University of Cape Town

Faculty of Science

Classification, Valuation and Real Options Analysis of Climate Change Projects in Africa: A case study of Ghana in West Africa

Dissertation

Submitted to

Department of Mathematics and Applied Mathematics

In partial fulfillment of the requirements

for a Research Master’s Degree in Applied Mathematics

By

Godwin Asumadagwine

Date: 27 September, 2022

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Student's Declaration

I hereby declare that I am the only author of this work and that no sources other than the listed here have been used in this work.

... ...

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LETTER OF APPROVAL

We certify that we have read this dissertation and in our opinion it is satisfactory in the scope and quality as a dissertation in the partial fulfillment for the requirement of Masters Degree in Computer Science and Information Technology.

Evaluation Committee

Date: ..., 2022

I dedicate this thesis to my lovely family.

ACKNOWLEDGEMENTS

I would like to express my heartfelt gratitude to God and my supervisors, Dr Dennis Ikpe, Prof Ronnie Becker and Dr Ebrahim Fredericks for their relentless guidance, advice and support during this study. I also want to thank my family for their prayers and love towards me.

This work was funded by a grant from the African Institute for Mathematical Sciences, www.nexteinstein.org, with financial support from the Government of Canada, provided through Global Affairs Canada, www.international.gc.ca, and the International Development Research Centre, www.idrc.ca.

ABSTRACT

Projects and investments such as those of R & D and climate change are subject to several uncertainties. These uncertainties, if not properly managed, could defeat the actual purpose and target of the project. In this work, we identify flexibility as a way in which uncertainties can be managed.

As the main aim of investments is to make profit, it is significant that investors conduct an in depth study of the project under consideration. This will aid in cost-benefit analysis to ascertain whether it is financially worth it or not. Real options in finance, is the tool that has proved effective in that regard.

However, not every project can be analysed using real options. This thesis introduces real options in climate change investment in Africa (Ghana), 2014-2020. To determine whether real options could be applied, we introduce and estimate certain measures: flexibility, optionability and realizability. These metrics help us to identify the project in which real options can be used.

In this case, we characterize real options into mechanisms and types. The mechanisms are noted to be the enablers of real options while the types are the particular ones enabled. This work also introduces the Decision Structure Matrix (DSM) in climate change investment. The logical Coupled Dependency Matrix (C-DSM) is used to specify the logical relations that exist among dependencies in the project. The logical dependencies are then used for the estimation of the metrics .

This study serves as the basis for the application of real options analysis in climate change investments.

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LIST OF ABBREVIATIONS

DSM Decision Structure Matrix

C-DSM Coupled Decision Structure Matrix

IPCC Intergovernmental Panel on Climate Change

UNFCCC United Nations Framework Convention for Climate Change

NAPA National Adaptation Programs of Action

LDC Least Developed Countries

UNDP United Narions Development Program

GEP Global Environment Program

IRF Integrated Real Options Framework

UAV Unmanned Air Vehicle

GHG Greenhouse Gases

UN United Nations

CCX Chicago Climate Exchange

CFI Carbon Financial Instrument

CDM Clean Development Mechanism

CERs Certified Emission Reductions

IT Information Technology

NPV Net Present Value

ROI Return On Investment

DCF Discounted Cash Flow

IRR Internal Rate of Return

GBM Geometric Brownian Motion

GEF Global Environment Facility

UNEP United Nations Environment Program

DNF Disjunctive Normal Form

GSGDAIT Ghana Shared Growth and Development Agenda

INDC Intended Nationally Determined Contributions

NCCLS National Climate Change Learning Strategies

Chapter 1

INTRODUCTION

1.1 Introduction

This work will provide a model for identifying mechanisms in a climate change project (adaptation or mitigation) that enables the use of real options analysis in its valuation and risk assessment. As climate change has become a major global threat, stakeholders have committed much resources into the area. Climate change adaptation/mitigation allows the policy maker to postpone investment or to invest the major (optimal) portion of the Gross Domestic Product (GDP) in projects that alleviate climate change or its impacts. The investors in this venture could be domestic (government or private) or foreign investors. As real options demonstrate more flexibility and are useful in modelling uncertainties, they become more suitable for the valuation of climate change projects. The challenge therefore is that, it is difficult to identify presence or otherwise of mechanisms in climate change project that activate the required flexibility in real options analysis of an investment. This project will consider several climate change projects in Africa and apply a model (DSM) to analyse whether they can be valued by using real options analysis. This work could also be used in several R & D projects to determine whether real options can be applied in any project or otherwise.

1.1.1 Problem statement

In this research, we investigate how decision structure matrix (DSM) models and real options analysis can be used in identifying mechanism that enable flexibility, optionality and realizability of climate change investment decisions. Specifically, we wish to analyse the features of climate change projects in Africa and identify the existence of active mechanisms suitable and relevant for real options analysis and valuation of such projects. This study will serve as a framework for modelling and valuation of long term investments, enabling accurate pricing and risk management of the next generation of investment vehicles in the financial market. Classification of the fundamental options and trade-offs in investing or abandoning an expensive, long-term capital project with a major irreversible component will be demonstrated.

1.1.2 Justification

Several scientific research has proved that climate change has already started affecting the atmosphere and, particularly, the continent of Africa (Meyer & Odeku, 2010). South Africa, as the leading industrial economy in Africa depends mainly on coal for energy. The overall economy is driven by energy production and use, with coal accounting for seventy-five percent of the fossil fuel demand and ninety-one percent of electricity generation (Meyer & Odeku, 2010).

As the world is making conscious efforts to mitigate and adapt to climate change, energy production is of paramount concern. South Africa, as the economic giant of the African continent has an annual per capita carbon dioxide emission rate of about 10 tons. This figure is 43% higher than the global average (Africa, 2014).

Eskom, the main provider of electricity (providing 95% of South Africa's electricity) derives 90% of its supply from coal. This makes Eskom a 50% contributor of South Africa's emissions. To address this menace in South Africa, (Africa, 2014) suggests that the current energy system must be overhauled. This calls on both the government, private and international investors to work towards renewable and more climate friendly sources of energy for the promising economy of South Africa. The negative consequences of climate change, especially in electricity supply is currently stressing the fundamental drivers of South African economy. Water shortage and load shedding are some of the major issues of national concern. As a result of the above, several researchers, (Woodward, Kapelan, & Gouldby, 2014), (Walker, Haasnoot, & Kwakkel, 2013), (Buurman & Babovic, 2016), (Kalra et al., 2014) and (Hamarat, Kwakkel, & Pruyt, 2013) have conducted studies on real options approach to deep uncertainty in climate change adaptation policies. In a paper, (Buurman & Babovic, 2016) described a step by step approach to reduce uncertainty in climate adaptation investments and policies as well. Their study enabled them to conclude that incorporating real options analysis for designing climate adaptation policies allows for monetary valuation of incorporating flexibilities in systems. In his paper, (Winkler, 2005) investigated the renewable energy policy in South Africa. He states that in order to reduce the economic, social as well as environmental impact of both energy production and consumption in South Africa, it is best to consider investing in both energy efficiency and renewable energy. He concluded that purchase of power agreements, accessing the grid and market creation for green electricity are some supporting activities that should be taken into consideration.

In a research conducted on the optimal climate policy mitigation and adaptation, (Glanemann, 2014) contributed to better understand how uncertainty about future climate damage costs can affect the design of climate policy. He analysed the decisions on adaptation and mitigation by a real options theory approach. The study revealed considerable asymmetry in the interaction and magnitude of real options values. The implication is that, real options analysis places more emphasis on adaptation as the preferred measure compared to the common expected net present value approach.

I plan to contribute to the existing literature on the subject by studying identification of real options mechanism and type classification on climate change investments. As a case study, we will focus on climate change projects in Africa, Ghana.

1.1.3 Research Objectives

The primary objective of this study is to develop a model to analyse the mechanisms and types of real options on climate change projects in Africa. The proposed project will address the following questions:

1. What are the various climate change project views that are suitable for a real option analysis ?
2. What factors influence/ affect climate change in Africa?
3. How good is the Decision Structure Matrix (DSM) in identifying the mechanisms and types of real options in climate change projects.
4. What climate change projects in Africa can be valued using real options analysis approach?
5. Can real options valuation be done on climate change project in Africa?

1.1.4 Methodology

Real options analysis is one robust decision making tool that extends to the principles of cost-benefit and it is good for modelling uncertainties. In this study, we will use a DSM approach/-model (classification model) to classify the various climate change projects in Africa and to identify the active real options mechanisms and types.

This will be a major contribution in climate change, finance theory and practice.

1.1.5 Significance

The proposed work is relevant in modelling and valuation of long-term investments, enabling accurate pricing and risk management of the next generation of investment in climate change intervention projects in Africa. This work is very significant as it will enable investors to analyse cost and benefits of climate change investments before the project is undertaken. It will be a contribution in finance and climate science as stakeholders will have the opportunity to apply the former in the latter for better analysis and investment decisions. As the case study is in Africa, it offers African countries the upper hand to lead the application of financial principles and methods in climate change and other investment projects. The study is useful for both governments and private investors alike.

1.1.6 Outline

The organization of this thesis is stated as follows. Chapter 2 gives literature in relation to climate change and industry. It also describes the various perspectives in which one can view a climate change project (investment). The chapter finally indicates the interdependence that exists among the views.

Chapter 3 introduces the methods to be used to analyse the data. The DSM is given as a tool to help in understanding the structure and components of a project. Furthermore, real options analysis is described as a financial method that is good in valuing capital investments. The real options have been characterized into mechanisms and types. Metrics are also introduced to study and identify how real options can be applied on a particular project.

Chapter 4 makes practical application of the theory. The DSM, real options and its metrics are then applied on a climate change project in Ghana. This allows us to confidently apply these concepts on any other project, including climate change and R & D projects.

Chapter 5 concludes the work. Contributions and the application of this research, recommendations and future work are stated.

Chapter 2

Related Work

This chapter gives a review of literature that relates to the current study. Climate change is presented to be an enterprise or an industry in which investments can be made. This industry is therefore perceived to be analysed through several views known as enterprise views. The views enable us to understand each component of the enterprise (investment project).

2.1 Literature Review

Global climate change refers to the change in the long-term weather conditions (patterns) that specify the various regions of the world. Modern climate change is influenced by the continues activities of man. Activities of man, including the burning of coal and oil have contributed a lot in the atmosphere. The effects of warming can already be observed which include rising sea levels, increase in temperature and melting snow (VijayaVenkataRaman, Iniyan, & Goic, 2012). This influence on atmospheric composition is mainly the result of emissions from energy use, urbanization and changes in land use (Karl & Trenberth, 2003). By burning fossil fuels, cutting and burning forests as well as the engagement in other activities that impact the environment, the heat balance of planet earth has been greatly altered. It is known that the average temperature has moved outside the range that characterizes the 10000 years recorded so far in the history of man (Lee, 2007).

Several studies have revealed that the amassing of greenhouse gases (GHGs) in the atmosphere is increasing by the anthropogenic causes. Many scientists have arrived at the conclusion that climate change and its impacts cannot be avoided even if the international community would make the best efforts ever to control the emission of greenhouse gases (Bryan, Deressa, Gbetibouo, & Ringler, 2009).

Climate change is a real phenomena that has started affecting human populations in the previous decades and the trend is expected to continue in the coming decades. The Intergovernmental Panel on Climate Change (IPCC) has therefore stated, that anthropogenic (human causes) greenhouse gas emissions will continue to drive change in the near future and beyond if dramatic measures are not taken (Vincent, 2004).

Notwithstanding the challenges posed by climate change, generating a global plan is not easy to be achieved. (Hussein, Hertel, & Golub, 2013) indicates that, there will continue to be debate about the nature, content and the impact of the policy actions that are required to reduce the emission of GHG. During international negotiations on climate change , macro-economic outcomes take a crucial component of the discussions. (Hussein et al., 2013) therefore studies the impact of these policies on the general economy. He concludes that both climate change and the policy responses aimed at mitigating these impacts are faced with uncertainties.

Though the emissions of carbon by Africa is minimal as compared to other advanced countries, adverse effects of climate change is likely to be felt more in Africa. This is because, most of the activities in Africa are climate dependent and that, the continent has a low capacity for adaptation. Existing literature predicts that some areas are becoming wetter (East Africa) whereas others are becoming more dryer and hotter (Southern Africa). In Sub-Saharan Africa, the warming is predicted by researchers to be higher than the global average. Rainfall is expected to drop in parts of the region. It is noted that even in East Africa where rainfall was expected to be high, there will be a decline according to recent studies (Bryan et al., 2009). These revelations pose threat to public health, food security, water security, biodiversity and natural resources (Bryan et al., 2009). This situation will affect crop yield and result in extreme weather conditions. In this regard, (Collier, Conway, & Venables, 2008) indicates that while in other parts of the world, the issue involves reducing carbon emissions, in Africa, the concern is being able to adapt production to changing and deterioration of opportunities.

The consequences of climate change in Africa is both prospects and vulnerability, hence proactive actions are necessary now in order to reduce the risks associated with it. In their paper (Downing, Ringius, Hulme, & Waughray, 1997) states that the most effective strategy at the moment is to minimize the current vulnerability of the continent and enhance the capacity in responding to environmental, resource and economic perturbations. Agriculture, the major source of livelihood in Africa is one of the most affected sectors in the continent since it is mainly naturally dependent. Leaving our farmers at the mercy of the climate will be suicidal for the continent. There is hence the need for both science and stakeholders to support decisions making across scales due to how uncertain and difficult agricultural productivity and food security has become in Africa (Adenle et al., 2017). (Bryan et al., 2009) conducted a survey of 1800 farm households in Ethiopia and South Africa to examine the perception that farmers have about climate change, hindrances to adaptation, the extent of adaptation, as well as the factors that influence adaptation. It was observed that in the countries, a larger percentage of the farmers realize temperature has been on the increase over time, and that rainfall is decreasing.

Though adaptation to climate change in Africa has become compulsory, it is fraught with several obstacles. These range from technical, institutional, political, organizational, economic, social as well as financial. It will therefore require comprehensive action from stakeholders including governments, Non Governmental Organization (NGOs) and international bodies to achieve climate change adaptation in Africa. Cost of climate change projects in Africa is approximated to be between two hundred and eighty and five hundred billion dollars each year by 2050 (Puig, Olhoff, Bee, Dickson, & Alverson, 2016). Hence, climate change projects in the continent necessitate assistance from international bodies such as United Nations Framework Convention for Climate Change (UNFCCC), National Adaptation Programs of Action (NAPA), for Least Developed Countries (LDCs), United Nations Development Program (UNDP), Global Environment Program (GEP) to mention but a few.

In view of the above challenges, (Adenle et al., 2017) studied the perspectives by several different stakeholders on the challenges of climate change adaptation in Africa. This research identified main challenges common to all stakeholder groups relating to inadequate climate data, limited well coordinated adaptation activities, difficulty in accessing finance as well as fragmentation of programs of adaptation. They stated that recent policies of adaptation projects implementation by bilateral and multilateral supporters is not likely to produce better outcome in several African countries. Addressing this issue, a 4-Cs framework was developed: Climate projection, Climate education, Climate governance and Climate finance as a suggested way to deal with some these challenges. With their framework, better project coordination, access to and proper management of finance is paramount to ensure effective implementation of climate change projects in the African continent and the world at large.

It is actually a herculean task trying to value systems (projects) of climate change since climate changes in highly unforeseeable ways. Real options is one of the useful tools that could be effective in valuing climate change related investments. Real options approach presents a robust way of analysing and valuing strategic investments such as climate change investments that are characterized with risks and uncertainties. This method considers investments that quantitatively takes the risks and value of the open options for the budget decision makers (Yang & Blyth, 2007). (Park, Kim, & Kim, 2014) proposes a decision framework to aid countries (organizations) to obtain optimal infrastructure investment strategy under climate change using real options. The study identified optimal investment decision from among available adaptation strategies. It also presented an effective way of valuing investments under climate change. (Yang & Blyth, 2007) quantified the impacts of climate change policy uncertainties on power investments using real options analysis . Then (Fernandes, Cunha, & Ferreira, 2011) applied real options in energy sector investments/projects. These investments are characterized by high costs and uncertainties. They concluded that real options analysis is a more realistic approach to value renewable energy sources. The valuation of wind energy projects by real options was conducted by (Abadie & Chamorro, 2014) and this type of investment was considered to be an American option. A valuation model for investments in wind energy was hence developed.

This research is motivated by the PhD work of (Mikaelian, 2009) who introduced an integrated real options framework (IRF) which supports holistic decision making under uncertainty by considering a spectrum of real options across an enterprise/project. The framework was implemented by examples (project) from Unmanned Air Vehicle (UAV) project.

In this study, a real options framework for climate change projects in Africa is developed. Real options across projects (case study investments) under consideration are identified and valued.

2.1.1 The Climate Change Mitigation Industry

Climate change mitigation refers to the various actions and activities that are undertaken to limit the extent of GHG emissions (global warming) and its related effects. There is a high risk in this industry and companies are taking it as an opportunity to make profits. A lot of organizations and countries have partnered to undertake and fund projects across the globe to work towards a carbon free atmosphere. Some of these organizations include: The Global Environment Facility (GEF) and The United Nations Environmental Program (UNEP). These organizations work to improve energy efficiency, promote renewable energy, encourage low carbon technology among others (Ransom, Ribeiro, et al., 2018). This gives the opportunity to several companies to trade in climate related instruments. An example is the Chicago Climate Exchange.

