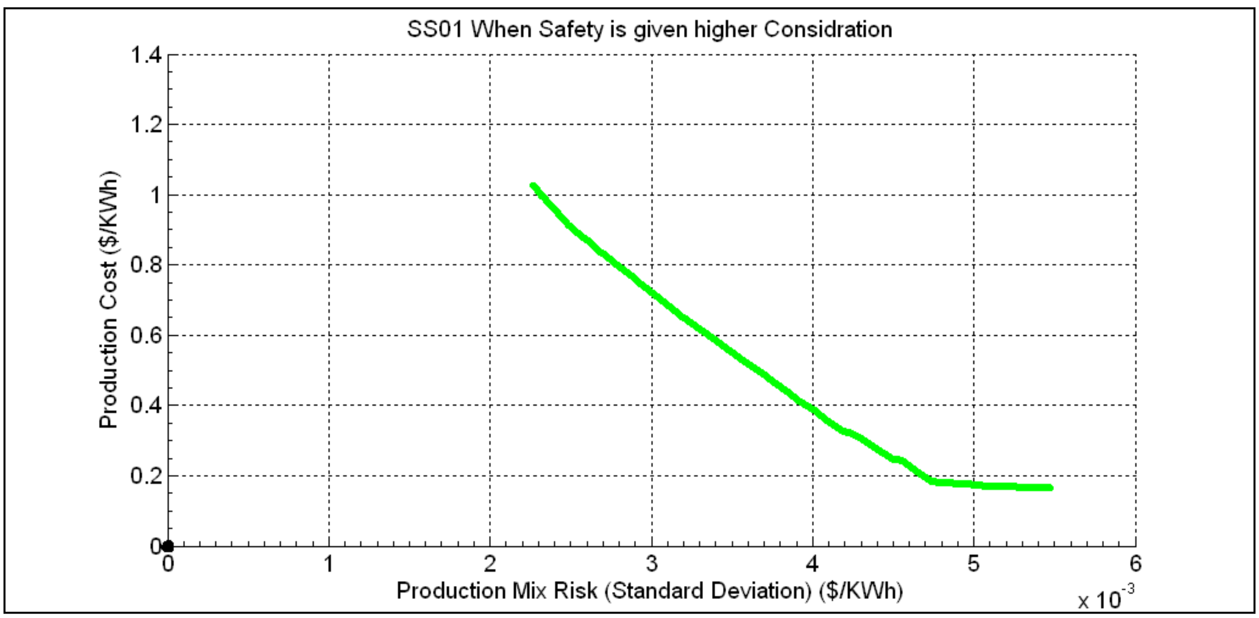

Figure 7.10: SS01 Efficient Frontier for High Safety Penalty Scenario

Table 7.14: SS01 Energy Production Percentage by Technology for High Safety Penalty Scenario

	Risk Aversion (β)						
Technology	**0**	**0.007**	**0.017**	**0.05**	**0.1**	**0.16**	**0.5**
Coal	31.60%	84.89%	90.22%	90.22%	90.22%	92.17%	51.40%
Oil	0.22%	0.22%	0.22%	0.22%	0.22%	0.22%	0.00%
Natural Gas	68.18%	14.89%	9.56%	9.56%	9.56%	7.33%	2.04%
Nuclear	0.00%	0.00%	0.00%	0.00%	0.00%	0.28%	46.55%

It is noted from Table 7.14 that even if safety of the nuclear is charged by very large number, it start showing in the fuel mix at risk aversion around 0.16. Also, nuclear become the dominant fuel at higher risk aversion when β around 0.5. This indicated that the nuclear is recommended, as an option in the fuel mix for generation planning even at very high consideration of safety.

CHAPTER 8

IMPLEMENTATION AND RESULTS (STUDY SYSTEM SS02)

In this chapter, results related to the second study system (SS02) are provided for a normal and a number of other scenarios in order to retest the proposed model implementation.

8.1 SS02 Without-Nuclear Energy Scenario

This case presents SS02 normal scenario where the existing units are fueled by heavy fuel oil (HFO), light crude oil (LCR) and natural gas. The efficient frontier for this scenario is shown in Figure 8.1. The variance (risk cost) is on the horizontal axis and the production cost is on the vertical axis. The risk aversion factor β is a weighting parameter to balance expected production cost against the risk cost (fuel price variance). When β ranges from near zero to a very large number, the efficient frontier shown in Figure 8.1 is obtained as a result of the optimizing proposed model for the fuel diversification given previously in equation (5.6). Any point lying on the efficient frontier represents an optimal fuel mix corresponding to level of risk aversion (value of β) .

Table 8.1 presents the predicted energy production by technology in 2020 at selective values of β. Table 8.2 presents the total cost per unit for each technology.

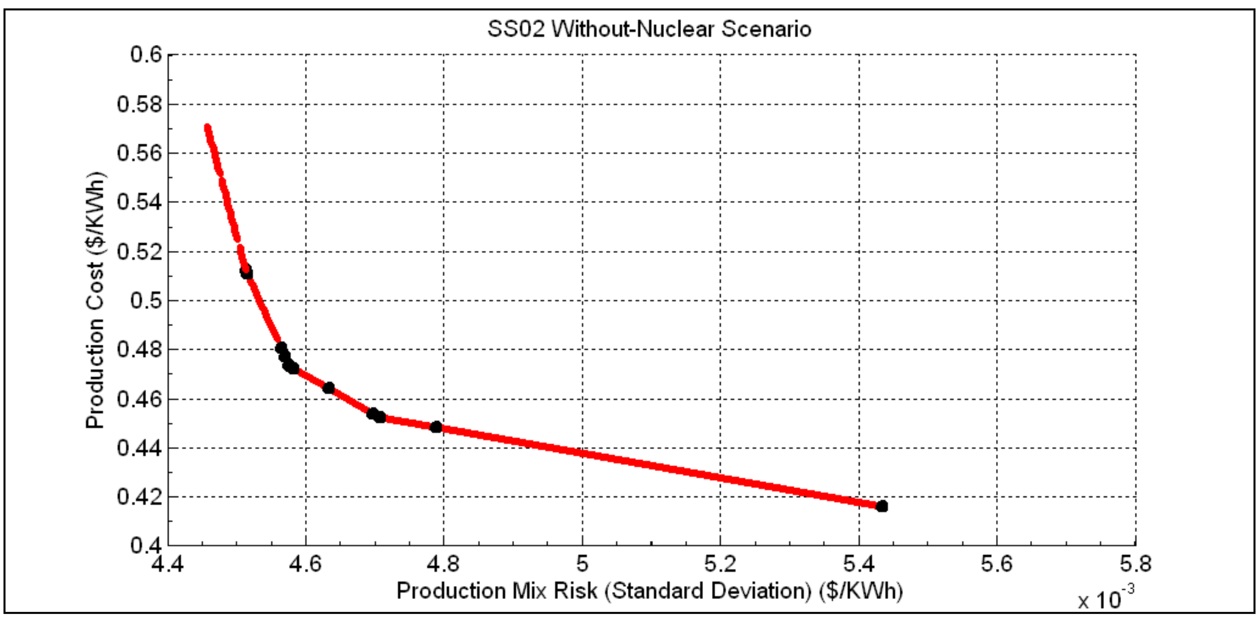

Figure 8.1: SS02 (Production-Risk) Cost Efficient Frontier for (Without-Nuclear) Scenario

Figure 8.1 shows that at mid-levels of β the efficient frontier get start to converge indicating that at these levels of risk aversion the asymptotic mean and standard deviation are quite close. Regardless of the level of risk aversion, HFO is the dominant source of energy providing over 53 to 82 percent.

Table 8.1: SS02 Energy Production Percentage by Technology at Selected Values of β in 2020 for (Without-Nuclear) Scenario

	Risk Aversion (β)				
Technology	**0**	**0.007**	**0.017**	**0.05**	**0.1**
HFO	50.07%	52.51%	78.42%	78.81%	86.54%
LCR	12.98%	12.36%	6.28%	5.89%	2.32%
Natural Gas	36.95%	35.13%	15.30%	15.30%	11.13%

Starting at low levels of risk aversion (β = 0 or near zero), HFO is the dominant fuel of generation energy (supplying 50 percent). The light crude oil (LCR) units supply 13 percent of the energy, while natural gas supply 37 percent. Some new natural gas-fired units are added for peaking loads.

For high level of risk aversion (β = 0.1), less LCR (2.32 percent) & natural gas (11.13 percent) are used, while more energy is provided by HFO (86.54 percent). The drop in both LCR and natural gas is because of their price volatility.

Table 8.2: SS02 Generation Total Cost in cent $/KWh for (Without-Nuclear) Scenario

	Risk Aversion (β)				
Per unit cost (cent $/KWh)	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Production Cost	34.8698	35.7231	38.1720	38.3377	41.6103
Mix Risk Cost	0.9123	0.6257	0.4316	0.4285	0.3834
Total Cost	35.7821	36.3488	38.6036	38.7662	41.9937

As seen in Table 8.2, the model further diversifies the fuel to reduce variance at the expense of expected cost as the level of risk aversion (β) increases. When β is near zero, cost is minimized and risk is given minimal consideration. A very large value of β indicates that risk is minimized and expected cost is given minimal consideration. Therefore, higher values of β mean greater risk aversion, with a willingness to pay a higher cost.

8.2 Nuclear Energy Scenario

In previous generation portfolio, SS02 relies on HFO and natural gas. In this section, consider a scenario when nuclear power is included to SS02 fuel mix. This can be done simply by running a program similar to the first scenario except that nuclear technology is available in the fuel planning mix. Energy demand is to be supplied by HFO, LCR, natural gas, and nuclear. Figure 8.2 shows the efficient frontier when nuclear is an option in the fuel mix. Table 8.3 presents the predicted energy production by technology in 2020 at selective values of β. Table 8.4 presents the total cost per unit for each technology when nuclear is now an option in the generation production plan of SS02.

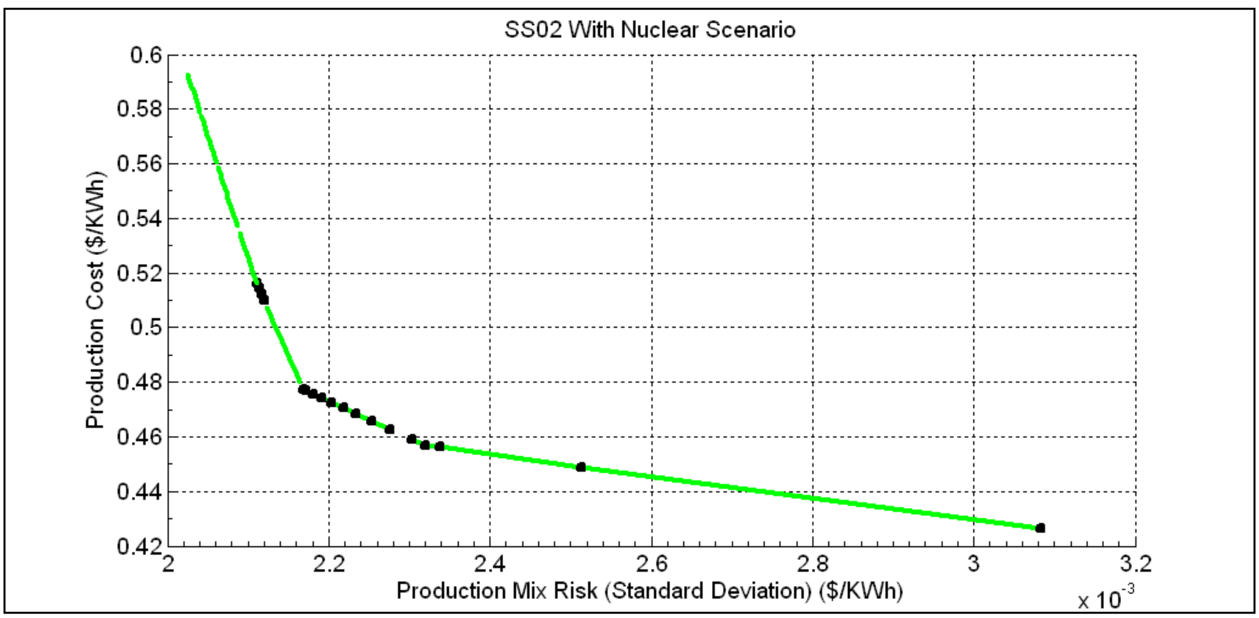

Figure 8.2: SS02 (Production-Risk) Cost Efficient Frontier for (With-Nuclear) Scenario

Figure 8.2 points that for Nuclear scenario, the mix has higher values of production cost and but less variance (risk cost).

Table 8.3: SS02 Energy Production Percentage by Technology at Selected Values of β in 2020 for (With-Nuclear) Scenario

	Risk Aversion (β)				
Technology	**0**	**0.007**	**0.017**	**0.05**	**0.1**
HFO	0.89	0.12%	0.09%	0.09%	0.09%
LCR	14.45	12.83%	7.93%	4.06%	2.10%
Natural Gas	49.05	37.01%	20.68%	15.30%	10.06%
Nuclear	35.61	50.05%	71.27%	80.55%	87.84%

When nuclear is an option in the planning fuel mix, for low values of β, the dominant source of energy is natural gas providing 49.05 percent. The electricity that would have been supplied by HFO is mainly produced from natural gas and nuclear. That is, natural gas increases (from 36.95 to 49.05 percent) and nuclear provided 35.61 percent, while HFO and LCR provide (0.9 percent) and (14 percent), respectively. Some of LCR is added for peaking purposes. For high risk aversion ($\beta = 0.1$), less natural gas (10.1 percent), light crude oil (2.1 percent), and almost no HFO (0.09 percent). It is noted that nuclear is used to replace HFO produced electricity. That is, nuclear provides more than 87 percent of energy. This result is shown in the efficient frontier indicates that have higher values of both cost and variance as in Figure 8.3.

Table 8.4: SS02 Generation Total Cost in cent $/KWh for (With-Nuclear) Scenario

	Risk Aversion (β)				
Per unit cost (cent $/KWh)	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Production Cost	35.1077	35.8200	37.9792	39.6226	42.6360
Mix Risk Cost	0.8245	0.5430	0.3450	0.2766	0.2078
Total Cost	35.9322	36.3630	38.3242	39.8992	42.8438

As seen in Table 8.4, where β increases, the model further diversifies to reduce variance at the expense of expected cost. When β is near zero, cost is minimized and risk is given minimal consideration, while a very large value of β indicates that risk is minimized and expected cost is given minimal consideration.

Results shown in Table 8.4 seem to coincide with what is observed in Figure 8.2 in the sense that the expected total production cost per unit of energy ($/kWh) gradually increases as the majority of the mix diversifies away from HFO & natural gas to nuclear. This generally costs more to produce due to a larger fixed cost. So, the demand is to be met by power generated only from light crude oil and natural gas and nuclear.

8.2.1 Comparison between With & Without Nuclear Scenarios

Figure 8.3 shows the efficient frontiers for with and without nuclear cases at selective values of β. It is clear that the With-Nuclear scenario presents a different and better set of results when compared to the Without-Nuclear case. In Figure 8.3, the efficient frontier points that for With-Nuclear scenario, the mix has higher production cost but less risk cost (variance).