The GEF was established on the eve of 1992 Rio Earth Summit to help tackle our planet's most pressing environmental problems. Since then, the GEF has provided close to $\$20.5$ billion in grants and mobilized an additional $\$112$ billion co-financing for more than 4800 projects in 170 countries [www.thegef.org]. The GEF helps in climate change mitigation by supporting countries (with finance, expertise etc) in areas like biodiversity, chemicals and waste, climate change, forests, international waters, land degradation etc.

A decision by GEF to work towards climate change mitigation is a mechanism for real options which involves the investment (more/less) in areas like: climate smart agriculture, energy efficiency, GHG accounting and technology transfer. These will therefore involve the implementation of strategies which include: retrofitting buildings to make them more energy efficient, adopting renewable energy sources, like solar, helping cities develop more sustainable transport and electric vehicles and promoting more sustainable uses of land and forest.

2.2 Climate Change Mitigation as an Enterprise

Climate change mitigation is defined by (Singh et al., 2016) as a commitment by an entity to reduce, limit the increase of, or enhance the removal of GHG emissions intensity by a specific quantity, to be achieved by a future date. A climate change mitigation project on the other hand is a specific activity or set of activities intended to reduce GHG emissions, increase the storage of carbon or enhance GHG removals from the atmosphere.

Climate change is an international environmental issue that has increasingly attracted business attention in the past decade due to its actual or potential impact on many companies. Existing classifications for climate change mitigation strategies reflect both political and economic components (Kolk & Pinkse, 2004). Climate change mitigation is a whole challenging task as a result of the interaction of two main features. These features are: the complexity of the socio-technical system that should undergo transformation to avoid climate change and the presence of uncertainties (Roelich & Giesekam, 2019). The uncertainties include political uncertainties and the interaction between decision makers with diverse ideologies (perspectives).

One cannot talk about climate change mitigation in this era without considering the Kyoto Protocol (Treaty). The Kyoto Protocol is an international agreement that aims at reducing the carbon dioxide emissions and Greenhouse Gases (GHG) into the atmosphere. It was signed in 1997 by members of the UN (United Nations) at the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) held in Kyoto, Japan (Prins & Rayner, 2007).

Although many players in the business arena are not ready to embrace the Kyoto treaty, policy makers have still created what businesses dislike most, that is uncertainty. Companies always desire to have a clear view of how profitable or bad their decisions will be before making investments. Hence the decision not to adhere to the Kyoto Treaty has made future market environment look more cloudy and unpredictable (Prins & Rayner, 2007). Notwithstanding the fact that some countries have not yet signed this treaty (e.g the US), some companies within them have found an investment opportunity in this situation. Those companies are setting their own targets and pace of reducing the emission of GHG. These companies have taken several steps in voluntary GHG reduction programs and strategies. This interesting decision is very strategic in preparation towards the long or medium term scenario of mandatory emission reduction while making profits (Hoffman, 2005). Recently, industry groups are pushing for cooperative action on climate change mitigation. Specifically, the Tokyo Conference Board is warning that businesses that ignore the treaty act at their own risk. This has made companies and industries around the world to prepare for any future outcome. Considering the control of GHG by a strategic issue that is driven by market pressure, GHG control represents a great transition in the market structure. Therefore, companies and industries now face a whole new competition. In this case, some will fall/decline while other ones will either emerge or rise to take their place in the market (industry). A typical example is the case of typewriter and computer where the latter took the place of the former. Climate change mitigation will virtually present the same type of competition. In this regard, companies with some features such as GHG emission reduction trading in emission credit will thrive in the emerging market of climate change mitigation (Hoffman, 2005).

A great market that has emerged from climate change mitigation over the years is the Chicago Climate Exchange (CCX). Under the CCX, member firms/companies make commitment to voluntarily reduce their GHG emissions. Even though membership is voluntary, once a firm becomes part of it, it becomes an obligation for the firm to abide by the GHG emission reduction regulation. In the exchange, companies make commitment to reduce their emissions by a set quantity below the standard level. Firms who are able to cut down their emissions beyond the target amount receive surplus to sell. Those companies who are not able to meet the set target purchase emission allowance known as Carbon Financial Instrument (CFI) contracts (Gans & Hintermann, 2013). CCX demonstrates that market mechanisms are viable (Lenssen et al., 2008).

The Kyoto Treaty also offers developed (industrialized) countries the opportunity to invest in emission reduction (climate change mitigation) projects in countries without emission targets (or less industrialized/developing countries). This instrument is known as Clean Development Mechanism (CDM) and the emission credits are known as Certified Emission Reductions (CERs) (Michaelowa & Jotzo, 2005). Practically, the CDM works as follows: an investor from a more industrialized country (or a government of an industrialized country), can make an investment in or in other cases, fund a project in a less industrialized country that produces less GHG emissions. In this case, the emissions are lower than they would have been in the absence of an additional investment. This gives the investor credits (carbon credits) as a result of the reduction. These credits can then be used to meet the Kyoto standard in the country of the investor (Watch, 2010).

Climate change mitigation is an issue that cannot be handled by the action of a single group or organization. It does require a global conscious effort. Hence, the involvement of all stakeholders, organizations (profit and non profit), and governments over the world is required. The success of an attempt in climate change mitigation depends on the collaborative efforts of all the above mentioned key players (Galderisi & Colucci, 2018). Mitigating climate change involves the adoption and the implementation of projects and strategies such as : making our buildings more energy efficient, adoption of renewable energy sources (e.g solar, wind and hydro), electric vehicle usage instead of petrol or diesel fuelled vehicles and the sustainable usage of land forests, among others.

2.3 The Climate Change Enterprise Views

An enterprise and enterprise architecture are defined by (Lankhorst et al., 2009). They defined enterprise as “any collection of organisations that has a common set of goals and/or a single bottom line” and an enterprise architecture as “a coherent whole of principles, methods, and models that are used in the design and realisation of an enterprise’s organisational structure, business processes, information systems, and infrastructure”. Enterprise architecting on the other hand is defined by (D. Nightingale & Rhodes, 2007) as “ Applying holistic thinking to design, evaluate and select a preferred structure for a future state enterprise to realize its value proposition and desired behaviours”.

Nightingale and Rhodes stated in (D. J. Nightingale & Rhodes, 2004) that generally, enterprises are perceived through some specific views (dimensions). For instance the Information Technology (IT) view that deals mainly with the IT architecture (which is considered as the foundation) of the enterprise. Nightingale and Rhodes introduced a new method (framework) so as to support a holistic approach to enterprise architecting. The new framework integrates diverse views that are used in describing enterprise architectures. These views include: Strategy, Organization, Policy, Products, Services, Processes, Knowledge and Information Technology (IT). These views can be applied in several projects including R & D projects.

Enterprises are organizations that combine several concepts –strategy, people, policy, process and technology. The enterprise is able to align these concepts towards achieving a particular mission/goal. However, despite large investments made on certain occasions, misalignment occurs which hinders the operation of the enterprise and affects the payoffs of investments made. The first step to be considered in defining the architecture model of an enterprise is to be able to identify the properties that the model represents and the architectural views to consider for successfully architecting those properties (Sousa, Caetano, Vasconcelos, Pereira, & Tribolet, 2007). Architecture in this work refers to the arrangements of the components within any type of socio-technical system and the relationship that exists between them, the environment as well as the design rules for developing the structure of the system (Hilliard, 2000).

For the investment, growth and development of an enterprise, it is worth stating that there is the need for an organization/enterprise to have a clear view of its structure, products, technology abilities, policy and the relations that bind these together in a project (Lankhorst et al., 2009). In this work, we proposed some concepts and the relationships that exists between them to describe an organization with the purpose of having a better understanding and facilitating its evolution. These concepts are part of an enterprise architecture that is stated in eight architectural views, each focusing on separate concerns within the enterprise. These views which are listed above can be applied in several projects in all sectors ranging from technology, agriculture, climate change (as done in this work) to research and development (Sousa et al., 2007).

In this work, I apply these views in climate change mitigation projects in Africa. These views framework is considered because it provides a clear, holistic and structured way that one can think of and understand the information relevant to modelling and the success of an enterprise(project) . As climate change continues to pose companies with lots of risks, uncertainties and business (market) opportunities, it has therefore necessitated the implementation of the above views in climate change projects or investments.

2.3.1 Strategy

The strategy of a company refers to the goals, vision and direction of the enterprise. It includes the business model and competitive environment of the company.

Climate change mitigation strategy refers to the set of goals and plans/ideas that a business entity (or government) intends to implement in order to reduce the emission of GHGs. It includes measures put in place for achieving short, medium or long term emission reduction targets from the operation of the company/corporation itself. Some of these operations may include: research, development and investment (Glancy, Horn, Pryor, Shahinian, & Shopoff, 2007). The climate change mitigation strategy of a company is clearly observed through its goals and objectives and the mobilization of resources to achieve those goals. (Sæverud & Skjærseth, 2007) defines climate change mitigation strategy formulation as the company's statements, objectives and goals where as the actual resource mobilization is the strategy implementation. Therefore, a company, government or any organization will need to clearly define its objectives, goals and source of resources before implementation.

Successful businesses make use of their set goals and objectives. Goals are the general statements of achievement that an entity wants to attain while objectives are the particular steps and actions to be taken in order to achieve the set goals. While it is appropriate for a company to set its goals and objectives, it is more appropriate to draw these set goals from internationally set goals or goals of climate change mitigation/adaptation set by the home country of the company. For instance the Kyoto Protocol. Several countries are recently setting up carbon dioxide emission reduction goals and targets to meet the globally set goals of global warming limit of +2 degrees Celsius. For instance, Germany targets a 40% carbon dioxide reduction by end of 2020. The UK has also set a goal of reducing carbon dioxide emissions by 26% by end of 2020 and 80% by 2050 (Wende, Bond, Bobylev, & Stratmann, 2012).

2.4 Real Options Analysis of an Enterprise

Real Options analysis can be usefully and effectively applied in several types of projects. This will give the investor more advantage to be able to understand the particular investment he is going into and the payoff to expect. Hence, real options can be applied in both climate change and R & D projects.

2.4.1 Application of Real Options in General Projects (Enterprise)

Existing literature shows that a lot of research works have applied real options to several kinds of projects. For instance, (Jeffery, Shah, & Sweeney, 2003) applied real options to information technology investments.

Making investments, especially on projects whose maturity takes a long time requires that a company takes time to investigate the returns of that project to aid in decision making. Hence calculating the net present value for each project is essential.

Calculating the Net Present Value (NPV) for certain projects using merely financial metrics (such as Liquidity ratio, Interest cover, Net cash flow and Gross profit margin) may lead to negative values (mostly, this may not be realistically so). Consequently, enterprises are likely not to invest in these projects. Introducing real options to most of these projects will result in a positive NPV. Hence, real options can turn a negative NPV project into a positive investment opportunity. In other words, we state that the use of real options is most likely to reflect reality as compared to other methods. Real options are also very much useful when applied to projects that already have a positive NPV. (Jeffery et al., 2003) focuses on the application of real options analysis on projects with a positive NPV. They then investigate the importance of real options in the project/investment selection of an enterprise(company).

Enterprises usually investigate the return on investment (ROI) of projects before the real investment decision is made . Mostly, this investigation makes use of traditional discounted cash flow (DCF) and internal rate of return (IRR) to understand/estimate the ROI of the project/investment. Nevertheless, a major setback of this traditional method is that it makes some assumptions which do not hold in reality. For instance, DCF assumes that enterprises will follow the underlined strategy of investment from beginning to end (Trigeorgis et al., 1996) and that investments are reversible. Myers (Myers, 1984) stated several limitations of the DCF method and recommended that real options analysis should be used.

Real options allow us to estimate the expected value of projects. As enterprises shy away from risks, a common technique of reducing risk in enterprises is to break the project (investment) into pieces (parts or components). This approach enables the management of the enterprise to evaluate the project at the end of each piece. If the project proves remunerative at the end of each piece, the enterprise proceeds with the project, otherwise, the project is terminated. Management learns to make improvement after each piece (Jeffery et al., 2003). Each of these pieces has a real options value.

Real options can be applied in several projects and investments. Lander and Pinches (Lander & Pinches, 1998) stated numerous areas in which real options are applicable and useful for realising better results. Some of these areas include: competition and business strategy, R & D, corporate governance, natural resources, advertising, interest rates as well as climate change mitigation, to mention just a few. Real options and capital budgeting was applied to ascertain the value of internet companies by Schwart and Moon (Schwartz & Moon, 2000).

However, real options may not also be suitable for all projects. It is hence, significant to understand the features of a project that will make real options suitable in valuing it. This work classifies some climate change projects into those that real options can be applicable and those that real options cannot be applied. A real options approach in analysing climate change projects is studied . We then investigate various views of enterprises and how these views are essential and applicable in our real options analysis.

2.5 Applying Real Options Analysis to climate change mitigation

The climate change sector (e.g the energy sector) has gone through several changes which include :regulatory, market and technological changes. The sector has however drifted from a monopolistic sector to a more competitive and more uncertain sector. Therefore, the implication is that, traditional capital budgeting methods will be insufficient to evaluate/assess investments in this (climate change) sector (Fernandes et al., 2011). This resulted in the significance of real options approach to climate change projects. In (Fernandes et al., 2011), real options are applied in renewable energy investment projects. Real options could also be used to investigate the value of investing in either a full CO_2 capture and sequestration (Heydari, Ovenden, & Siddiqui, 2012). (Ceseña, Mutale, & Rivas-Dávalos, 2013) also applied real options in electricity generation projects. They indicate that real options analysis are suitable for different stages of projects such as planning, operation and design stages. Other areas of climate change where real options analysis could be used include but not limited to agriculture, transportation and oil and gas areas.

2.5.1 Mapping climate change views to theory

The eight views as stated above demonstrate several interdependence/relationships. These relationships could either be primary or secondary. An example is the fact that the structure of an organization is being demonstrated through the various partnerships and departments and it is influenced by certain strategic objectives which includes offering a product in a new market. The interdependence of the various views varies from one enterprise to the other. The Figure 2.1 demonstrates the interrelationships between the various views in climate change projects.

As seen in Figure 2.1, the arrows indicate interdependence and linkages that exist among enterprise views. It can therefore be stated that, as far as it depends on the particular enterprise, each of the views impacts the others. The arrows show the flow/direction of this impact. We state the impact of each view on the other views below.

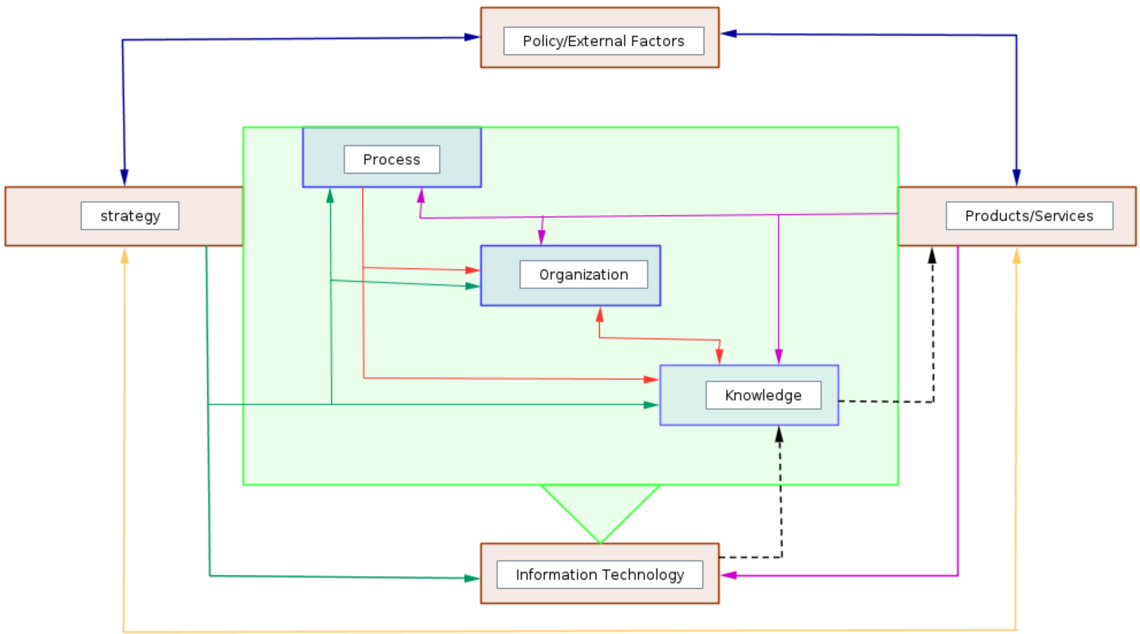

Figure 2.1: Interrelationship of Views

2.5.2 Strategy View

From the Figure 2.1, the strategy view impacts almost all the other views: policy, organization, information technology (IT), knowledge, products and services. An example of a case where strategy affects policy (policy view) is a lobbying strategy that is intended to change government policy. Another instance is the strategy to reduce development costs and efforts that directly affects the policy on hardware and software products that are readily available for sale to the general populace. The organization of technology sectors in an enterprise/company clearly reflects or demonstrates strategy priorities of the company. In this instance, we see that the strategy view affects/impacts the organization view. The product/service view is also impacted by the strategy view. For example, a digitization strategy makes certain products such as computers necessary. The business strategy also impacts the services offered (service view). A competitive strategy demands an investment in information technology (IT). This situation is an example of strategy view impacting IT view. Finally, an identified strategy in a particular direction requires knowledge creation and development in that direction. Hence, the strategy view influences the knowledge view.