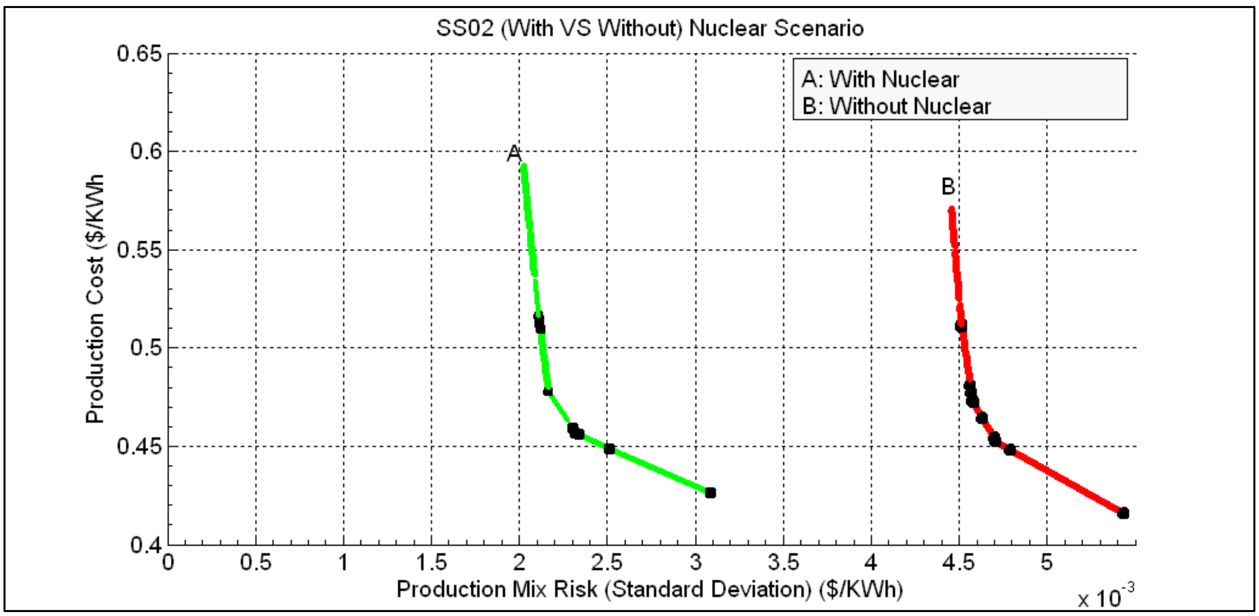

Figure 8.3: SS02 (With VS. Without) Nuclear Scenarios Comparison

Figure 8.3 combines Figures 8.1 & 8.2. As seen in Figure 8.3, the graph for the With-Nuclear scenario lies above of the Without-Nuclear scenario indicating higher expected total cost per unit of energy for all the optimal mixes. Also, the figure shows the plot for the Without-Nuclear scenario lies to the right of the With-Nuclear scenario indicating higher variance cost per unit of energy for all the optimal mix.

Furthermore, it can be seen from Figure 8.3 that at low level of β (low risk aversion), the production cost is (43 cent $/ kWh), while the standard deviation is (0.32 cent $/ kWh). This is a result of the model using less of the high variance nuclear and toward higher production cost alternatives. At the opposite end of the spectrum (high level of β), the production cost is (55 cent $/ kWh), while the standard deviation is (0.21 cent $/ kWh). This result could be expected as the model looks to mitigate risk at any cost.

At same level of risk aversion, with-nuclear case has a little higher production cost (48 cents per kWh) than without nuclear case (46 cents per kWh). However, the variance cost (0.23 cents per kWh) in with-nuclear scenario is less than without nuclear case (0.46 cents per kWh)

Table 8.5 gives comparison between with and without nuclear scenarios for the total cost per unit of energy. It shows that the production cost has a slight increase from (Without-Nuclear) scenario to (with nuclear) scenario where we can notice major decrease in the risk cost.

Table 8.5: SS02 Total cost for Comparison between With & Without Nuclear Scenario

		Risk Aversion (β)				
		0	**0.007**	**0.017**	**0.05**	**0.1**
Production Cost (cent $/KWh)	With Nuclear	35.1077	35.8200	37.9792	39.6226	42.6360
	Without Nuclear	34.8698	35.7231	38.1720	38.3377	41.6103
Mix Risk Cost (cent $/KWh)	With Nuclear	0.8245	0.5430	0.3450	0.2766	0.2078
	Without Nuclear	0.9123	0.6257	0.4316	0.4285	0.3834
Total Cost (cent $/KWh)	With Nuclear	35.9322	36.3630	38.3242	39.8992	42.8438
	Without Nuclear	35.7821	36.3488	38.6036	38.7662	41.9937

For low risk aversion (low value of β), the production cost (mean) increases slightly from 35.1077 cent $/KWh to 34.8698 cent $/KWh [1 percent increase]; and decreased in the mix risk cost (variance) from 0.9123 cent $/KWh to 0.8245 cent $/KWh [9 percent decrease]. The total cost is the total summation between production and mix risk costs. It is clear that the total cost increased slightly from 35.7821 cent $/KWh (Without-Nuclear) scenario to 35.9322 cent $/KWh (with nuclear) scenario [less than 1 percent increase].

For high risk aversion (high value of $\beta = 0.1$) the mean price (production cost) was increased from 41.6103 cent $/KWh to 42.6360 cent $/KWh [2 percent increase]; and clear decrease in the variance price (mix risk cost) from 0.3834 cent $/KWh to 0.2078 cent $/KWh [46 percent decrease]. The total cost increased slightly from 41.9937 cent $/KWh (Without-Nuclear) scenario to 42.8438 cent $/KWh (with nuclear) scenario [2 percent increase].

To conclude, the total cost (production cost and risk cost summation) is slightly higher for with nuclear scenario than without nuclear scenario. For, these reasons more constraints will be included. The following section is considering CO2 emissions as cost to see if nuclear still not recommended being an option.

8.3 Effect of Carbon Dioxide Emission Costs in SS02

In similar manner to section 7.3, the alternative scenario in which the carbon dioxide emission is penalized is now considered. All fuel costs and variances as described previously in section 6.2, are applied to the problem model equation (5.7). In this scenario, fuel costs are increased proportionately to their CO2 emission.

8.3.1 Effect of Carbon Dioxide Emission on (Without-Nuclear) Energy Scenario

The Without-Nuclear scenario for SS02 is represented in order to display the effect of CO2 emission on this scenario. This can be done by using all fuel costs factors and price variances as marked earlier in sections 6.2 & 6.3 and applied it to the model equation (5.7) in order to demonstrate the capability for each technology to absorb the cost related to carbon emission.

Table 8.6 presents the predicted energy production by technology in 2020 at selective values of β under the effect of CO2 emissions. Correspondingly, Table 8.7 presents the total cost per unit for each technology.

Table 8.6: SS02 Energy Production Percentage by Technology for (With-Nuclear) Scenario - Effect of Carbon Emission

	Risk Aversion (β)				
Technology	**0**	**0.007**	**0.017**	**0.05**	**0.1**
HFO	47.61	51.38%	78.42%	78.83%	86.45%
LCR	14.54	12.62%	6.28%	5.87%	2.34%
Natural Gas	37.85	35.99%	15.30%	15.30%	11.21%

In the carbon cost scenario, the carbon dioxide cost adder impacts the various fuels differently, since different fuels have different carbon contents. The highest carbon content fuel is HFO. It experiences the greatest impact. It is followed by LCR and natural gas. For this reason there is no noticeable influence for the carbon emission effect in generation percentage by technology. For example, there is slight drop in electricity from HFO from (50 to 47 percent).

Table 8.7: SS02 Generation Total Cost in cent $/KWh for (With-Nuclear) Scenario - Effect of Carbon Emission

	Risk Aversion (β)				
Per unit cost (cent $/KWh)	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Production Cost	37.89	38.3421	40.9609	41.1379	44.3682
Mix Risk Cost	0.6888	0.6356	0.4316	0.4282	0.3838
Total Cost	38.5788	38.9777	41.3925	41.5661	44.7519

The primary effect of the carbon dioxide emission cost is to increase the production cost while having little impact on risk cost (variance). Thus, the efficient frontier for the Without-Nuclear case lies directly under the frontier for carbon cost as shown in Figure 8.4.

Figure 8.4 includes the efficient frontiers with and without carbon cost cases determined by the equation (5.7) in order to show the effect of carbon emission on the without nuclear scenario. The curve labeled “CO2 considered” in Figure 7.7 assumes a cost adder of $32.5/ton for emitting carbon dioxide.