2.5.3 Policy View

The policy view impacts other views such as the strategy and product views in many ways. Government policies can affect strategic selection (strategy view) of target market. In this case, the government policy directs and regulates the market for which the enterprise produces (product view).

2.5.4 Organization View

The organization and stakeholders of a company (enterprise) have a great impact on other views. The workers (employees) of an enterprise are the main source of the knowledge and inventions of the enterprise (i.e the knowledge view). The organizational divisions and the functions of these divisions impact the information needs of the company (IT view).

2.5.5 Process View

The process view also impacts other views. The organization (organization view) of an enterprise is impacted by the process view. The production process (process view) of an enterprise determines the labour force or type of workers to be employed. The workforce then forms the organization (organization view) of the enterprise. The process involved in an enterprise also impacts/influences the knowledge (knowledge view) requirement of the workforce for a smooth and successful operation of the enterprise. The enterprise process (process view) has a great impact in determining the information needs and IT system needed by the enterprise (IT view).

2.5.6 Product/Services View

The desired products/services (product and services views) will obviously influence the strategy (strategy view) put in place to attain these products. Products also affect the information and IT tools (IT view) required to achieve the specific product/services. The product view also impacts the various processes (process view) to undertake. In the case of organization, the organization

(organization view) is structured according to the product development. The products of an enterprise also influence the knowledge pattern/needs (knowledge view) of the enterprise.

2.5.7 Information Technology (IT) View

The IT view becomes even more crucial especially in this age of computer literacy. The IT view impacts almost all the views (depending on the enterprise). IT tools are necessary in an enterprise as they are useful in discovering and impacting/spreading knowledge (knowledge view).

2.5.8 Knowledge View

This view forms the basis of an enterprise. For example, an organization (organizational view) is affected by knowledge as seen in the partnership designed to leverage other areas of competency. The knowledge of the needs and requirements of consumers/customers and the market in which an enterprise operates (knowledge view) helps in developing the products (product view). Also, IT design (IT view) is much influenced by the knowledge dissemination needs in a company (Mikaelian, 2009).

Chapter 3

Methodology

This chapter presents the main methods that will be used to analyse our data. Real options and Decision Structure Matrix (DSM) are the main methods that are used. DSM is applied to understand the relationship that exists among the various components of the project and the logical DSM used to estimate metrics that are interpreted and useful for a real options framework. Real options can finally be employed to value the project under study. Example scenarios are also indicated to understand the concepts before they are applied on a climate change project in the next chapter.

3.1 Financial Options Theory

Option, as the name suggests, represents the existence of choice. Financial options can be defined as a financial instrument that offers the holder the right and not the obligation to buy or sell an underlying at an agreed price on or before an agreed date (Cox & Rubinstein, 1985). Profits from options depend upon the price of the underlying. There exists two types of options in finance. These are : Call and Put options.

3.1.1 Call Options

A call option offers the holder/owner the right but not the obligation to buy an asset /stock at a specific exercise or strike price on or before a specific exercise date (Hull, 2019). In the situation where the option can be exercised only on one particular day (date of expiry), it is known as a European Call while in the situation where the option can be exercised on or at any time before the maturity date, it is called an American Call (Brealey, 2001). The value of a call option increases as the price of the underlying security/asset rises. For call options, the maximum loss the holder can incur is the amount paid for the option since the holder can decide not to exercise the option. However, the maximum profit from a call is limitless (Ehrman, 2006). It is rational for the owner of a call to exercise the option when the market price (actual price) of the underlying at the exercising time is more than the strike price. In which case, the profit of the holder is the difference between the market price and the strike price.

3.1.2 Put Options

The put option is the exact opposite of call options. While the call option offers the right to buy, the put option offers the right to sell. As the price of the underlying falls, the price of put options increase. The risk (loss) in buying a put is the premium that the buyer pays for the option and the maximum profit is limitless (Ehrman, 2006). The put option is very similar to the call option in every aspect. One will exercise the put option when the price of the underlying is less than the strike price.

3.2 Valuation of Options

Project (option) valuation is very essential for the investor/stakeholder, not only to determine the merits of that investment decision, but also to understand how the project performs against alternative investments. Project valuation is arguably the most significant aspect of project selection process, because at this point, a monetary value is assigned to the project. Broadly speaking, the value of the project is the difference between the cost and revenue of the project over its whole life period (Kodukula & Papudesu, 2006). If the revenue over-weights the cost, then the project is worth undertaking, otherwise, it is a worthless venture.

There are three main commonly used methods of valuing financial options. These are: the

Binomial pricing model, the Monte Carlo Simulation and the Black-Scholes model. We apply the binomial model in this research.

3.2.1 The Binomial Pricing Method

The Binomial tree (method) is the most useful and commonly used method for pricing options. The tree demonstrates possible paths followed by the option through its life period. The method works with the major assumption that the stock price follows a random walk. At every step of time, known as a node, there is the possibility or the probability of moving up by a particular percentage amount. There is also a certain probability of moving down by a certain percentage amount (Hull, 2019). From the initial price, S, at the next time step, the price of the stock can

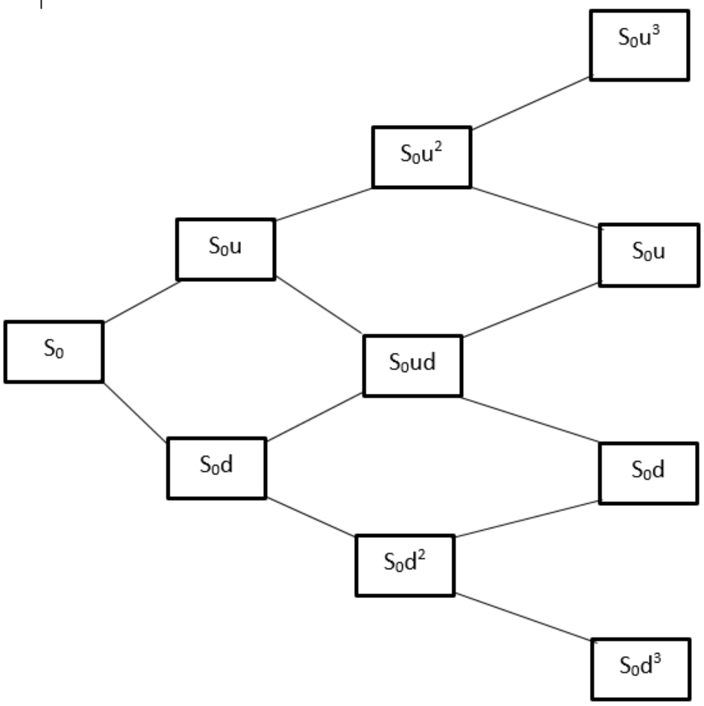

Figure 3.1: Binomial Pricing Model

either move up to a new value, Su or down to a new value Sd. Generally, $u > 1$ and $d < 1$. The probability of an up movement is given as p while the probability of a down movement is

$1-p$. Then, p, u and d are determined by the formulae:

$$p = \frac{a-d}{u-d} \tag{3.1}$$

$$u = e^{\sigma\sqrt{\Delta t}} \tag{3.2}$$

$$d = \frac{1}{u} \tag{3.3}$$

$$a = e^{r\Delta t} \tag{3.4}$$

The variable a is called the growth factor and Δt is the small change in time. The variable σ refers to the volatility (in the case of stocks, it is the volatility of the price of the stock). The derivation of the binomial tree method is given in (Cox & Rubinstein, 1985).

3.3 Real Options Theory

Financial options is the origin of the concept of real options. Financial options generally deals with stocks and bonds. These bonds and stocks are usually traded in financial markets. The particular options for these assets are usually listed or traded on exchanges, for instance Chicago Board Options. Real options on the other hand deals with real assets such as real estate and projects. In real options, the decision ,action or option may include : to undertake a project or not, to defer or expand a project or not (Kodukula & Papudesu, 2006). Real options was first introduced by (Myers, 1984).

3.3.1 Real Options Analysis

The Discounted Cash Flow (DCF) method is the traditional approach for the valuation of capital investments. Some of the attributes of an investment are usually not taken into account when one uses the DCF method. Managerial flexibility is not usually taken into consideration when using the traditional methods (Mun, 2002).

There are several DCF models but they all base on the foundation and that is the NPV estimation of a project over its life period (Kodukula & Papudesu, 2006). In the DCF method, the Net

Present Value (NPV) of a project or an investment is given by

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \tag{3.5}$$

C_t refers to the amount of money (cash) at the time, t while r is the discount rate. However, the DCF is flawed with several challenges. For instance, they do not take flexibility into consideration but therefore assume that all outcomes are static and decisions made are irrevocable. This is not the case in reality. As a result, recently, the three methods introduced above are used.

3.4 The Concept of The Mechanisms and The Types of Real Options

A mechanism in this concept can be referred to as the set of decisions and actions in a project that will enable real options to be applied. For instance the decision to undertake a project.

The type of option represents the set of decisions and various actions that may be implemented by the holder (owner) of the real option. Examples include: the option to abandon/expand a project.

(Mikaelian, 2009) identified two set of actions that are associated with real options: that is the mechanism and type. He then characterizes a real option by a tuple, $<$ Mechanism, Type $>$. Identifying and implementing mechanisms has become very crucial in the quest to obtain flexibility for the management of uncertainties.

3.4.1 The Real Options On Projects Versus Real Options In Projects

The Real options on projects deals with flexibility associated with uncertainty. This particular type of real option considers the entire project as one whole system. Then options are then implemented over this whole system. It should be stated that these types of options are generally applied in the situation where the source of uncertainty is associated with market factors. Real options in projects however, are/can be created within the design of the project (system).

Real Options “ON” Projects	Real Options “IN” Projects
Value opportunities	Design flexibility
Valuation important	Decision important (go or no go)
Relatively easy to define	Difficult to define
Interdependency/Path-dependency less an issue	Interdependency/Path-dependency an issue

Table 3.1: Difference Between Real Options ON and Real Options IN Projects, Source (Wang & De Neufville, 2005).

The project is divided into sub-projects or sub-systems. The various options can then be applied within these systems. The difference between real options on and real options in projects include the following on Table 3.1.

3.4.2 The Mechanisms and Types of Real Options Mapped with Enterprise Views

In this section, I develop a theoretical mapping of the various mechanisms and the types of real options in the context of some of the enterprise views introduced earlier in chapter two.

We note that for the tuple $< \text{Mechanism}, \text{Type} >$, each mechanism or type of option can possibly appear in any one of the enterprise views. It is seen from Figure 3.2 above, that a mechanism like partnership (organization view) and a whole new technology (product view) can be needed in order to allow a type of option which is operational option (process view). A mechanism like a modular design (product view) enables types of options which include: option to reuse design (product view), option to switch function (process view) and the option to expand coverage area (strategy view). It is shown from the diagram that a mechanism can enable several types of real options. We can also have a compound mechanism. A compound mechanism is a situation in which a set of actions are needed in order to enable a particular type of option (real option). These mechanisms can be found in different enterprise views.

A complex real option is defined by (McConnell, 2007) as: “ A complex real option is composed of multiple components across a variety of dimensions, such as technical, financial,

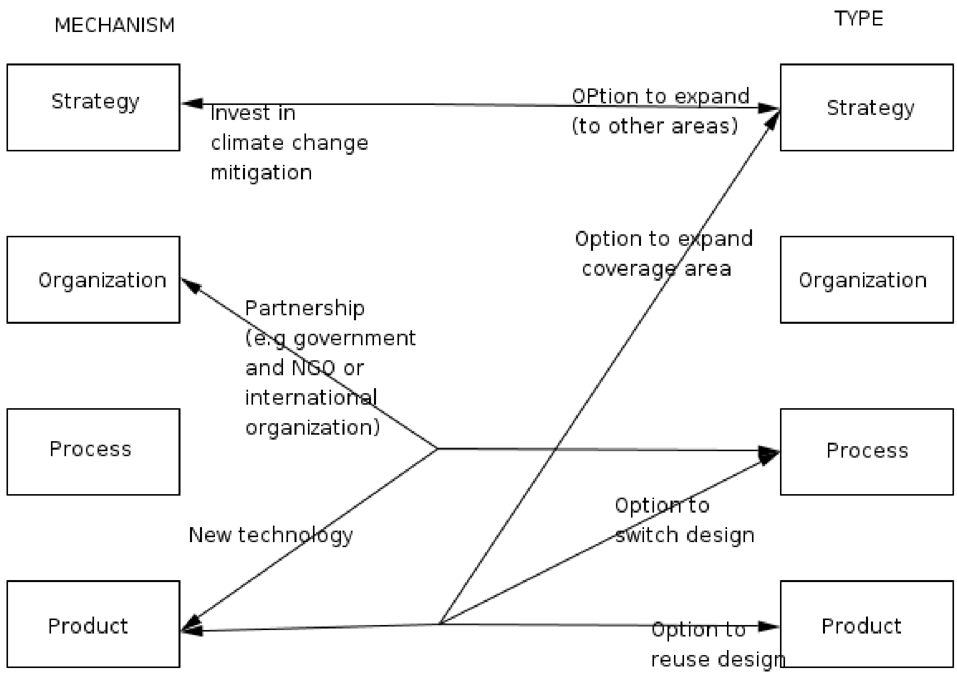

Figure 3.2: Mapping Enterprise views to types of real options

political, organizational and legal. All components are necessary for the option to be deployed and exercised; no single component is enough”. This definition has been interpreted by (Mikaelian, 2009) mathematically as a set of mechanisms $M_1, M_2, ...M_n$ where each mechanism, $M_i, i = 1, ..., n$ is located in any of the enterprise views and where only one mechanism is not enough to allow the particular type of option. In the context of the enterprise views, (Mikaelian, 2009) defined the mechanisms and types of real options as sets M and T such that;

$$M = M_i, \quad i = 1, 2, ...n \tag{3.6}$$

$$T = M_i, \quad j = 1, 2, ...m \tag{3.7}$$

$$(\forall M)(\forall n)(\forall i \in \{1, ...n\}) : (\exists v | M_i \in V) \tag{3.8}$$

$$(\forall T)(\forall m)(\forall j \in \{1, ...m\}) : (\exists v | T_j \in V) \tag{3.9}$$

Where V represents an enterprise view. In short, the above expression means that each mechanism and type of real option belongs to at least one enterprise view. Mapping the mechanisms and real options, we can have a mapping in Figure 3.3.

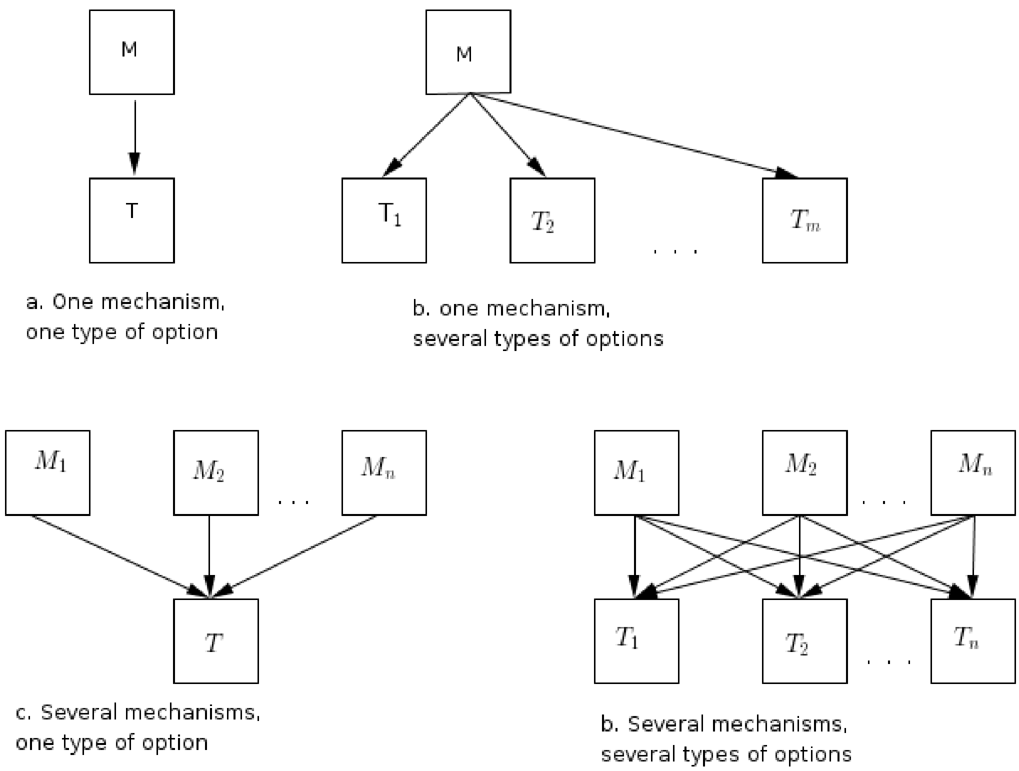

Figure 3.3: mapping mechanisms and types of options

3.5 Decision Structure Matrix (DSM)

The Decision Structure Matrix is also called Design Structure Matrix (Dependency Structure Matrix or a Dependency Source Matrix). The DSM is a matrix (n $\times$ n) representation of a directed graph. A directed graph (or a digraph) refers to a graph with vertices connected by edges, the edges are hence directed. The nodes in this graph are the column and row headings. The arrows in the graph are represented by the marks in the matrix (Sharman & Yassine, 2007). The DSM gives a representation of the interactions that exists among the components of a system (project). In the early 1980s, researchers tried to illustrate that graph theory can be useful in analysing complex systems/projects. This resulted in the introduction of the DSM (Bartolomei et al., 2007).