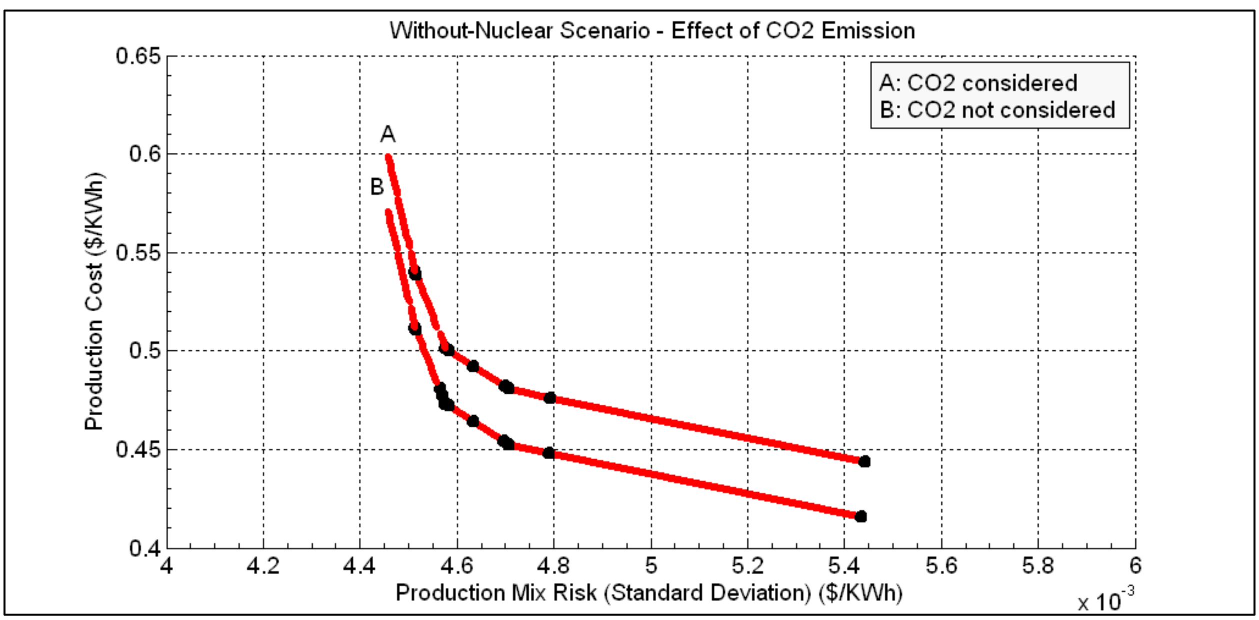

Figure 8.4: SS02 (Production-Risk) Cost Efficient Frontier for (Without-Nuclear) Scenario - Effect of Carbon Emission

8.3.2 Effect of Carbon Dioxide Emission on Nuclear Energy Scenario

The Nuclear scenario for SS02 is represented in order to display the effect of CO2 emission on this scenario. The plot labeled “CO_2 Considered” in efficient frontiers shown in Figure 8.5 is obtained as a result of the optimizing proposed model for the fuel diversification given previously in equation (5.7) by changing β from near zero to a very large number. Nuclear energy has no cost adder since it emits no carbon dioxide.

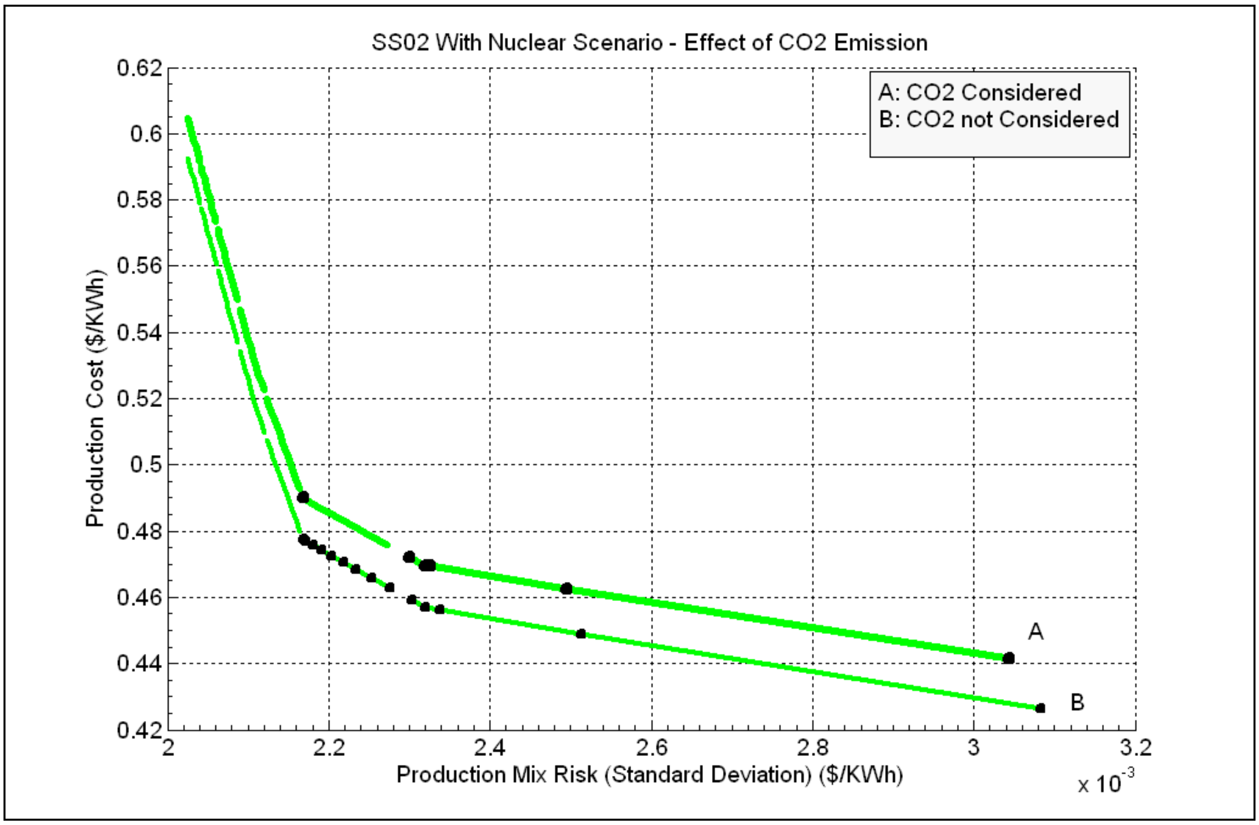

Figure 8.5: SS02 (Production-Risk) Cost Efficient Frontier for (With-Nuclear) Scenario – Effect of Carbon Emission

The efficient frontier when CO2 emission is considered lies above the normal curve (if CO2 not considered). This happens because the main impact of the carbon dioxide emission cost is to increase the production cost, whereas having a slight effect on the risk cost (variance). The plot labeled “CO_2 considered” assumes a cost adder of $32.5/ton of carbon dioxide emitted.

Table 8.8 presents the predicted energy production by technology in 2020 at selective values of β under the effect of CO2 emissions. Correspondingly, Table 8.9 presents the total cost per unit for each technology.

Table 8.8: SS02 Energy Production Percentage by Technology for (With-Nuclear) Scenario - Effect of Carbon Emission

	Risk Aversion (β)				
Technology	**0**	**0.007**	**0.017**	**0.05**	**0.1**
HFO	0.89	0.12%	0.09%	0.09%	0.00%
LCR	14.45	12.83%	7.93%	4.06%	2.10%
Natural Gas	49.05	37.01%	20.68%	15.30%	10.06%
Nuclear	35.61	50.05%	71.27%	80.55%	87.84%

When nuclear is an option, for a high value of β there is a noticeable difference between the two cases (with and without carbon emission effect). The HFO has the highest carbon content , so it experiences the greatest impact. It is followed by LCR and natural gas. On the other hand, it is noticed that nuclear energy has the least cost adder since it emits almost no carbon dioxide.

Table 8.9: SS02 Generation Total Cost in cent $/KWh for (Without-Nuclear) Scenario - Effect of Carbon Emission

	Risk Aversion (β)				
Per unit cost (cent $/KWh)	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Production cost	37.0199	37.8307	39.0194	40.4013	44.1573
Mix risk cost	0.4944	0.4471	0.3208	0.2682	0.2050
Total cost	37.5143	38.2778	39.3402	40.6695	44.3623

The primary effect of the carbon dioxide emission cost is to increase the production cost while having little impact on risk cost (variance). Thus, the efficient frontier for the Without-Nuclear case lies directly under the frontier for carbon cost as shown in Figure 8.5.

8.3.3 Comparison between With & Without Nuclear Scenarios with Effect of CO2 Emission

The with-nuclear scenario provides a different and better set of results when compared to the without-nuclear scenario. Starting with the low values of β, the efficient frontier points have a lower cost and lower variance than the equivalent points from the (Without-Nuclear) scenario.