If there is an arrow from D to A, we place a mark (cross, x) in the column D and row A. This represents a relationship or a dependency between A and D. Same analogy applies for the rest of the variables. The diagonal is irrelevant and therefore it is not usually considered .

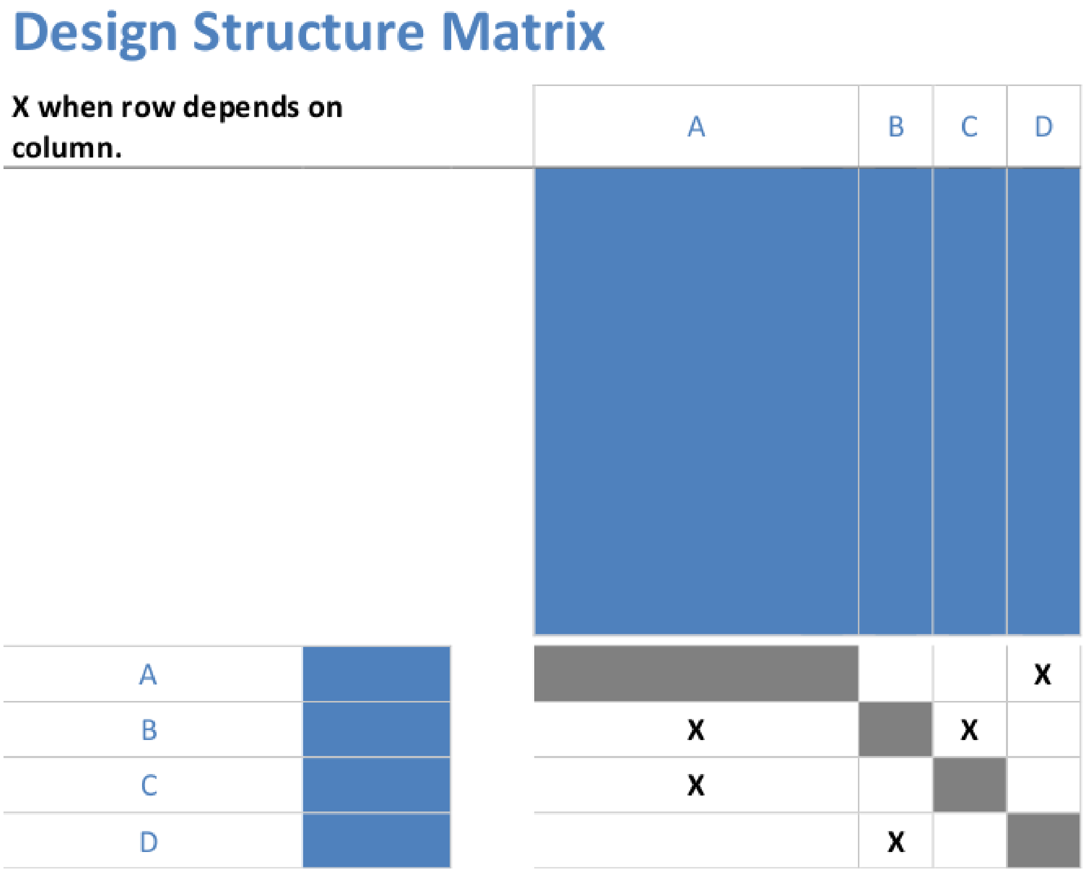

Figure 3.4: Decision Structure Matrix

In a situation where the off diagonal of the DSM represents the existence or non existence of dependency or relationship, such a DSM is called a binary DSM. In such case, the mark of dependency could either be zero (empty space) or one (1). However, when further attributes including the strength of interactions and number of interactions, we refer to such DSM as a numerical DSM (Eppinger & Browning, 2012). There are three main ways of describing the relationship that exists in a system using the DSM: Parallel, Sequential and Coupled.

In the parallel configuration, there is no interaction between the components (elements). In that case, to understand the system requires that one actually understands the individual elements. When dealing with a project, it implies that the tasks are independent of each other.

Sequential configuration on the other hand is the configuration in which one element (A) influences the other (B) in a uni-directional way. In project sense, it implies that one task should be performed before the other.

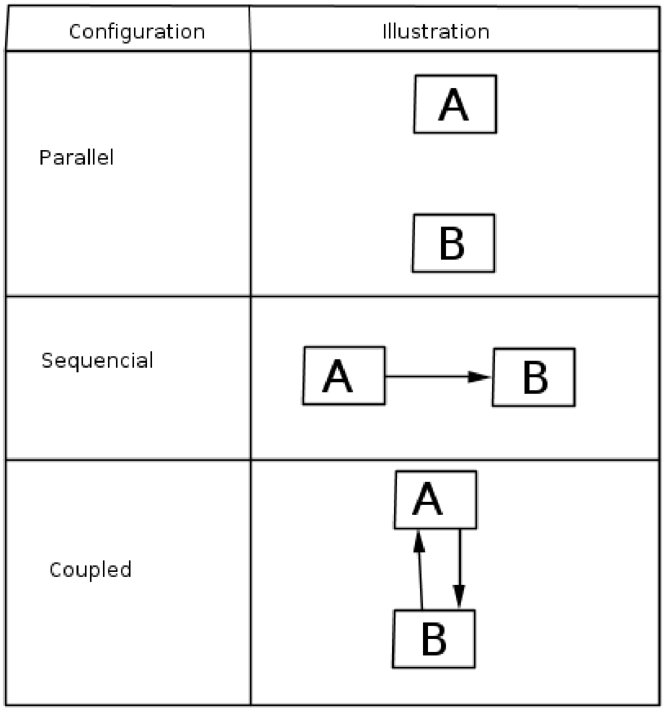

Figure 3.5: DSM showing tasks dependencies. Source (*Decision Structure Matrix*, n.d.)

The coupled configuration refers to the system where dependence is intertwined. For instance, elements/tasks A depends on task B and vice versa. This relationship is called cycle (*Decision Structure Matrix*, n.d.).

This thesis makes use of the Coupled dependency relationship (C-DSM) due to the fact that the various components of the project under consideration belongs to the project views in a inter-relationship manner. I demonstrate how these are inter related in the subsequent chapters. The DSM is used in this work as it offers several advantages some of which are stated by (Eppinger & Browning, 2012). These are:

1. Visualization ; using the DSM, a system designer is able to identify various relationship (dependency) patterns that exists in the project.

2. Intuitive understanding; one of the main reasons for introducing DSM is to make complex systems as simple as possible. When DSM is introduced into a complex system, people are able to gain much and quick understanding of the system or the project.

3. Analysis; DSM aids in making sense out of and explaining a project.

4. Concise; it is able to represent a large system in a smaller space. The DSM, since its introduction, has gained much attention especially by the engineering community (Sharman & Yassine, 2007).

3.6 Identification of Mechanisms and Types of Options by Metrics Using Logical Decision Structure Matrix (DSM)

Having studied the mechanisms and the types of real options, that leads us to another property of projects crucial to identifying options in a project called Optionability. The DSM is not able to model flexibility and optionability of a project. In that case, it can be extended to a logical DSM which will easily model flexibility and optionability as we require in this thesis. Here, we will devise metrics that will enable us estimate the flexibility and optionability from the Decision Structure Matrix and hence identify the various mechanisms and types of real options (Mikaelian, 2009).

We implement a logical C-DSM to identify the mechanisms and the types of real options in a climate change investment. This is useful in making and analysing decisions under uncertainty. The measure, known as flexibility measure (or flexibility metric) is developed for the DSM that is useful to identify the actual types of real options. Another metric, optionability metric is used to locate the various mechanisms where as a realizability metric is used to indicate the applicability of a particular type of option.

3.6.1 Flexibility and Optionability

Uncertainty is something that investors are always trying as much as possible to manage. In the quest to reduce uncertainty, they resort to the sources, enablers and the types of flexibility to manage the uncertainty. Real options are used to manage uncertainty in the sense that the option may or may not be exercised at all.

The type of a real option deals with the possibility and ability to effect changes depending on events and occurrences in the future. This can therefore be characterized by flexibility. So the distinction between a mechanism and the type of real option is called optionability and it is the property of an option mechanism (Mikaelian, 2009).

Flexibility on the other hand can be termed as the ability to implement different types of options in order to manage uncertainty. Flexibility results from exercising the option(s) while the ease with which these option(s) are exercised is in the mechanisms. We are therefore interested in the part of the climate change projects that enable changes (flexibility).

It therefore implies that the projects comprise of optionable (flexible) and non-optionable (non-flexible) aspects. An example is the fact that several personnel could be trained to help reduce Greenhouse Gases (GHG) emission or to plant more trees. This will then enable the option (flexibility) to use them in any of the former or latter project (i.e tree planting or GHG emission reduction). In short, flexibility refers to the ability to implement the types of real options. This is mostly with the intention of managing an uncertainty. However, optionability has to do with the ability to enable types of real options (Mikaelian, 2009).

Then the tuple, $<$ Mechanism, Type $>$ can also be translated as $<$ Optionability, Flexibility $>$ because optionability indicates the mechanism and the flexibility indicates the types of options.

We indicate metrics to represent flexibility and optionability in a model (project) by defining the following:

- Flexibility metric (Flex): is the number of edges going out from a node.
- Optionability metric (Opt): is the number of outgoing edges that lead to nodes of Flex of more than one. That is Flex> 1.

Consider Figure 3.6) Source (Mikaelian, 2009) .

The Figure 3.6 gives a representation of flexibility and optionability. At node (A), we have flexibility to be equal to 3 because we have the opportunity to take either of three steps to (B), (C) or (D). At the nodes (B) and (C), the flexibility is 3 and 2 respectively. This is because, we have the the opportunity of taking 3 and 2 choices respectively. In logical terms, we state that at node (A), we have a choice to either move to (B) OR (C) OR (D). Putting it on an OR diagram, we have:

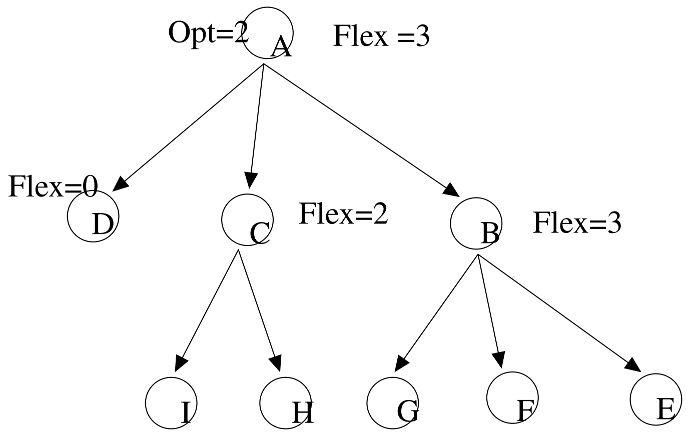

Figure 3.6: Illustratiopn of flexibility and optionability

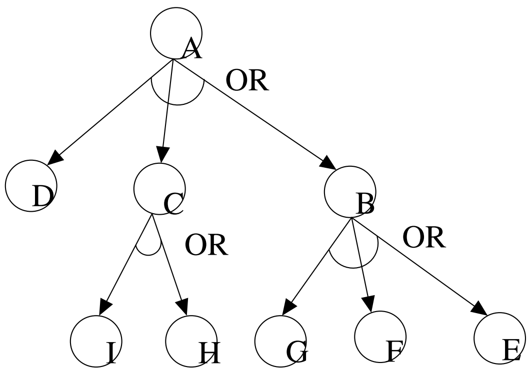

Figure 3.7: Logical OR relationship

The DSM models logical AND dependencies (relationships) as in Figure 3.8.

So we indicate that the node (A) will affect node (B) AND (C) AND (D). Node (B) also affects nodes (E) AND (F) AND (G). Then (C) affects node (H) AND node (I). We could also have a similar illustration.

So we say that, node (E) depends on node (B) AND (C). Node (F) also depends on nodes (B) AND (C) AND (D). The logical DSM does not allow for the case where we state that node (E) depends on either node (B) OR (C) in such manner. Hence we model both (all) dependencies in the logical DSM once each of the nodes (B), (C) and (D) affect (F). Therefore, we note that the logical DSM does not model choice (flexibility). Hence flexibility in the context of DSM

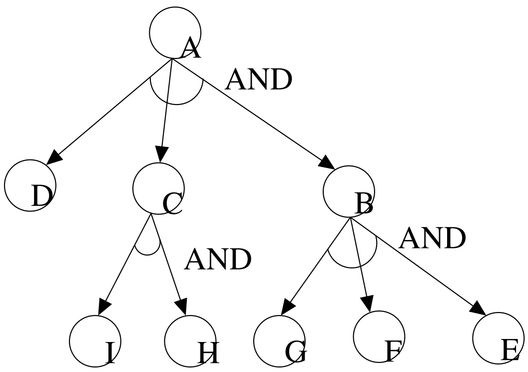

Figure 3.8: Logical AND relationship

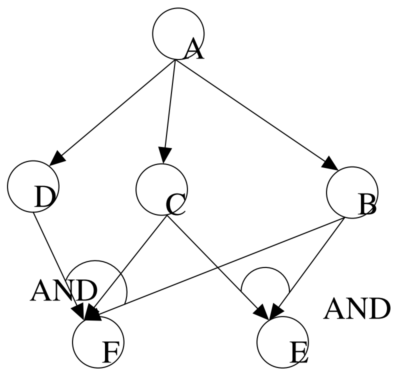

Figure 3.9: Further Logical AND relationship

model is defined with respect to specific nodes to identify specific types of options rather than being an aggregate measure of flexibility of the enterprise state (Mikaelian, 2009).

3.7 Climate Change Mitigation Scenario

We consider a project that focuses on mitigating climate change. Several actions are then taken to achieve the main aim of climate change mitigation. We can represent this case using the logical DSM. In the diagram the actions taken to achieve the aim are stated in the diagram as: ”Reduce GHG emission”, ”Introduce Renewable energy sources” and ”delay (don’t implement) renewable energy. These all affect the climate change aim that is sought to be achieved. We can however interpret the dependency model as having the logical AND relationship (semantics). This is to say that all the three cases have an impact on climate change mitigation. Now, the flexibility of the climate change mitigation node is less than the number of edges coming into the node (climate change mitigation node). For us to estimate the flexibility for achieving our

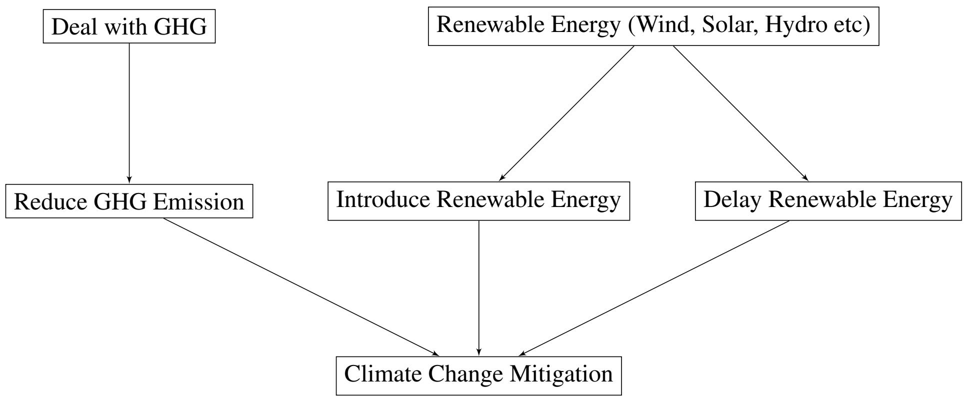

Figure 3.10: Logical Representation of the Climate Change Mitigation Scenario

aim (climate change mitigation node), we can proceed to identify the OR relationships in the model. In order to do that, lets consider an extension of Figure 3.10 to Figure 3.11.

It is clear enough from Figure 3.11 that there is no flexibility in achieving Slow mitigation and quick mitigation. This is because, the only way to achieve Quick mitigation is by both Reducing GHG and Introducing Renewable energy sources. In the same manner, the only way to achieve slow mitigation is to reduce GHG and Delay renewable energy sources. For the main aim that

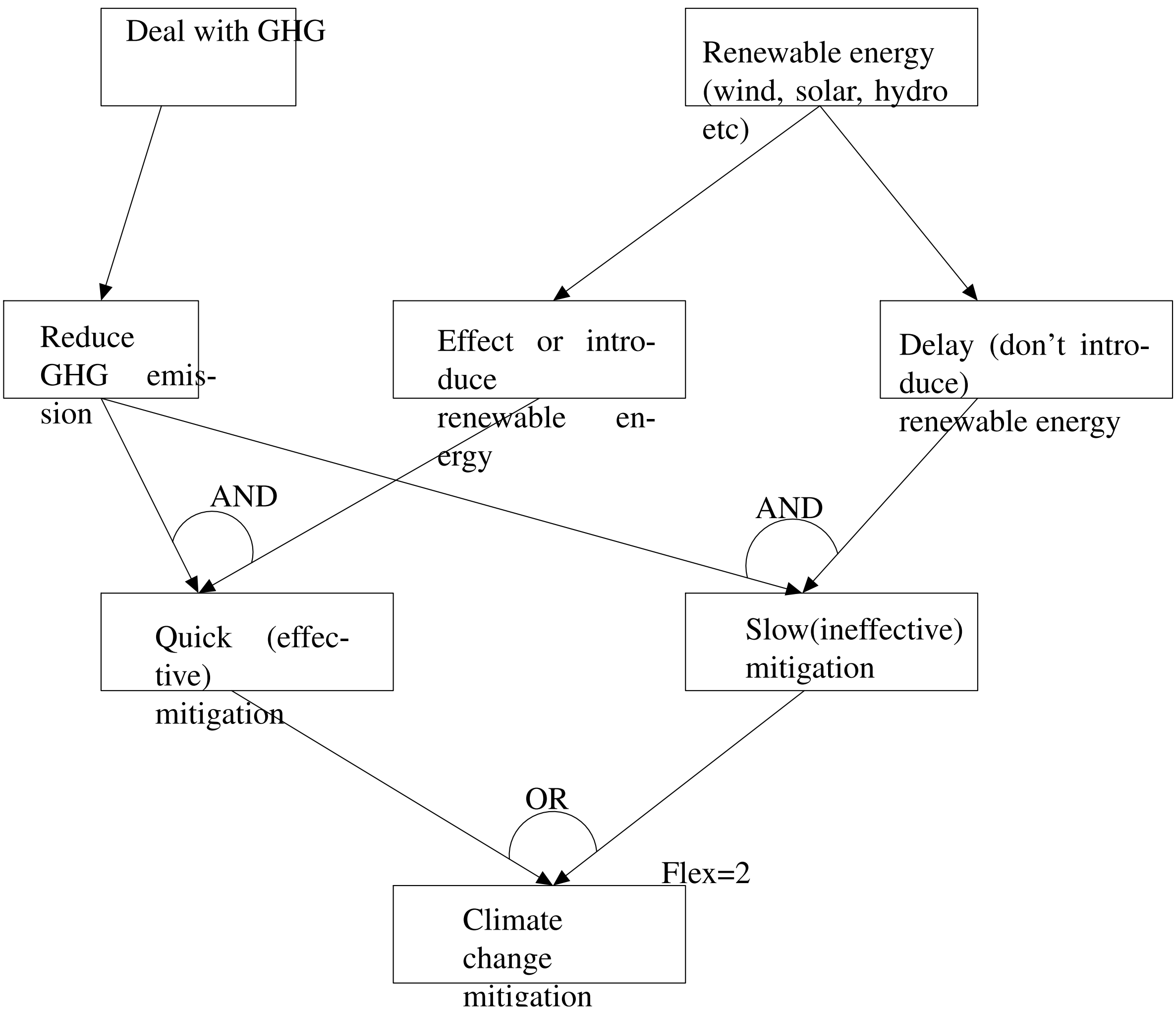

Figure 3.11: Logical Representation of climate change scenario

is climate change mitigation, we have a flexibility of 2 since we can either achieve climate change mitigation by either Quick or Slow mitigation.

Therefore, the classical C-DSM can only be interpreted as the AND relation in logic. It is the OR relationship that is used to estimate flexibility of a model. Hence, to calculate the flexibility metric for the C-DSM, we will have to separate the AND and the OR relationships in the model just as we did in Figure 3.11. This can be done by the logical structure in the C-DSM.

3.7.1 Logical Dependency in a C-DSM

Estimating flexibility (and or optionability) with the C-DSM would mean that we have to extend it into a logical C-DSM. This is done in a way that, given any node, say i, we write a logical dependency or relationship or dependency that exists between the particular node, i and the nodes that affect (are related) to the node, i. For the scenario given above, for the climate change mitigation node, we can write a logical dependency structure as follows:

$$(\text{Deal with GHG}) \wedge (\text{Use renewable energy} \vee \text{ Delay use of renewable energy}) \tag{3.10}$$

The logical ∧ (conjunction or "and") and ∨ (disjunction or "or") are used to connect the various cases. The explanation is that, we need to deal with GHG in order to mitigate climate change. Then, we can either decide to introduce renewable energy or not, and we will achieve our aim anyway. But an issue with the formula above is that, it does not model mutual exclusion (exclusive OR). Use renewable energy and delay use of renewable energy cannot be implemented at the same time. We will therefore need to rely on the negative operator, ¬ to achieve that. Re-writing the formula (3.10) using the negation operator, then becomes;

$$(\text{Deal with GHG}) \wedge$$

$$[(\text{Use renewable energy}) \wedge \tag{3.11}$$

$$\neg(\text{Delay renewable energy}) \vee \tag{3.12}$$

$$(\text{Delay renewable energy} \wedge \neg\text{Use renewable energy})] \tag{3.13}$$

(Mikaelian, 2009) indicates that the logical operators, ¬, ∧ and ∨ are the basic connectives of propositional logic that can be used to construct logical formulae to model the behaviour among multiple variables that influence each node, i, that is climate change mitigation in our case.

As indicated earlier, the flexibility is estimated by the OR relationships in the model. So we need to be able to seperate the OR dependencies, and we do that using the Disjunctive Normal Form (DNF).

3.8 Estimating Flexibility in a Logical Coupled-Dependency Structure Matrix (C-DSM) Model

Our aim here is to be able to seperate the logical OR relationships that exist in a logical dependency structure for estimating flexibility . Before going deeper into the DNF, lets consider the definition of DNF.

Prime formulas and their negations are known as literals. Then, a disjunction , $\alpha_1 \vee \alpha_2 ... \vee \alpha_n$, where each α_i is a conjunction of literals, is known as a disjunctive normal form (DNF). Consider the formula $p \vee (q \wedge \neg p)$, it is a DNF (Rautenberg, 2010). We can express (3.11) as :

$$\begin{aligned}&(\text{Deal with GHG} \wedge \text{Use renewable energy } \wedge \neg\text{Delay renewable energy}) \vee \\ &(\text{Deal with GHG} \wedge \text{ Delay renewable energy } \wedge \neg \text{ Use renewable energy})\end{aligned} \tag{3.14}$$

This successfully isolates the ANDs ($\wedge$) and the ORs ($\vee$) and allows for flexibility estimation. Now lets see how the flexibility metric can be estimated.

3.8.1 Estimation of Flexibility metric

For the node i (climate change mitigation), the flexibility metric (Flex) is the number of conjunctive clauses that exist in the disjunctive normal form of the logical formula that represents the node, i. We define a conjunctive clause as the conjunctive portions of the DNF (Mikaelian, 2009). For the equation (3.14), the clauses are:

$$(\text{Deal with GHG} \wedge \text{Use renewable energy } \wedge \neg\text{Delay renewable energy}) \tag{3.15}$$

or

$$(\text{Deal with GHG} \wedge \text{ Delay renewable energy } \wedge \neg \text{ Use renewable energy}) \tag{3.16}$$

Hence, the flexibility of mitigating climate change is 2, that is the number of DNF clauses. Now, we have to bear in mind that we are seeking to reduce (manage) the uncertainty of the project, in this case, the climate change mitigation project. It implies that the uncertainty regarding the climate change mitigation (node i) should be factored into the formula for node i. In our case, achieving climate change mitigation is affected by the uncertainty of whether the objective will be achieved in the short-run or long-run, so factoring this uncertainty into (3.14), we have:

$$(\text{Deal with GHG} \wedge \text{Use renewable energy} \wedge \neg \text{Delay renewable energy} \wedge \text{Short-run achievement}) \vee (\text{Deal with GHG} \wedge \text{Delay renewable energy} \wedge \neg \text{Use renewable energy} \wedge \text{Long-run achievement}) \tag{3.17}$$

Equation (3.17) implies that the flexibility is 2 and this means that there is an option to determine whether to attain the aim at the Short-run or in the Long-run. Therefore, the uncertainty is managed by this option.

3.9 The United Nations Framework Convention on Climate Change (UNFCCC)-Trinidad and Tobago

Trinidad and Tobago is a republican state that is located in the Southern Caribbean. It lies north east of Venezuela and south of Grenada in the lesser Antiles. It is a small Island developing country. Trinidad and Tobago is prone to the negative effects of climate change (Hassanali, 2017). Under the UNFCCC, Trinidad and Tobago is undertaking a climate change mitigation project (program). This program focuses on the major areas of Trinidad and Tobago that are contributing more to climate change. Examples of these areas include: the industrial and energy sectors. Using this climate change mitigation program/project as a case study, a dependency model and hence a logical dependency model can be established.

3.9.1 Key Components of the Project

1. Industrial Sector: Carbon dioxide emissions from industrial sector have increased by 86.7% from 1990 to 2006. As a way of curbing this, Trinidad and Tobago is implementing carbon dioxide capture and storage (Hassanali, 2017). This carbon dioxide stored can be used for other purposes instead of releasing it into the atmosphere which will cause global warming. Carbon dioxide is a very useful industrial gas. It has several uses some of which include the following: production of chemicals, like urea, refrigeration systems, beverages, welding systems etc (Rubin & De Coninck, 2005).

2. Energy Sector: This sector deals with fuel combustion . The industries here include construction, manufacturing and transport industries. As a way of dealing with this climate change issue, the project seeks to implement intervention such as increase investment in renewable energy and promote research to discover more efficient and climate friendly energy sources.

3. National Climate Change Policy: The National policy has been enforced with the objective of providing policy guidance towards legislative and administrative mechanism that will encompass other policies and sectors required for the realization of low carbon development in the country. This will be done through strategies and actions to mitigate climate change (Hassanali, 2017).

The model for the case of Trinidad and Tobago is illustrated in Figure 3.12.

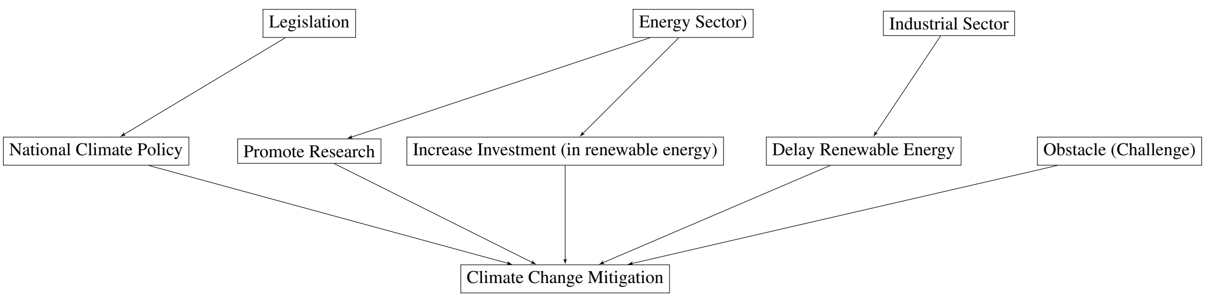

Figure 3.12: Logical Representation of the Climate Change Mitigation Scenario in Trinidad and Tobago

We can make the flexibility analysis easier by extending the dependency model to a logical dependency structure. In that case, "achieve climate change mitigation" will be our main objective and it will be expressed in the DNF. For convenience sake, we represent the various

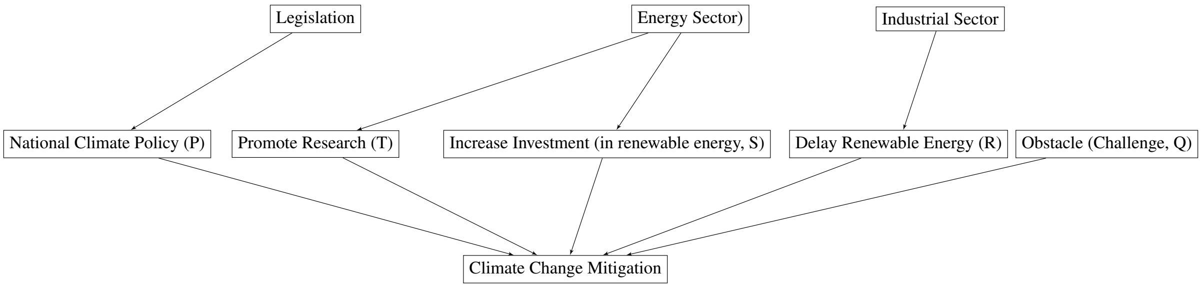

Figure 3.13: Logical Dependency Model Formulation

nodes (cases) with variables Q, R,S,T and P respectively. The DNF is written as:

$$
\begin{aligned}
(R \wedge \neg S \wedge \neg T \wedge \neg P \wedge \neg Q) \vee \\
(R \wedge S \wedge T \wedge \neg P \wedge Q) \vee \\
(\neg R \wedge \neg S \wedge \neg T \wedge P \wedge Q)
\end{aligned} \tag{3.18}
$$

The DNF illustrates that, if there is no unforeseen circumstances/uncertainty (Q) that will affect the project, then the industrial sector, which refers to carbon dioxide capture and storage (R) can be implemented to mitigate climate change. On the other, if there is an unforeseen circumstance (that will affect the project), then carbon dioxide capture and storage and both increased investment in renewable energy and promoting research can be implemented. Finally, if there is an unforeseen circumstance/obstacle, then, legislation can be enforced to mitigate climate change. The flexibility in this case is three (3) since the number of clauses in the DNF in equation (3.18).

3.9.2 Identification of the Various Types of Options in the Tridad and Tobago Project

We realize that the subsets of the conjunctive clauses of the DNF is used to identify the types of real options. The subsets do not include the unforeseen (uncertain) literal. For the objective node (achieve climate change mitigation), if in the DNF, any positive literal appears in all the clauses (subsets), then such a literal is considered to be mandatory for achieving the objective and not an option.

In our case, there is flexibility (flex>1) in obtaining the objective, Flex=3. The flexibilities are: "carbon dioxide capture and storage", "carbon dioxide capture and storage" ∧ "increased investment in renewable energy" ∧ "Promote research" and "National climate change policy".

We now want to show the types of options by the C-DSM model. It is shown by the coloured part in Figure 3.16.

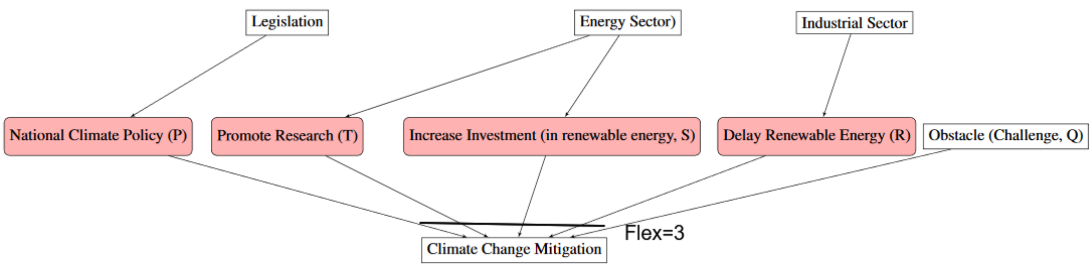

Figure 3.14: Logical Dependency Model

$$
\begin{aligned}
(\underline{R} \wedge \neg S \wedge \neg T \wedge \neg P \wedge \neg Q) \vee \\
(\underline{R \wedge S \wedge T} \wedge \neg P \wedge Q) \vee \\
(\neg R \wedge \neg S \wedge \neg T \wedge \underline{P} \wedge Q)
\end{aligned}
\tag{3.19}
$$

3.9.3 Estimating the metric for Identifying Optionability (The optionability metric in the Tridad and Tobago Project

We have been able to establish in the previous section that flexibility is the ability to exercise several types of options in an attempt to manage the uncertainty involved in achieving a particular objective. This section deals with estimating an optionability metric. While flexibility deals with the types of options available, optionability deals with the mechanisms available that will enable the types of options.

We could have estimated the optionability metric node by node in the C-DSM model. However, we wish to identify a subset of the nodes in the C-DSM as potential mechanisms. This is done using the DNF. To get the potential mechanisms, we need to locate the nodes that produced positive literals in the DNF. Then after identifying these nodes, we pick each node and trace back to the nodes that resulted into that node with a positive literal. This results into the potential or candidate mechanisms. (Mikaelian, 2009) has proposed an algorithm for estimating the optionability metric for a potential mechanism, C.