Table 8.10 gives compassion between with and without nuclear scenarios for the total cost per unit of energy in case of the effect of carbon emission. It shows the total cost increases from With-Nuclear scenario to Without-Nuclear scenario.

Table 8.10: SS02 Total cost for Comparison between With & Without Nuclear Scenario- Effect CO2 Emission

		Risk Aversion (β)				
		0	**0.007**	**0.017**	**0.05**	**0.1**
Production Cost (cent $/KWh)	With Nuclear	37.0199	37.8307	39.0194	40.4013	44.1573
	Without Nuclear	37.8900	38.3421	40.9609	41.1379	44.3682
Mix Risk Cost (cent $/KWh)	With Nuclear	0.4944	0.4471	0.3208	0.2682	0.2050
	Without Nuclear	0.6888	0.6356	0.4316	0.4282	0.3838
Total Cost (cent $/KWh)	With Nuclear	37.5143	38.2778	39.3402	40.6695	44.3623
	Without Nuclear	38.5788	38.9777	41.3925	41.5661	44.7519

For low level of risk aversion (β equal to near zero), the production cost is (37.8900 & 37.0199 cent $/ kWh) [2 percent decrease], while the risk cost (standard deviation) is (0.6888 & 0.4944 cent $/ kWh) [28 percent decrease] for without and with nuclear respectively. At the opposite end of the spectrum (high level of risk aversion), the production cost is (44.3682 & 44.1573 cent $/ kWh) [1 percent decrease], while the standard deviation cost is (0.3838 & 0.2050 cent $/ kWh) [44 percent decrease] for without and with nuclear respectively. This indicates that the system is using less of the high variance (LCR & natural gas) and toward to have lower cost alternatives such as nuclear. Furthermore, Table 8.7 shows that the total cost (production cost and risk cost summation) decreases from 41.5661 cent $/ kWh (With-Nuclear) scenario to 40.6695 cent $/ kWh (Without-Nuclear) scenario [3 percent decrease]. This result gives us a major advantage for using nuclear energy scenario.

Figure 8.6 shows the efficient frontiers for with and without nuclear cases at selective values of β for the effect of carbon emission.

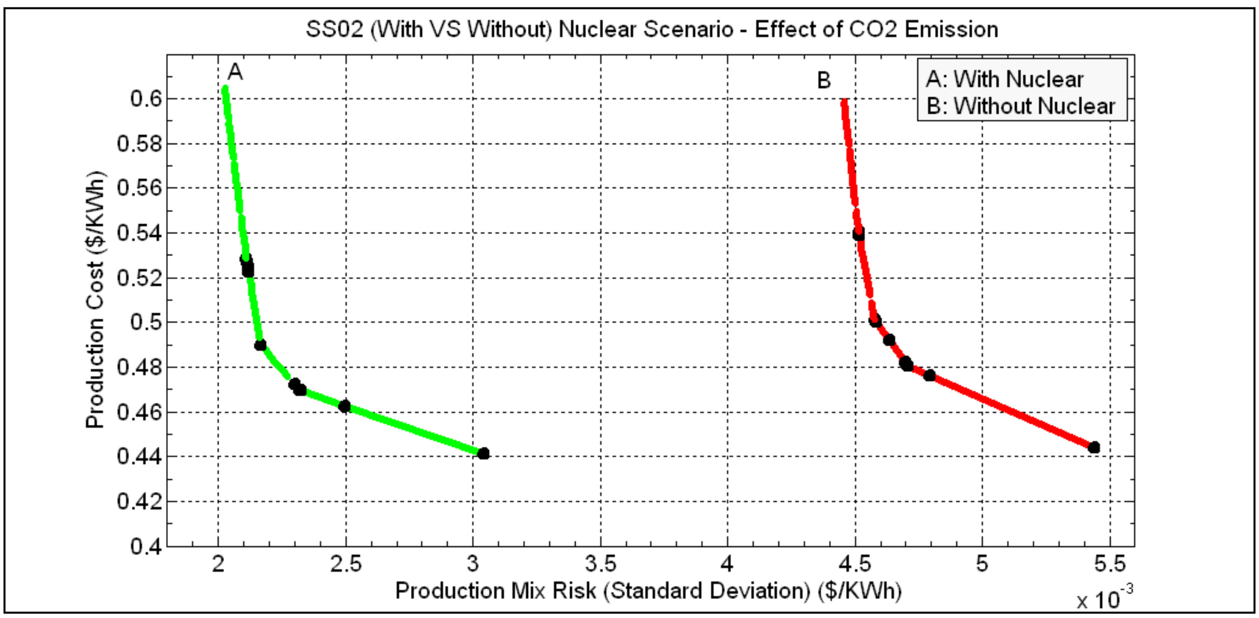

Figure 8.6: SS02 (With VS. Without) Nuclear Scenarios Comparison - Effect of Carbon Emission

Figure 8.6 shows the combination between the scenarios for SS02 under effect of carbon emission effect. As seen in Figure 8.6, the frontier for the (With-Nuclear) scenario lies below and to the left of the (Without-Nuclear) scenario, indicating less expected production (mean) and risk (variance) costs per unit of energy for all the optimal mixes. It is clear that the total cost decreases from 44.75 cent $/KWh (in Without-Nuclear scenario) to 44.36 cent $/KWh (in With-Nuclear scenario).

To conclude, the with-nuclear option gives better results than without nuclear both if carbon dioxide emission is considered. So, it is recommended to go with nuclear as an option in the fuel mix plan. The following section will test the use of nuclear when safety issues are considered.

8.4 Analysis When Safety is taken into consideration for SS02

The model is tested on the use of nuclear power usage based on the safety issues related to nuclear plants.

An alternate scenario is considered in which the safety of nuclear plant is penalized as a cost adder. This can be done by using all fuel costs factors and price variances as marked earlier in sections 6.2, 6.3 & 6.4.1 and applied it to the model equation (5.8) in order to demonstrate the effect of normal consideration of safety on the last result where carbon emission effect is emphasized. It is clear from the data given in section 6.4 that the nuclear energy is the only technology that will affected by safety element. In this scenario, fuel cost for nuclear is increased proportionately to its safety element. The objective in this section is to determine how much the proposed model will be affected when safety is taken into consideration.

The efficient frontier shown in Figure 8.7 is obtained as a result of the solving proposed model for the fuel diversification given previously in equation (5.8) by changing β from near zero to a very large number. Table 8.11 presents the predicted energy production by technology in 2020 at selective values of β under the effect of safety of nuclear energy. Table 8.12 presents the total cost per unit for each technology.

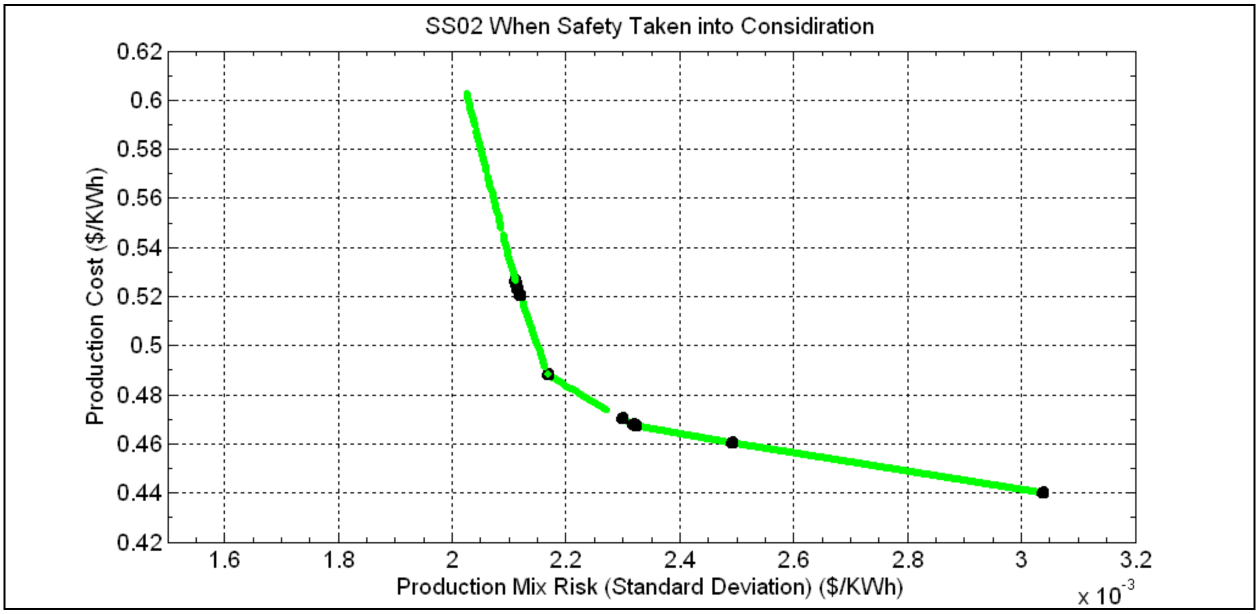

Figure 8.7: SS02 (Production-Risk) Cost Efficient Frontier for (With-Nuclear) Scenario – If Safety Is Taken into consideration

Table 8.11: SS02 Energy Production Percentage by Technology for With-Nuclear Scenario- If Safety is taken into consideration

	Risk Aversion (β)				
Technology	**0**	**0.007**	**0.017**	**0.05**	**0.1**
HFO	0.00%	0.00%	0.00%	0.00%	0.00%
LCR	13.61%	11.56%	7.37%	3.58%	2.03%
Natural Gas	36.84%	32.52%	18.83%	15.30%	9.72%
Nuclear	49.55%	55.92%	73.80%	81.12%	88.25%

Table 8.12: SS02 Generation Total Cost in cent $/KWh for With-Nuclear Scenario – If Safety is taken into consideration

	Risk Aversion (β)				
Per unit cost (cent $/KWh)	**0**	**0.007**	**0.017**	**0.05**	**0.1**
Production cost	38.09	38.1439	39.6620	41.1315	43.9994
Mix risk cost	0.4778	0.4816	0.3292	0.2708	0.2046
Total cost	38.567	38.6255	39.9913	41.4022	44.2039

In this scenario, the safety element cost adder impacts nuclear and non-nuclear fuels differently. Nuclear fuel has the highest impact. The effect of the safety cost is to increase the cost while having little impact on variance.

8.5 Final Results: SS02 Power Generation Planning in 2020

Three cases were discussed for three different scenarios. The first is the SS02 Without-Nuclear scenario that is based on normal plan relative to 2008 in SS02. The second scenario is when carbon emission is considered. The third is taking the safety issues in the normal consideration. For SS02 power generation planning in 2020, the third scenario "with nuclear" is used in the projected energy generation planning. The planning is developed based on the model that takes both CO_2 emission and safety in the consideration in all obtained results.

Table 8.13 provides the detailed portfolios for each of five (5) selected values of the risk aversion factor (β). They are grouped by fuel type (HFO, LCR, natural gas, and nuclear), within technology by existing versus new energy. For each energy fuel/technology, existing and new energy production, expected production standard deviations of cost are all indicated.

Table 8.13: 2020 Predicted Energy Production by Technology (GWh) for SS02

		Risk Aversion (β)				
Technology		**0**	**0.007**	**0.017**	**0.05**	**0.1**
HFO	Existing	0	0	0	0	0
	New	0	0	0	0	0
	Total Coal	0	0	0	0	0
LCR	Existing	5874	5652	5101	1404	1020
	New	37162	7850	4027	3029	1491
	Total Oil	43036	13502	9128	4433	2511
Natural Gas	Existing	80864	40296	23333	18954	12048
	New	0	0	0	0	0
	Total Gas	80864	40296	23333	18954	12048
Nuclear	Existing	0	0	0	0	0
	New	0	69282	91439	100513	109342
	Total Nuclear	0	69282	91439	100513	109342
Expected Production cost (million $)		41449.08	47261.12	49142.07	50962.71	54516.08
Variance of cost (million $2)		2072185.89	356039.19	166374.87	112561.99	64234.15
S.D. of cost (million $)		1439.5089	596.6902	407.8908	335.5026	253.4446
Expected unit cost ($/kWh)		0.3345	0.3814	0.3966	0.4113	0.4400
Unit S.D. of cost ($/kWh)		0.0116	0.0048	0.0033	0.0027	0.0020
Total Cost ($/kWh)		**0.3461**	**0.3862**	**0.3999**	**0.4140**	**0.4420**

To begin with, consider the lower level of risk aversion ($\beta = 0.007$). The existing Natural Gas is used to generate 40,296 GWh of energy. No new Natural Gas energy is added. The existing LCR of 5,652 GWh is used and adding new LCR to generate 7,850 GWh , reflecting the usefulness of this existing capacity for serving extreme peak loads despite its high variable cost. Finally for SS02, no nuclear energy exists but new nuclear energy of 69,282 GWh is fully utilized. The expected production cost is about $47, 26 billion. The standard deviation of costs due to variations in fuel prices is about $596.69 million. On a per kWh basis, the expected cost of generation is $0.38, with a standard deviation of $0.012. It is very clear that HFO is no longer needed either existing or new units

Moving across the columns of Table 8.11, the risk aversion rises, and the total energy fueled by Natural Gas and LCR drops substantially with the gap being filled primarily by nuclear generation. The full existing Natural Gas capacity is used in the intermediate risk aversion case. The other changes in capacity and utilization are relatively minor. The minor amount of LCR capacity is fully utilized in the Without-Nuclear case, but delayed in the cases with higher risk aversion. The expected costs increase by about $3 billion as risk aversion moves from 0.007 to 0.05. The standard deviation of costs due to variations in fuel prices decrease by about $261.2 million. On a per kWh basis, the expected cost of generation increases from $0.381 to $0.411 to $0.135, while the standard deviation of cost decreases from $0.0048 to $0.0027 to $0.0020.

To conclude, it is recommended to have nuclear fuel as an option in SS02 fuel mix for 2020 generation planning. This recommendation is a result of that with-nuclear gives better result than without from cost point of view if CO2 is considered. We can notice this conclusion even the safety for nuclear is penalized as cost.

8.6 Effect of High Safety Penalty

This section attempts to answer the question "is nuclear still proposed if safety weighting factor (F) assigned with too high value, that is higher consideration for safety?" To answer this question, WF is assigned a value of 100. Then the model equation (5.8) is solved in order to demonstrate the effect of higher consideration for nuclear safety.

The efficient frontier shown in Figure 8.8 is obtained as a result of the optimizing proposed model for the fuel diversification given previously in equation (5.8) by changing β from near zero to a very large number. Table 8.14 presents the predicted energy production by technology in 2020 at selective values of β under the effect higher consideration of safety for nuclear energy.

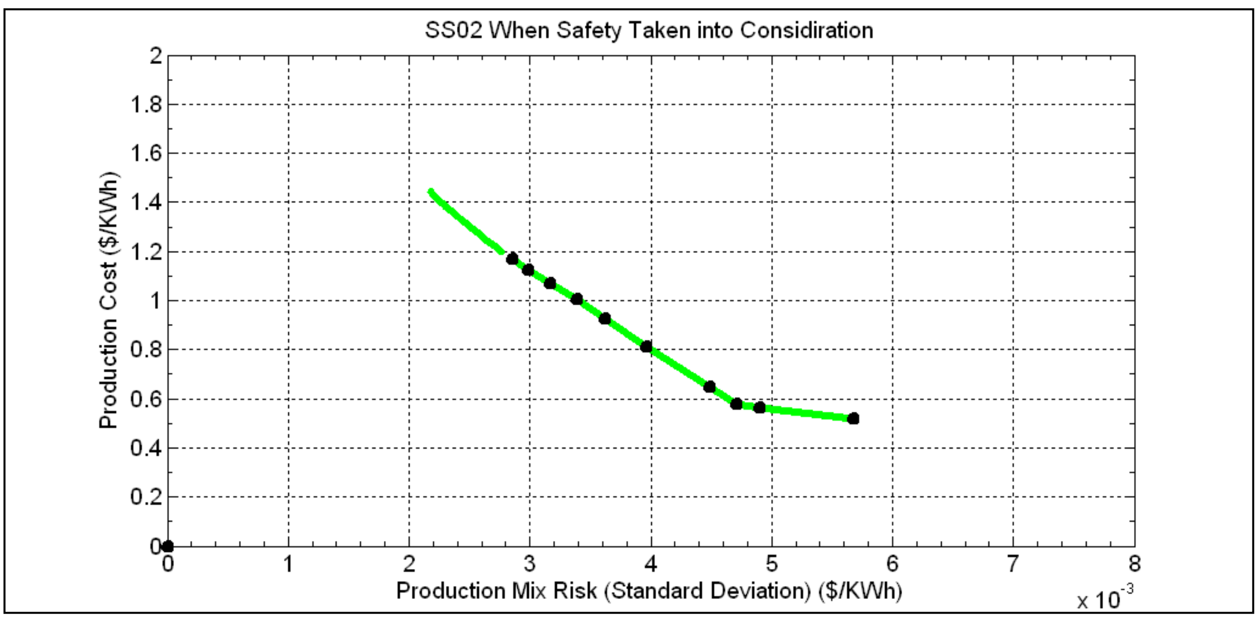

Figure 8.8: SS02 Efficient Frontier for High Safety Penalty Scenario

Table 8.14: SS02 Energy Production Percentage by Technology for High Safety Penalty Scenario