- First, the optionability metric Opt$=0$ should be indicated for the candidate, C.
- We form the set, S by grouping the outgoing nodes coming from C.
- the optionability metric, Opt for the potential mechanism, C, is known to be, C= number of conjunctive clauses in the DNF formula of all objective nodes that contain any positive literal that appears in S. The exception is that the literal should not appear in all clauses of single DNF. In other words, we don't count cases that lead to obligations and not choices.

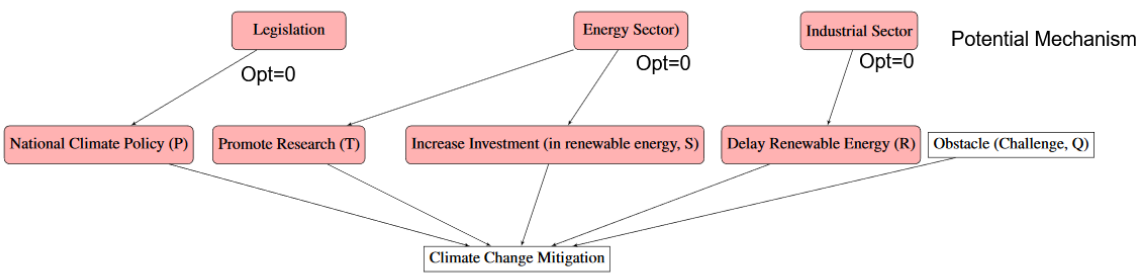

Figure 3.15: Steps 1 and 2 of Estimating the Optionability Metric

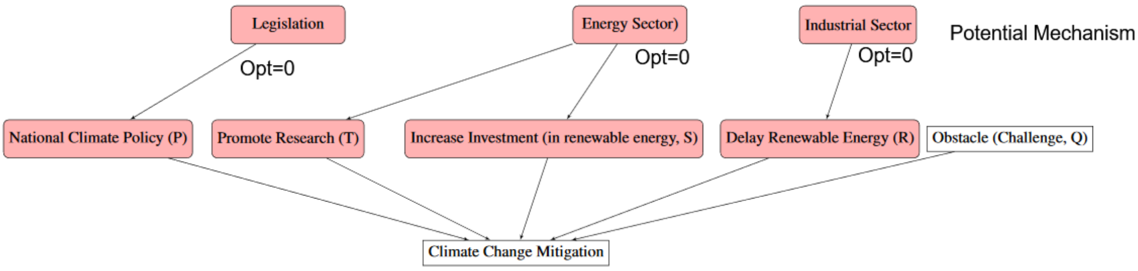

Figure 3.16: Step 3 of Estimating the Optionability Metric

In the diagram of step 1, and 2 above, the potential mechanisms have been identified to be : Industrial Sector, Energy sector and Legislation. This is done by tracing back from the nodes: carbon dioxide capture and storage, Increased Investment in renewable energy, Promote research and national climate change policy. These appeared as positive literals in the DNF. Hence, we initially assume the optionability metric to be zero for each potential mechanism. Then we group the outgoing nodes from these potential mechanisms. Finally, calculating the optionability metric (Opt) is done in the next diagram.

Now, for the industrial sector, Opt=2 because, carbon dioxide capture and storage has appeared as a positive literal two (2) times in the DNF. For the energy sector, Opt=1 since increased investment in renewable energy and promote research have appeared as a positive literal one time in the DNF. Finally, for legislation, Opt=1. The national climate change policy appears only one time in the DNF form.

3.10 Mechanisms of the Project

The Opt metric measures the optionability of a given node. In other words, it demonstrates the extent to which a particular node enables/allows options (flexibility). The mechanisms that allows options are the nodes with Opt greater than zero (Opt>0).

In our case, the mechanisms are: industrial sector, energy sector and legislation. Now we realized that the industrial sector gives us the option to resort to carbon dioxide capture and storage and it therefore contributes in several times to attaining our aim of climate change mitigation under uncertainty. The energy sector and legislation however enabled single options.

3.10.1 Realizability

Notice that we dealt with flexibility metric which has to do with how (or the ability) one is able to implement types of real options required in the management of uncertainty. Optionability on the other hand, has to do with the ability to enable types of real options. The next thing we have to consider is the ability to exercise a particular type of real option. This brings us to the realizability metric. In the C-DSM, the metric of realizability is calculated as the number of edges coming into a given state (or node). The calculation of both the flexibility metric (Flex) and Realizability metric (Rel) look similar since both are estimated based on the number of incoming edges to a particular node. Similarly, the OR relationships in the DNF should be separated in order to enable one to locate the various means by which each type of option is enabled. The realizability measure (Rel) for a given type of real option is considered as the number of the AND (conjunctive) clauses that appear in the DNF of the logical expression for the particular type of option (Mikaelian, 2009). Lets consider Figure 3.17 . Since only

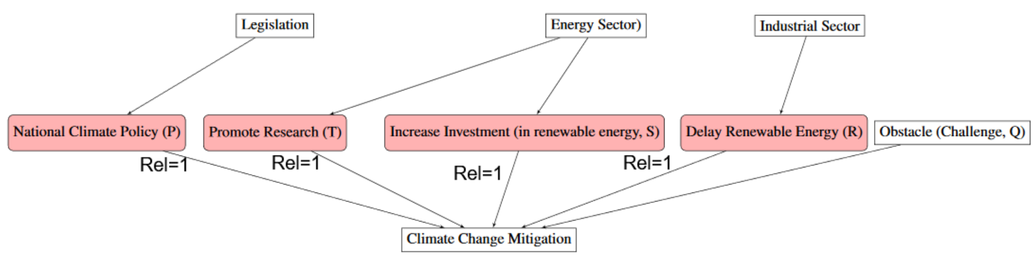

Figure 3.17: Estimating the Realizability Metric

one mechanism enables/leads to each of the options, then the Rel for each of the options has

Rel$= 1$. So we clearly see that optionability considers the outgoing edges but in the case of realizability, the incoming ones are considered.

3.10.2 Flexibility and Real Options Theory

Flexibility has been an area of interest to researchers due to the fact that it involves the allocation of resources and planning under uncertainty. There is much existing literature that deals with the issue of investment decision making under uncertainty (Saleh, Mark, & Jordan, 2009). In this work, we consider flexibility to be the way in which uncertainty is being managed. This constitutes both managerial and project implementation. Managerial flexibility is defined by (Smit & Trigeorgis, 2012) as ”the ability of management to adjust the course of a project by acting in response to the resolution of market uncertainty over time”. This implies that flexibility reduces the extent to which a particular project is exposed to uncertainty.

Real options analysis deals with the financial value of flexibility. One needs to understand that the measure of flexibility is totally different from the value of flexibility. So real options deals with value of flexibility. Hence real options measures the value of flexibility. So, being able to adjust the course of a project to manage uncertainty is simply the exercise of real options. The source of flexibility is identified by the optionability metric as expalined and estimated in the preceding sections. Once we have been able to use the various metrics to locate the specific types of options and mechanisms that enable the options, we can then go ahead to use real options to do the valuation.

Chapter 4

Climate Change Projects in Africa: Ghana

This chapter is the practical application of the theory presented in the earlier chapters. Here we implement the theory on a climate change project in Africa. A project undertaken in Ghana (2014-2020) is considered as a case study. The data is obtained from the report of the project that is accessible online. Implementing the methods introduced in chapter three on this project will give us the understanding and ability to be able to do same in other projects (in climate change or other areas).

4.1 Climate Change Learning Strategy in Ghana (2014-2020)

There has been a global call for countries to pay heed to the adverse effects of climate change on the planet. Individual nations are hence, expected to take steps in minimizing the negative impacts of climate change. Ghana as a member of United Nations Framework Convention on Climate Change (UNFCCC) has taken steps to inculcate climate change (climate science) in the overall development agenda of the country.

Ghana's commitment to climate change is realized in the establishment of the Ghana Shared Growth and Development Agenda I and II (GSGDA). The GSGDA is a medium term national development policy framework with the goal of achieving and sustaining macro-economic stability as well as putting the economy on a way to shared growth and poverty reduction. GSGDA has a medium term target of laying a strong foundation required for the structural transformation of the Ghanaian economy by the end of the year 2020 (Commission et al., 2010). The GSGDA takes into account, the negative impacts of climate change in the growth and sustainable development of the country, Ghana.

It is noted that the Intended Nationally Determined Contributions (INDCs) and National Climate Change Learning Strategies (NCCLS) must both be influenced by the long term development framework of the country. Hence, the NCCLS, INDCs and long term development plans/objectives should be strongly linked (Program, 2021).

Various state institutions have adopted several steps to mainstream climate change. Some of these institutions include: Ministry of Science, Technology and Innovation (MESTI), National Development Planning Commission (NDPC) and Ministry of Finance and Economic Planning (MoF). Some of the major steps include: High level awareness programs, development of policy briefs on climate change and a study on climate public expenditure and institutional review, among several others (Program, 2021).

4.1.1 National Priority Areas in Relation to Climate Change Main-streaming

In Ghana, there are five major priority areas that are identified. Within these five areas, there are ten focus/project (program) areas. Table 4.1 indicates the various priority areas and various project focus areas.

PRIORITY AREA	FOCUS AREAS
Agriculture and food safety	Develop climate-resilient agriculture and food security systems
Disaster Preparedness and Response	Build climate-resilient infrastructure Increase resilience of vulnerable communities to climate-related risks
National Resource Management	Increase carbon sinks Improve management and resilience of terrestrial, aquatic and marine ecosystems
Equitable Social Development	Address impacts of climate change on human health Minimize impacts of climate change on access to water and sanitation Address gender issues in climate change Address climate change and migration
Energy, Industrial and Infrastructural Development	Minimize greenhouse gas emissions.

Table 4.1: National Climate Change Priority and Focus Areas. Source: National Climate Policy, 2013

4.1.1.1 Projected Budgetary Allocation for Climate Change Learning (2014-2020)

A total amount of $ 8219 million was committed to the whole project. Figure 4.1 gives the graphical representation of the budgetary allocation to the various priority areas while Table 4.2 indicates the specific amount allocated for each area.

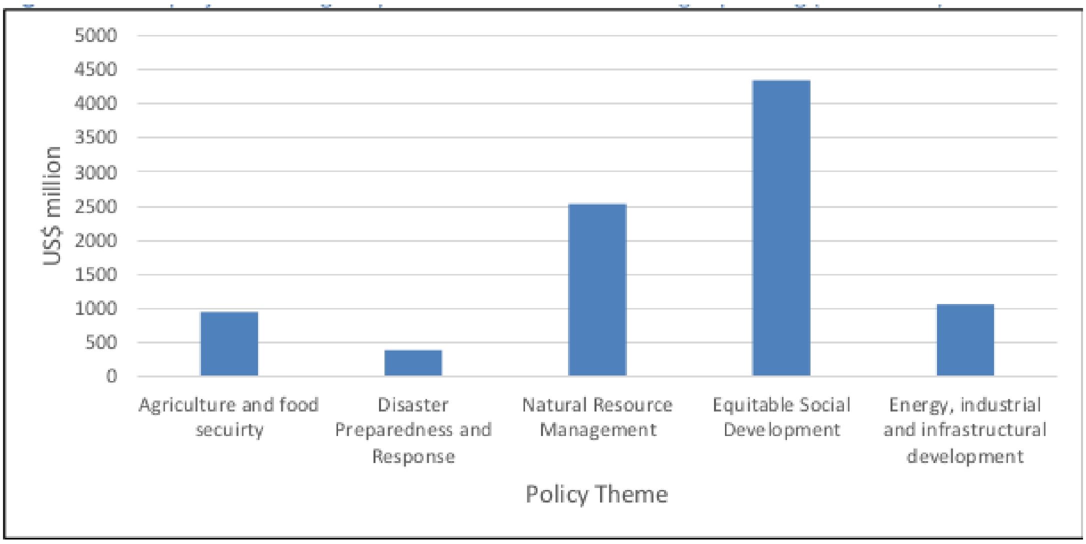

Figure 4.1: Budgetary Allocation. Source: National Climate Policy, 2013

PRIORITY AREA	Budgetary Allocation in $ million
Agriculture and food systems	950
Disaster Preparedness and Response	386
National Resource Management	2535
Equitable Social Development	4348
Energy, Industrial and Infrastructural Development	1057
TOTAL	8219

Table 4.2: Monetary Allocation to the Various Priority Areas

4.1.2 Mismanagement (Corruption) and its Impacts on Projects in Ghana (Africa)

Corruption is defined by (Gould & Amaro-Reyes, 1983) as "The practice whereby some public money is illicitly diverted for private gain is present to some degree in all societies". However, corruption's widespread occurrence in developing countries has raised substantial concern. A significant body of scholarly literature based on empirical data attests to the existence of widespread corruption in developing countries, alongside periodic journalistic accounts of recurring incidents of bribery, patronage, embezzlement, and extortion, and, very rarely, reports of official inquiry (Gould & Amaro-Reyes, 1983).

The paper (Awadzie & Garr, n.d.) indicates that Corruption is both a symptom and a product of structural weakness, and it can have a negative impact on a country's economic performance. This study looked at how corruption affects Ghana's economic growth from a statistical standpoint. The study examined secondary time series data spanning 22 years, from 1998 to 2020. The study used GDP per capita as a metric of economic growth. The analysis employed the Corruption Index and overall government spending as explanatory variables. This study shows that unless corruption is reduced in Ghana, the economy would be unable to grow significantly. According to the findings, policies that encourage sustainable development should be aided in order to boost economic growth by minimising corruption.

Based on the study of (Awadzie & Garr, n.d.), this research considers corruption as a major hindrance to the success of the Climate Change Learning Project in Ghana. We therefore use that (corruption) as the obstacle (uncertainty) in our subsequent analysis.

4.1.3 Modelling the Project: Climate Change Learning Strategy in Ghana

The climate change project under consideration will be modelled to identify the mechanisms and types of real options of the project. Real options valuation will consequently be done. The objective of the project is climate change learning in Ghana. The assumptions made are that:

1. the main uncertainty (challenge/hindrance) to the project is corruption/financial mismanagement since the project involves huge sums of money. Hence the overall corruption in the country has the same impact on the project.

2. combining the various focus areas of priority can result into two possibilities, namely, more expensive and less expensive areas which can be considered separately.

3. partial implementation of a particular possibility is not feasible.

4.1.4 Logical Dependency Model and Calculation of Metrics

The national priority areas, focus areas and the main objective (goal) of the project can be represented as done in Figure 4.2 .

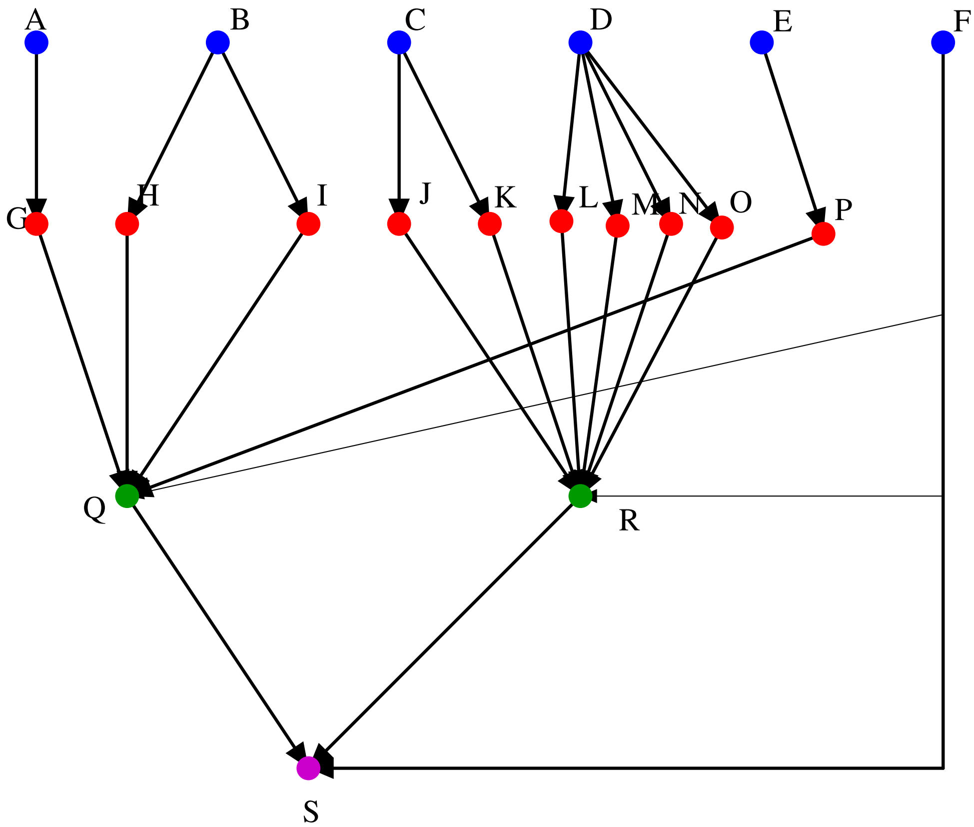

Figure 4.2: Logical Dependency Model of the Project

We can combine some of the focus areas of the project given in Figure 4.2 to obtain Figure 4.3.