	Risk Aversion (β)						
Technology	**0**	**0.007**	**0.017**	**0.05**	**0.1**	**0.4**	**0.7**
Coal	0.00%	16.94%	65.69%	78.83%	83.78%	87.25%	46.62%
Oil	21.58%	20.69%	9.27%	5.87%	2.80%	0.82%	0.82%
Natural Gas	78.42%	62.36%	25.04%	15.30%	13.41%	4.02%	4.02%
Nuclear	0.00%	0.00%	0.00%	0.00%	0.00%	7.90%	48.53%

It is noted from Table 8.14 that even if safety of the nuclear is charged by very large number (high weighted factor of safety), it starts showing in the fuel mix at risk aversion around 0.4. Also, nuclear become the dominant fuel at higher risk aversion when β around 0.7. This indicated that the nuclear is still recommended as an option in the fuel mix for generation planning even at very high consideration of safety.

CHAPTER 9

CONCLUSION & FUTURE WORK

9.1 Conclusion

The goal of this thesis was to determine an optimal fuel mix for electricity generation planning using an advanced Mean-Variance portfolio optimization method. The generation fuel mix may include the nuclear energy as an option. The cost variance is the cost resulted from the mix fuel price variation, and called the mix risk cost. In order to have the optimal fuel mix, both production cost and mix risk cost need to be minimized. So it is recommended to divert from the risk in order to get less cost. Numerical results proved that more aversion from the risk (fuel price variation), less risk cost and hence less total production cost to generate electricity. The fuel of nuclear is uranium which has a stable price (no variation) which will add a riskless element to the whole system resulting in less total cost. Data for two (2) study systems provide numerical results that illustrate the use of the proposed portfolio method. The model has the capability to be used for scenario analysis such as the case of higher carbon dioxide costs or when a certain technology or fuel choice is eliminated. Also, the model has the capability to be used for scenario analysis when safety is taken into account.

Finally, it is recommended to have the nuclear fuel as an option in the fuel mix of generation planning for both study systems. This recommendation is a result of that with-nuclear scenario gives better result than without from cost point of view. This result is noticeable even the safety for nuclear is penalized as a cost.

9.2 Future Work

In the future, the following works can be practiced:

- Renewable energy could be used with nuclear to be added in the generation fuel mix.
- The effects of the number of load factors on the improvement in the mean-variance frontiers.
- Finally, selecting the value of risk aversion (β) that will give the optimal fuel mix

APPENDIX

Characteristics of Proposed Steam Units.

Operating Area	ISO Rating (MW)	Net Site Rating (MW)	Heat Rate (BTU/kWh)	Primary Fuel	Capital Cost (SR/kW)
EOA	800	800	9,410	HCR	7,500
	600	600	9,420	HCR	8,000
WOA	600	600	9,420	HCR	8,000
SOA	400	400	9,430	HCR	9,000
	250	250	9,460	HCR	9,300
YIC	250	250	9,460	HCR	9,300

Characteristics of Proposed Gas Turbines.

Operating Area	ISO Rating (MW)	Site Rating (MW)	Heat Rate (BTU/kWh)	Primary Fuel	Capital Cost (SR/kW)
EOA	85	57	11,700	LCR	5,570
	165	127	10,000	NG	5,200
COA	85	53	12,100	LCR	5,570
	165	120	10,000	NG	5,200
WOA	85	57	11,700	LCR	5,570
SOA	85	60	11,700	LCR	5,570
YIC	85	57	11,700	LCR	5,570

Characteristics of Proposed Combined Cycle Units.

Operating Area	ISO Rating (MW)	Site Rating (MW)	Heat Rate (BTU/kWh (HHV)	Primary Fuel	Cost (SR/kW)
EOA	800	632	5,954	NG	6,500
COA	560	450	6,200	NG	6,500

Characteristics of the proposed generating units.

Unit Type	ISO Rating (MW)	Primary Fuel	EFOR (%)	Maintenance (Weeks)	Fixed O&M (SR/kW-Yr)	Variable O&M (SR/MWh)
ST	800	HCR	6	6	37.5	5.7
ST	600	HCR	6	6	42	6.15
ST	400	HCR	6	6	52.5	7.95
ST	250	HCR	6	6	64.5	9.6
CC	800	NG	8	6	37.5	10.2
CC	560	NG	8	6	46.5	12.45
GT	85	LCR	9	4	45	16.5
GT	165	NG	9	4	42	15

Cash flow and operating life for generation expansion

Unit Type	ISO Rating (MW)	Primary Fuel	Operating Life (Years)	Const. Period (Years)	Annual Construction Cash Flow			
					Year 1	Year 2	Year 3	Year 4
					(%)	(%)	(%)	(%)
ST	800	HCR	35	4	9	32	32	27
ST	600	HCR	35	4	9	32	32	27
ST	400	HCR	35	4	9	32	32	27
ST	250	HCR	35	4	9	32	32	27
CC	800	NG	30	3	35	40	25	-
CC	560	NG	30	3	35	40	25	-
GT	165	NG	25	3	35	35	30	-
GT	85	LCR	25	3	35	35	30	-

Domestic fuel prices.

Fuel Type	Fuel Price ($/BBL)	Fuel Price (SR/BBL)	Heat Content HHV (MMBTU/m^3)	Heat Content LHV (MMBTU/m^3)	Fuel Price HHV (SR/MMBTU)	Fuel Price LHV (SR/MMBTU)
NG	-	-	0.042	0.038	2.55	2.81
LCR	4.24	15.9	35.96	33.93	2.78	2.95
DO	3.6	13.51	36.09	34.05	2.36	2.5
HFO 180cst	2.54	9.54	38.9	-	1.54	-
HFO 380 cst	2.08	7.79	40.61	-	1.21	-
HCR	2.67	10.02	37.1	-	1.7	-

Shadow fuel prices.

Fuel Type	Fuel Price ($/BBL)	Fuel Price (SR/BBL)	Heat Content HHV (MMBTU/m3)	Heat Content LHV (MMBTU/m3)	Fuel Price HHV (SR/MMBTU)	Fuel Price LHV (SR/MMBTU)
NG	-	-	0.042	0.038	12.26	13.5
LCR	16.6	62.24	35.96	33.93	10.89	11.54
DO	20.25	75.95	36.09	34.05	13.24	14.03
HFO 180cst	12.8	48	38.9	-	7.76	-
HFO 380 cst	12.21	45.79	40.61	-	7.09	-
HCR	13.2	49.49	37.1	-	8.39	-

Table A.3. Carbon Dioxide Uncontrolled Emission Factors

Fuel	EIA Fuel Code	Source and Tables (As Appropriate)	Factor (Pounds of CO_2 Per Million Btu)***
Bituminous Coal	BIT	Source: 1	205.30000
Distillate Fuel Oil	DFO	Source: 1	161.38600
Geothermal	GEO	Estimate from EIA, Office of Integrated Analysis and Forecasting	16.59983
Jet Fuel	JF	Source: 1	156.25800
Kerosene	KER	Source: 1	159.53500
Lignite Coal	LIG	Source: 1	215.40000
Municipal Solid Waste	MSW	Source: 1 (including footnote 2 within source)	91.90000
Natural Gas	NG	Source: 1	117.08000
Petroleum Coke	PC	Source: 1	225.13000
Propane Gas	PG	Sources: 1	139.17800
Residual Fuel Oil	RFO	Source: 1	173.90600
Synthetic Coal	SC	Assumed to have the emissions similar to Bituminous Coal.	205.30000
Subbituminous Coal	SUB	Source: 1	212.70000
Tire-Derived Fuel	TDF	Source: 1	189.53800
Waste Coal	WC	Assumed to have emissions similar to Bituminous Coal.	205.30000
Waste Oil	WO	Source: 2, Table 1.11-3 (assumes typical heat content of 4.4 MMBtus per barrel)	210.00000

Notes:
****** CO_2 factors do not vary by combustion system type or boiler firing configuration.***

Sources:
1. Energy Information Administration, Office of Integrated Analysis and Forecasting, Voluntary Reporting of Greenhouse Gases Program, Table of Fuel and Energy Source: Codes and Emission Coefficients; available at: http://www.eia.doe.gov/oiaf/1605/coefficients.html
2. U.S. Environmental Protection Agency, AP 42, Fifth Edition (Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources); available at: http://www.epa.gov/ttn/chief/ap42/

http://www.eia.gov/electricity/annual/html/epa_a_03.html [24]

Table 8.2. Average Tested Heat Rates by Prime Mover and Energy Source, 2007 - 2011

(Btu per Kilowatthour)

Prime Mover	Coal	Petroluem	Natural Gas	Nuclear
2007				
Steam Generator	10,158	10,398	10,440	10,489
Gas Turbine	--	13,217	11,632	--
Internal Combustion	--	10,447	10,175	--
Combined Cycle	W	10,970	7,577	--
2008				
Steam Generator	10,138	10,356	10,377	10,452
Gas Turbine	--	13,311	11,576	--
Internal Combustion	--	10,427	9,975	--
Combined Cycle	W	10,985	7,642	--
2009				
Steam Generator	10,150	10,349	10,427	10,459
Gas Turbine	--	13,326	11,560	--
Internal Combustion	--	10,428	9,958	--
Combined Cycle	W	10,715	7,605	--
2010				
Steam Generator	10,142	10,249	10,416	10,452
Gas Turbine	--	13,386	11,590	--
Internal Combustion	--	10,429	9,917	--
Combined Cycle	W	10,474	7,619	--
2011				
Steam Generator	10,128	10,414	10,414	10,464
Gas Turbine	--	13,637	11,569	--
Internal Combustion	--	10,428	9,923	--
Combined Cycle	W	10,650	7,603	--

Notes: W = Withheld to avoid disclosure of individual company data.

Heat rate is reported at full load conditions for electric utilities and independent power producers.
The average heat rates above are weighted by Net Summer Capacity.
Coal Combined Cycle represents integrated gasification units.

Source: U.S. Energy Information Administration, Form EIA-860, 'Annual Electric Generator Report.'

http://www.eia.gov/electricity/annual/html/epa_08_02.html [25]

REFERENCES

[1] N. Nabona and P. Adela, “Long-Term Electric Power Planning In Liberalized Markets Using The Bloom And Gallant Formulation”, The University Of Engineering Of Barcelona, Spain, 2004: pp. 3-10.

[2] “Energy and Nuclear Power Planning Study For Armenia”IAEA-TECDOC-1404, July 2004. Available: http://www-pub.iaea.org/MTCD/publications/PDF/te_1404_web.pdf

[3] M. Ben Abdelhamid, C. Aloui and C. Chaton, "The Role Of Nuclear Power In Reducing Risk Of The Fossil Fuel Price And Diversity Of Electricity Generation Portfolio in Tunisia", Public Utility Research Center, JEL classification: C61, D81, L52, Q42, 2009: pp. 4-9.

[4] WNA Report, “The New Economics of Nuclear Power”, World Nuclear Association, 2012: pp. 11-24. Available: http://pbadupws.nrc.gov/docs/ML1000/ML100050089.pdf.

[5] I. N. Kessides, “Nuclear Power: Understanding the Economic Risks and Uncertainties”, The Energy Policy journal 38 (2010) 3849–3864, 2010.

[6] K. Irie, “The Economics of Nuclear Energy”, Institute of energy Economics (IEEJ), Japan, April 2009.

[7] M. T. Hogue, “A Review of the Costs of Nuclear Power Generation”, University of Utah, Bureau of Economic and Business Research (BEBR), USA, March 2012: pp. 9-51

[8] M. Ayres, M. MacRae and M. Stogran, “Levelised Unit Electricity Cost Comparison of Alternate Technologies for Baseload Generation in Ontario”, Canadian Energy Research Institute, August 2004: pp. 20-65.

[9] F. Susan and A. Okie, "Fuel Diversity in the New York Electricity Market", New York Independent System Operator (ISO), October 2008: pp. 8-30.

[10] S. Awerbuch, “Portfolio-Based Electricity Generation Planning: Implications for Renewable and Energy Security”, Basel Agency for Sustainable Energy (BASE), May 2004: pp. 3-9.

[11] S. Awerbuch, Barger “Efficient Electricity Generating Portfolios For Europe: Maximizing Energy Security And Climate Change Mitigation”, EIB PAPERS Volume12 N°2, 2007: pp. 3-40.

[12] S. Thomas, “The Economics of Nuclear Power”, World Institute of Scientology Enterprises (WISE), December 2005: pp. 5-35.

[13] Bar-Lev, D., and Katz, S., "A Portfolio Approach to Fossil Fuel Procurement in the Electric Utility Industry." Journal of Finance, June 31(3), 2012: pp. 933-947.

[14] H. Beltran, “Modern Portfolio Theory Applied To Electricity Generation Planning”, Master in Science in Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, 2009: pp. 21-52.

[15] http://www.euronuclear.org/info/encyclopedia/n/nuclear-power-plant-world-wide.htm; accessed in 01/02/2013.

[16] http://www.nei.org/resourcesandstats/nuclear_statistics/worldstatistics; accessed in 01/02/2013.

[17] “Energy, Electricity and Nuclear Power Estimates for The Period Up To 2030”, International Atomic Energy Agency, 2009: pp. 12-53.
Available: http://www-pub.iaea.org/MTCD/publications/PDF/RDS1-29_web.pdf.

[18] http://www.world-nuclear.org/info/Current-and-Future-Generation/Nuclear-Power-in-the-World-Today/; accessed in 20/04/2013.

[19] http://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-54.html; accessed in 02/03/2013.

[20] http://world-nuclear.org/; accessed in 01/02/2013.

[21] http://www.energy.gov.sa/en; accessed in 13/12/2012.

[22] http://www.power-eng.com; accessed in 01/03/2013.

[23] D. Gotham, K. Muthuraman, R. Rardin and S. Ruangpattana" A load factor based mean-variance analysis for fuel diversification", School of Industrial Engineering, Purdue University, West Lafayette, IN 47906, 2009.

[24] http://www.eia.gov/electricity/annual/html/epa_a_03.html; Table A.3. Carbon Dioxide Uncontrolled Emission Factors; accessed in 29/04/2013.

[25] http://www.eia.gov/electricity/annual/html/epa_08_02.html; Table 8.2. Average Tested Heat Rates by Prime Mover and Energy Source, 2007 – 2011; accessed in 29/04/2013.

[26] Dr. E. Ares "Carbon Price Floor", House of Commons Library, Science and Environment Section, SN/SC/5927, March 2013: pp. 8

Vitae

Name:	**Arnan Jufain AlQahtani**
	عرنان بن جفين بن جليغم القحطاني
Nationality:	Saudi
Education:	**M.S**. (Electrical Engineering, Major: Power Systems), King Fahd University of Petroleum and Minerals Dhahran, Saudi Arabia
	B.E. (Electrical Engineering, Major: Power Systems), King Fahd University of Petroleum and Minerals Dhahran, Saudi Arabia
Experience:	**Procurement Planner**, 5 years 7 months Saudi Aramco Dhahran, Saudi Arabia
	Electrical Engineer, 5 months Saudi Electricity Company Southern Area, Saudi Arabia
Contact:	+966500555623, +966(3)8740781 Arnan.qahtani@aramco.com Hotmail6060@hotmail.com