The key to the Figure 4.2 and Figure 4.3 is given in Table 4.3.

The nodes represent the priority and focus areas of the project. The last node (S) is the main objective. The arrows on the other hand are used to indicate that the target node depends on the source node. We can then use logical specifications that demonstrate the logical structure of the inputs to that particular node. The logical formulae are in disjunctive normal form (DNF). We can use a truth table to list the allowed combinations of the logical values that satisfy the logical formula.

The main objective of the project: Climate change learning(S) has a logical formula:$(6 \wedge R \wedge \neg Q) \vee (Q \wedge \neg R)$.

For the more expensive decision (R) we obtain: $(6 \wedge \mu \wedge \neg\gamma) \vee (6 \wedge \gamma \wedge \neg\mu)$.

For the less expensive decision (Q) we obtain: $(\xi \wedge \neg\lambda \wedge \neg G) \vee (6 \wedge \lambda \wedge \neg\xi \wedge \neg G) \vee (6 \wedge G \wedge \neg\xi \wedge \neg\lambda)$.

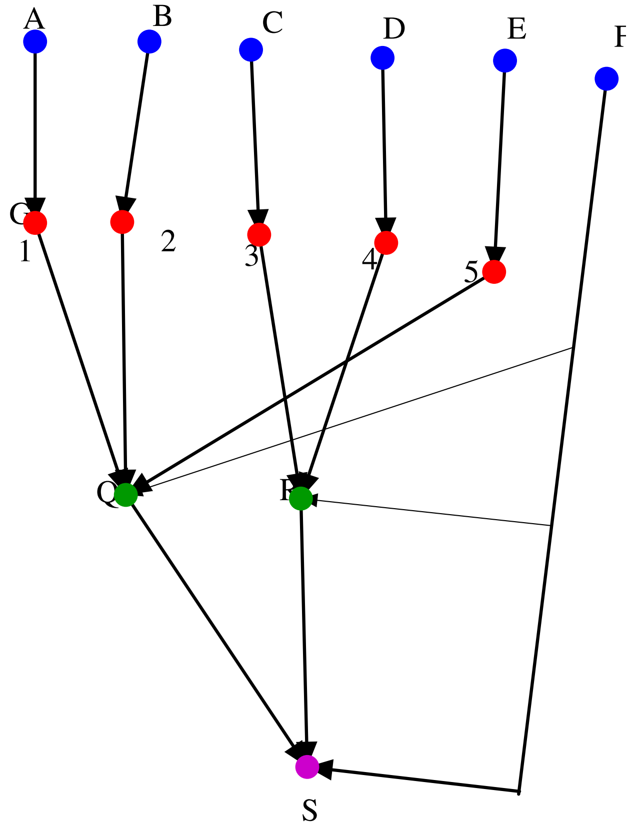

Figure 4.3: Simplification of the Logical Dependency Model of the Project

4.1.5 Estimating Metrics (measures) of the Project

The measures: Optionability, Flexibility and Realizability can be obtained following the logical dependency model. These measures have been explained in detail earlier.

4.1.6 Flexibility (Flex)

The existence of flexibility indicates that there exists alternative ways of attaining a particular goal. That is, for the presence of flexibility, then we should have the flexibility metric (measure) to be greater than unity. We see that the flexibility for the main objective of the project, that is climate change learning (S) is two (Flex=2). The alternative ways of obtaining the objective are: undertaking more expensive (R) and less expensive (Q) priorities. Once flexibility is greater than one, it indicates the presence of options. Therefore, the types of options here are the alternatives, R and Q.

LABEL	PRIORITY OR FOCUS AREA(S)
A	Agriculture and Food Safety
B	Disaster Preparedness and Response
C	National Resource Management
D	Equitable Social Development
E	Energy Industrial and Infrastructural Development
F	Corruption and Financial mismanagement
G	Develop climate-resilient agriculture and food security
λ (2)	1.Build climate-resilient infrastructure (H) and 2. Increase resilience of vulnerable communities to climate- related risks
γ (3)	1. Increase carbon sinks (J) and 2. Improve management and resilience of terrestrial, aquatic and marine ecosystems (K)
μ (4)	1. Address impacts of climate change on human health, 2. Minimize impacts of climate on access to water and sanitation (M), 3.Address gender issues in climate change (N) and 4. Address climate change and migration (O)
ξ (5)	Minimize greenhouse gas emissions
Q	Less expensive Priorities(decision)
R	More expensive Priorities(decision)
S	Climate change learning (Main objective/goal)

Table 4.3: Key to the diagrammatic representation of the Priority and Focus Areas

6	R	Q
T	T	F
F	F	T

Table 4.4: Combinations of values (T-true, F-false) satisfying S

6	μ	γ
T	T	F
T	F	T

Table 4.5: Combinations of values (T-true, F-false) satisfying R

4.1.7 Optionability (Opt)

It is worth noting that optionability is distinct from the types of options enabled. It rather shows the different ways of managing uncertainty taking into consideration, the relationship that exists among the types of options. Optionability greater than zero shows that the corresponding node is a mechanism that contributes to enabling at least one type of option. We realized that

ξ	G	λ	6
T	F	F	F
F	F	T	T
F	T	F	T

Table 4.6: Combinations of values (T-true, F-false) satisfying Q

Agriculture and food systems (A) leads to a single action which appears once in the DNF of Q. So the optionability of Agriculture and food systems is one (Opt=1). Disaster preparedness and response (B) leads to two actions of which they both appear together in the DNF of Q. So the optionability is two (Opt=2) and that follows for D and E.

4.1.8 Realizability (Rel)

Realizability indicates the number of specific ways by which a particular type of option can be enabled (exercised). The realizability of undertaking more expensive priorities (R) and that of less expensive (Q) are two and three respectively. So we indicate that Rel>1 demonstrates that there exists mechanisms alternatively that enable the particular option. It implies that there are more alternative ways of undertaking the less expensive priorities.

4.1.9 Coupled Decision Structure Matrix (C-DSM)

The project under consideration will be analysed using the coupled decision structure matrix. It is coupled because there is inter-dependence of the various views. This inter-dependence is illustrated in the DSM figure in Figure 4.4. V1 to V8 represent the views as indicated in Section (2.5.1) respectively.

Design Structure Matrix

row depends on column.	V1	V2	V3	V4	V5	V6	V7	V8
V1				1		1	1	
V2			1	1		1		1
V3		1		1		1	1	1
V4	1	1	1			1	1	
V5								
V6	1	1	1	1			1	1
V7	1		1	1		1		1
V8		1	1			1	1	

Figure 4.4: C-DSM

4.1.10 DSM for the Various Priorities and Focus Areas

The priorities and focus areas of the project of Ghana have to be analysed on the DSM before we can estimate the metrics. The Figure 4.5 gives us the DSM representation of the priorities and focus areas as well as the dependencies that exist among them. Presence of a dependency/relation is indicated by 1 while the absence of relationship is shown by an empty space.

Design Structure Matrix

row depends on column.	G	2	3	4	S	5	Q	R	6
G									
2									
3									
4									
S							1	1	1
5									
Q	1	1				1			1
R			1	1					1
6									

Figure 4.5: DSM of Climate Change Learning in Ghana

4.1.11 Logical C-DSM

The various priority and focus areas can be related to the enterprise (climate change) as introduced in the earlier chapters. In this case, the most critical views that can easily be identified in this project are: strategy, process and knowledge views. In the knowledge view, we have; financial mismanagement/corruption. This is as a result of the fact that knowledge about corruption and financial mismanagement in the project is required. For the strategy view, we have decisions of implementation and the main objective. The process view, “undertaking less expensive” and “undertaking more expensive” are considered. The process view in this case refers to the process of undertaking those (any) decisions.

The DSM in Figure 4.6 gives a representation of the various priority and focus areas of the project. The rows depend on the columns. Where there is a dependency, the value allocated is one (1) while an empty space represents no relationship. Therefore, it is seen that the main objective, climate change learning (S) depends on undertaking less expensive (Q) and more expensive (R) priorities. "undertaking less expensive" priorities also depends on "Developing climate-resilient agriculture and food security" and so on. Logical formulae are also being stated to represent the relation among the various priorities and focus areas and the alternative ways of achieving the main aim. The diagonals shaded represent the comparison of a priority/focus area with itself which is not our interest, so it is not significant. Moving forward, we can employ the C-DSM to demonstrate the various measures: Optionability, Realizability and Flexibility.

Row depends on column.	G	λ	γ	μ	S	ξ	Q	R	F	Logical Formula
G										
λ										
γ										
μ										
S							1	1		$(F \wedge R \wedge \neg Q) \vee (Q \wedge \neg R)$
ξ										
Q	1	1				1			1	$(\xi \wedge \neg \lambda \wedge \neg G) \vee (F \wedge \lambda \wedge \neg \xi \wedge \neg G) \vee (F \wedge G \wedge \neg \xi \wedge \neg \lambda)$.
R			1	1					1	$(F \wedge \mu \wedge \neg \gamma) \vee (F \wedge \gamma \wedge \neg \mu)$.
F										

Figure 4.6: Logical C-DSM in DNF

We begin by identifying the uncertainty in the project. In our case, the source of uncertainty as indicated earlier is financial mismanagement (corruption). Hence we identify the uncertainty with the letter “U” on the diagonal where corruption is being compared with itself. The uncertainty column and row are in red.

Row depends on column.	G	λ	γ	μ	S	ξ	Q	R	F	Logical Formula
G										
λ										
λ										
λ										
S							1	1	1	$(F \wedge R \wedge \neg Q) \vee (Q \wedge \neg R)$
ξ										
Q	1	1				1			1	$(\xi \wedge \neg \lambda \wedge \neg G) \vee (F \wedge \lambda \wedge \neg \xi \wedge \neg G) \vee (F \wedge G \wedge \neg \xi \wedge \neg \lambda)$
R			1	1					1	$(F \wedge \quad \wedge \neg \gamma) \vee (F \wedge \gamma \wedge \neg \mu)$
F									U	

Figure 4.7: Identification of source of Uncertainty and main Objective

Then, since we have identified the source of uncertainty, we have to consider how this uncertainty is being managed to obtain the main objective. The flexibility measure needs to be estimated to enable us obtain the options to help manage the uncertainty. As identified previously, the flexibility of the main objective of the project is two (Flex=2). This value can be indicated on the main diagonal where the main objective is being compared with itself.

Row depends on column.	G	λ	γ	μ	S	ξ	Q	R	F	Logical Formula
G										
λ										
γ										
μ										
S					Flex=2		1	1	1	$(F \wedge R \wedge \neg Q) \vee (Q \wedge \neg R)$.
5										
Q	1	1				1			1	$(\xi \wedge \neg \lambda \wedge \neg G) \vee (F \wedge \lambda \wedge \neg \xi \wedge \neg G) \vee (F \wedge G \wedge \neg \xi \wedge \neg \lambda)$
R			1	1					1	$(F \wedge \neg \gamma) \vee (F \wedge \gamma \wedge \neg \mu)$
F									U	

Figure 4.8: Estimation of Flexibility metric

The Realizability measure follows after flexibility is obtained. Realizability as the ability to implement the various types of options is indicated. The realizability of "undertaking less expensive" and that of "undertaking more expensive" priorities are written on the respective diagonals.

Row depends on column.	G	λ	γ	μ	S	ξ	Q	R	F	Logical Formula
G										
λ										
γ										
μ										
S					Flex=2		1	1	1	$(F \wedge R \wedge \neg Q) \vee (Q \wedge \neg R)$
ξ										
Q	1	1				1	Rel=3		1	$(\xi \wedge \neg \lambda \wedge \neg G) \vee (F \wedge \lambda \wedge \neg \xi \wedge \neg G) \vee (F \wedge G \wedge \neg \xi \wedge \neg \lambda)$
R			1	1				Rel=2	1	$(F \wedge \neg \gamma) \vee (F \wedge \gamma \wedge \neg \mu)$
F									U	

Figure 4.9: Estimation of Realizability metric

Optionability relates to the ability to enable types of options. The optionability is elaborated more earlier. The various optionability values are indicated.

Row depends on column.	G	λ	γ	μ	S	ξ	Q	R	F	Logical Formula
G	Opt= 1									
λ		Opt =2								
γ			Opt =2							
μ				Opt =4						
S					Flex=2		1	1	1	(F $\wedge R \wedge \neg Q$) $\vee (Q \wedge \neg R)$.
ξ						Opt =1				
Q	1	1				1	Rel=3		1	$(\xi \wedge \neg \lambda \wedge \neg$G) $\vee$(F $\wedge \lambda \wedge \neg \xi \wedge \neg$G) $\vee$(F $\wedge$ G $\wedge \neg \xi \wedge \neg \lambda$)
R			1	1				Rel=2	1	(F $\wedge \neg \gamma$) $\vee$ (F $\wedge \gamma \wedge \neg \mu$)
F									U	

Figure 4.10: Estimation of the Optionability metric

The complete diagram on Figure 4.11 is given with all the measures/metrics and the mechanisms. Hence,for the tuple <mechanism, type>, we have the mechanisms in yellow while the types of options are in green (<mechanism, type>=<yellow, green>)

Row depends on column.	G	λ	γ	μ	S	ξ	Q	R	F	Logical Formula
G	Opt=1									
λ		Opt =2								
γ			Opt =2							
μ				Opt =4						
S					Flex=2		1	1	1	(F $\wedge R \wedge \neg Q) \vee (Q \wedge \neg R)$
ξ						Opt =1				
Q	1	1				1	Rel=3		1	$(\xi \wedge \neg \lambda \wedge \neg$G) $\vee$(F $\wedge \lambda \wedge \neg \xi \wedge \neg$G) $\vee$ (F $\wedge$ G $\wedge \neg \xi \wedge \neg \lambda$)
R			1	1				Rel=2	1	(F $\wedge \neg \gamma$) $\vee$ (F $\wedge \gamma \wedge \neg \mu$)
F									U	

Figure 4.11: Identification of Options

4.1.12 Relevance of Options in the Project

It is realized that without the options, the uncertainty directly affects the project objective. However, the presence of the options leads to the introduction of an “absorber” or reducer of risk (uncertainty). This scenario can be illustrated in Figure 4.12.

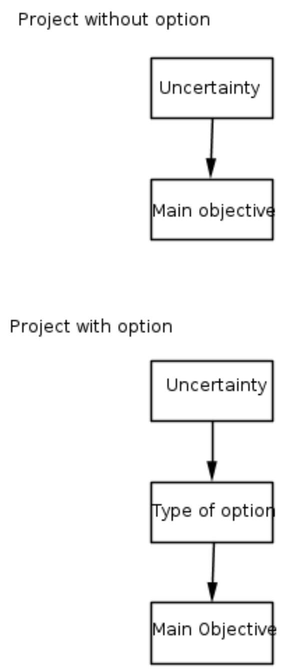

Figure 4.12: Significance of options. Source (Mikaelian, 2009)

4.1.13 Real Options Valuation of Identified options in the Project

At this stage, we employ real options analysis on the project in order to understand whether it is valuable to invest in any of the mechanisms or options. Cost and benefit analysis is considered to make valuation of alternative options under uncertainty. This section looks at real options valuation with the use of binomial lattice pricing model.

4.1.14 Uncertainty Model

The uncertainty of this project is corruption in the country, Ghana. The uncertain outcome is modelled as the perception (data) on how Ghana is positioned in terms of corruption relative to other African countries. Since this project started in 2014, we track the performance of the country in terms of corruption management since 2014 till the end of the project (2020) to be able to analyse the success of the project. We can then estimate or predict how the project performed each year within the life period of the project. We assume that higher corruption has equal proportionate consequence on the success/failure of the project (International, 2022). Ghana was third (3rd) among the top ten countries in Africa that are able to manage corruption well (International, 2022). This is a good position to start the project. Once the country is placed third among the top ten countries, we consider the value out of ten to be 0.3 $(3/10)$. That is to say that, the country is placed 3 out of 10 countries. Though this value seems encouraging when compared to the other countries in the given period, much needs to be done to improve the situation since developing countries like Ghana are deemed generally to be performing poorly relative to other countries in the world (Gould & Amaro-Reyes, 1983) . This value is assumed to be the outcome of the country from the commencement of the project. This assumption is relevant as it will help us to obtain the outcome lattice which is crucial for the real option valuation (binomial tree). The country can either drop or increase in terms of the position (value) in subsequent years. The smaller the value, the better the position and hence, the better for the country (project). Hence we can come out with the following outcome lattice for the whole project starting from the first year which is 2014 (t=0) to 2020 (t=6). Each year, the position of the country can either drop or increase (we consider that the drop or increase is by a single step per year). This assumption may not be realistic enough but the intuition behind is significant for valuation to be done in similar projects when all data can be obtained. It will however give us a picture of the performance of the project, having the assumptions considered in mind. We can add a projection year, 2021 to make a possible projection of the next year, should there be a continuation or to predict the behaviour or outcome for similar projects with the same conditions in the seventh year, 2021.

The probability lattice however shows the probability of each corresponding outcome value. The probability lattice is considered as the risk neutral probabilities needed for the valuation. At every stage (step) the risk neutral probability of obtaining the outcome (the corresponding value in the outcome lattice) of that corresponding step is stated. We start with a probability of 1 since the first outcome is known from the beginning. The subsequent outcomes are not certain hence they come with various probabilities. The probabilities in each step should add up to 1. Figure 4.13 shows how the probability is obtained.

0	1	2	3	4	5	6	7
0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
	0.2	0.3	0.4	0.5	0.6	0.7	0.8
		0.1	0.2	0.3	0.4	0.5	0.6
			0.0	0.1	0.2	0.3	0.4
				0.0	0.0	0.1	0.2
					0.0	0.0	0.0
						0.0	0.0
							0.0

Table 4.7: Outcome Lattice

0	1	2	3	4	5	6	7
1	0.50	0.25	0.125	0.063	0.032	0.016	0.008
	0.50	0.50	0.375	0.250	0.157	0.095	0.056
		0.25	0.375	0.375	0.313	0.235	0.165
			0.125	0.250	0.313	0.313	0.274
				0.063	0.157	0.235	0.274
					0.032	0.095	0.165
						0.016	0.056
							0.008

Table 4.8: Probability Lattice

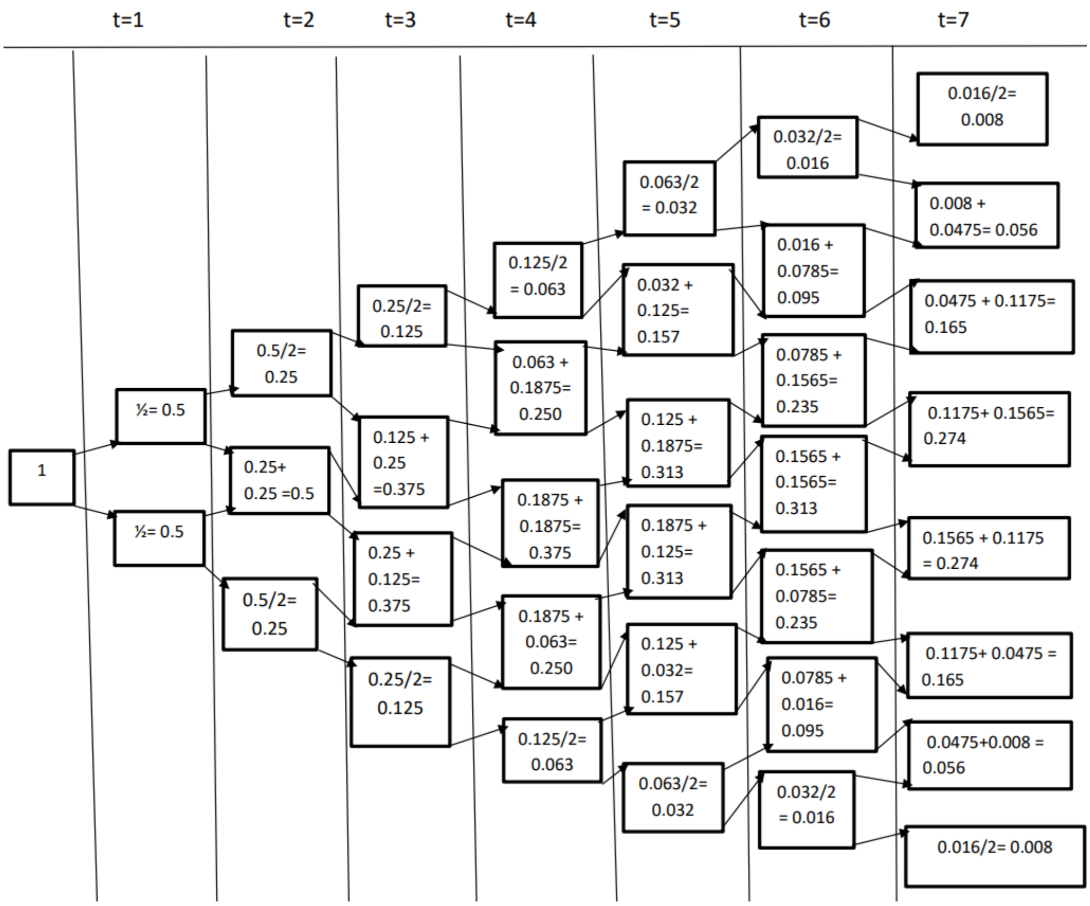

Figure 4.13: Explanation of the Probability Lattice

4.1.15 Cost and Relative Benefit Quantification

Each priority area is allocated with a particular amount of funds. More money is invested in the more important and more pressing areas than the less pressing areas. It is therefore expected that the benefit derived from each area should be proportional to the amount committed into it. Table 4.9 gives the amount invested in each area and the expected benefits of each area (in percentage).

PRIORITY AREA	Budgetary Allocation in $ million	Normalized Cost	Expected Benefit (%)
Agriculture and Food Systems	950	0.12	11.6
Disaster Preparedness and Response	386	0.05	4.70
Natural Resource Management	2535	0.31	30.84
Equitable Social Development	4348	0.53	52.90
Energy, Industrial and Infrastructural Development	1057	0.13	12.86

Table 4.9: Cost-Benefit Analysis

4.1.16 Real Options Valuation of The Project

The real options valuation is done for each sector of the project. With the use of the probability lattice, the expected net present value (ENPV) of each area/sector of the project is estimated. Using binomial real options valuation method. The results are shown (in red) in Figures 4.14 through 4.18. The relative cost of each sector is subtracted from each ENPV (in red) at $t = 0$ to obtain the real options value. The final value becomes the value by which the holder of the real option (government in this case) can his decision about undertaking each sector of the project or the project in its entirety.

The project considered is estimated as an American Call Option. When we have an up movement, the payoff of the option is stated as

$$C^{+} = Max(0, uS_0 - P_x) \tag{4.1}$$

while for that of a down movement, we have

$$C^{-} = Max(0, dS_0 - P_x) \tag{4.2}$$

Where P_x is the exercise price. We can simply express (4.1) and (4.2) as

$$Call = Max(0, X - S_0) \tag{4.3}$$

Where X represents uS_0 or dS_0 depending on the position at which we are making the calculation. The value of C^{+} or C^{-} will be obtained at the end of the whole period of the lifespan of the project. To obtain the main value of the call option at the beginning of the project $(t = 0)$, we work backwards from $t = 7$ to $t = 0$ and the cost subtracted from the value obtained. The formula used to work backwards at each node is

$$C = \frac{P_u C^{+} + P_d C^{-}}{(1 + r)^t} \tag{4.4}$$

P_u and P_d are the probabilities of going up and down from the point (node) of consideration.

The values obtained after working backwards are in red. These probabilities are given in the probability lattice. The value t is the time (years in this case) of the project at that node.

To make the option valuation, we will need the risk free rate (r) and volatility (σ). These are difficult to obtain from our project of consideration. In that case, we will make use of the market values. Hence the risk free rate in Ghana at the time the project is undertaken (2014) is used (Central Bank, 2022). For the volatility, we make use of the international market. S&P 500 is considered as the benchmark market. This is because mostly, S&P 500 is used in recent literature as the benchmark market (Global, 2022). The parameters used for the estimation are: Risk free rate $(r) = 3\%$, volatility $(\sigma) = 13.69\%$, $u = e^{\sigma\sqrt{\Delta t}}$, $\Delta t = 1$, $d = \frac{1}{u}$. The S_0 value of each sector is the taken as the budgetary allocation of that particular area (sector). For brevity, we present only the results of the calculations.

t= 0	t=1	t=2	t=3	t=4	t=5	t=6	t=7
950 6	1089 6	1249 6	1432 6	1643 8	1884 10	2160 54	2477 1527
	828 6	950 10	1089 16	1249 24	1432 58	1643 110	1884 934
		723 4	828 11	950 31	1089 57	1249 240	1432 482
			630 0.5	723 2	828 9	950 32	1089 139
				550 0	630 0	723 0	828 0
					479 0	550 0	630 0
						418 0	479 0
							364 0

Figure 4.14: Valuation of Agriculture and Food Systems

From Figure 4.14 the ENPV from Agriculture and Food Systems is \$6 million and the cost is \$0.12 million. Therefore, the real options value of Agriculture and Food Systems is \$5.88 $(6-0.12)$ million. From Figure 4.15 the ENPV from Disaster Preparedness and Response is \$1 mil-

t= 0	t=1	t=2	t=3	t=4	t=5	t=6	t=7
381 1	443 1	508 1	582 1	667 2	765 4	878 22	1006 620
	337 1	386 2	443 3	508 5	582 12	667 45	765 379
		292 0.7	337 2	386 4	443 12	508 40	582 196
			256 0.2	294 1	337 4	386 13	443 57
				75 0	256 0	294 0	337 0
					195 0	75 0	256 0
						170 0	195 0
							148 0

Figure 4.15: Disaster Preparedness and Response

lion and the cost is $\$0.05$ million. Therefore, the real options value of Disaster Preparedness and Response is $\$0.95 \quad (1 - 0.05)$ million.

t= 0	t=1	t=2	t=3	t=4	t=5	t=6	t=7
2535 7	2907 7	3333 7	3822 8	4383 12	5026 44	5763 144	6609 4074
	2211 6	2535 10	2907 17	3333 32	3822 77	4383 295	5026 2491
		1928 4	2211 11	2535 28	2907 76	3333 263	3822 1287
			740 1	1928 6	2211 23	2535 85	2907 372
				1466 0	740 0	1928 0	2211 0
					1279 0	1466 0	740 0
						1115 0	1279 0
							973 0

Figure 4.16: Natural Resource Management

From Figure 4.16 the ENPV from Natural Resource Management is $\$7$ million and the cost is $\$0.31$ million. Therefore, the real options value of Natural Resource Management is $\$6.69 \quad (7-0.31)$ million.

t= 0	t=1	t=2	t=3	t=4	t=5	t=6	t=7
4348 11	4986 11	5717 12	6556 14	7518 20	8621 45	9885 247	11335 6987
	3792 10	4348 17	4986 29	5717 55	6556 133	7518 506	8621 4273
		3307 7	3792 19	4348 47	4986 131	5717 452	6556 2208
			2884 3	3307 11	3792 39	4348 146	4986 638
				2515 0	2884 0	3307 0	3792 0
					2193 0	2515 0	2884 0
						1913 0	2193 0
							1668 0

Figure 4.17: Equitable Social Development

From Figure 4.17 the ENPV from Equitable Social Development is $\$11$ million and the cost is $\$0.53$ million. Therefore, the real options value of Equitable Social Development is $\$10.47 \quad (11-0.53)$ million.

t= 0	t=1	t=2	t=3	t=4	t=5	t=6	t=7
1057 4	1212 4	1390 4	1594 5	1828 6	2096 11	2403 60	2756 1699
	923 4	1057 7	1212 11	1390 20	1594 41	1828 123	2096 1039
		804 3	923 8	1057 20	1212 51	1390 151	1594 537
			701 1	804 6	923 21	1057 76	1390 333
				611 0	701 0	804 0	923 0
					533 0	611 0	701 0
						465 0	533 0
							406 0

Figure 4.18: Energy, Industrial and Infrastructural Development

From Figure 4.18 the ENPV from Energy, Industrial and Infrastructural Development is $\$4$million and the cost is $\$0.13$ million. Therefore, the real options value of Energy, Industrial and Infrastructural Development is $\$3.87 \quad (4-0.13)$ million.

4.1.17 Relating the Climate Learning project to the various Views

It is possible to relate the eight climate change views given in the earlier chapters with the project under consideration. This is important as it aids in identifying the overlapping that exists within the enterprise views of the project. We are also able to locate which area of the project is identified in which particular view. This concept is summarized in Table 4.10.

Enterprise View	Area (Component of project) in that View
Strategy	1. Climate change learning (main objective) 2. The focus areas of the various priority areas 3. undertaking less and costly priorities
Policy	1. Policy priority areas
Organization	1. Major stakeholders and individuals in the priority areas
Process	1. Various procedures and processes to attain the priority areas 2. The focus areas of the priority areas
Product	1. Education awareness and intervention
Service	1. Services rendered by stakeholders in the the priority areas 2. Services rendered by stakeholders/workers in the focus ares
Knowledge	1. Knowledge about the challenges posed by climate change 2. Knowledge about the priority areas 3. Knowledge about the focus areas
Information Technology	1. Technology needed to improve work towards priority areas e.g renewable energy 2. Information and communication

Table 4.10: Relating the Climate Change Project to the various Views

4.1.18 Discussion

It is not uncommon that African countries go into several investments without really being able to quantify the benefits to be obtained from these projects. Most of these projects are usually not financially quantifiable. This makes it difficult for investors to actually be able to analyse as to whether the project was worth it or not.

Real options (finance) gives us the opportunity to measure the benefits or loss of any investment in monetary sense. This research considers climate change investment. The benefits of projects in these areas are not financially analysable. Climate change investments in Africa are similar in terms of operation, major areas and challenges. In that case, we have considered a project in Ghana as a case study. The method, results and findings can therefore be replicated in other countries and projects. The project under consideration is a 7 year national investment of Ghana. It is a capital intensive venture. It involves the major areas of the economy: Agriculture and energy sectors . These are indicated as priority areas in the project. The budgetary allocation of each area is stated. For the overall success of the project, each area must successfully perform. Since the funds allocated to each of the areas is not the same, we have grouped the areas into two: more expensive and less expensive areas, for the purpose of the analysis. The assumptions of the analysis is stated in subsection 4.1.11.

To be able to obtain the dependencies that exists among the various areas (components), and to estimate our metrics, the uncertainty (hindrance) of the project is identified. Financial mismanagement (corruption) is assumed to be the main uncertainty of this project. This issue of corruption is a general canker against the growth and development of every country in Africa. Hence, it is crucial to assess the impacts of this challenge on climate change investments such as those that involve huge sums of monetary commitment.

It is seen from the logical dependency model that, the uncertainty affects every component of the project. The uncertainty is what is most likely to affect the success of the project. The logical representation and combinations of the various components are given on truth tables. The DNF of the logical representation helps to estimate the various metrics.

The measures (metrics) estimated are: Flexibility (Flex), Optionability (Opt) and Realizability

(Rel). These measures are clearly explained in chapter 4. The interdependence of the views identified in the project is illustrated on Figure 4.4. The illustration of the logical representation, interdependence as well as the measures is demonstrated on Figure 4.6 through to Figure 4.11. These enabled us to identify the options that exist in this project as: undertake less expensive and undertake more expensive priorities.

Finally, having obtained all those, we will need probability and outcome lattices which will assist us to do real options valuation of the project. The real option valuation conducted on the project shows that all the sectors of the project are valuable from real options perspective since all the real options values are positive. Hence, a project which would otherwise not be suitable for real options has been simplified and valued using real options analysis.This is an achievement of the thesis.

Chapter 5

Conclusion, Recommendations and Future Work

This is the final chapter of the study. It gives the conclusions made based on the research conducted and the findings made. The contributions made are also indicated.

5.1 Conclusion

This study introduced the application of real options analysis in a climate change investment project in Africa (Ghana). Climate change investments are usually not undertaken with the goal of reaping direct financial benefits (profits), but to manage a particular climate related problem (short-term or long-term). In this regard, it is usually a challenging task for the stakeholders to immediately assess the success of the project. The application of real options analysis (framework) helps to overcome that difficulty.

This thesis is able to combine DSM and real options approach to resolve the problem of project assessment. We initially identify the various project architecture views in the entire project. Some of the views as identified include: policy, Information Technology and Process. With the identification of the views, the research objective 1 has been achieved.

We have also identified, from existing literature, that the major cause of climate change is anthropogenic. In Africa, we do not contribute a greater percentage of global climate change.

That notwithstanding, we experience the adverse effects of climate change more than any other continent. Hence, the second objective has been achieved.

The DSM was useful in modelling the project under consideration. The DSM is effective in modelling the various views and identifying the inter-relationships that exist among the various components of the project. The C-DSM is then used to facilitate the estimation of the metrics including optionability and flexibility which are in turn crucial in the real options analysis of the project. With this done, the third objective has been achieved successfully.

The concept of mechanisms and types of real options in climate change investments has been introduced in this work. A major achievement is the implementation of all the above concepts in a practical climate change investment project in Africa (Ghana). That provided room for real options analysis and valuation to subsequently be undertaken. This gives an understanding of the features that one should look forward to seeing or deriving in a project before real options could be applied. These features as identified by this study include but not limited to: explicit identification of the various components of the project and the expected performance of each component or the project as a whole at the end of the project lifespan. The project should also be time bound and should not operate to infinity. That leads to the attainment of the final objective. Hence, the objectives as stated in section 1.1.3 have been achieved. Therefore, the study was successfully conducted.

5.1.1 Contribution of the thesis

The contributions of this thesis are in the areas of climate change and real options (finance). This work provides a framework by which climate change projects can be financially quantified and analysed. The specific contributions of the work includes the under-listed.

1. One contribution is the introduction of real options analysis in climate change projects.
2. It demonstrates the application of DSM in project or investment analysis.
3. This work also provides an approach by which DSM and real options analysis could be applied hand-in-hand to better analyse and investigate the worth of an investment (particularly climate change).

4. Another major contribution is the identification of mechanisms that enable options in a climate change investment in Ghana (Africa) and the types of options enabled.
5. Projects and R & D investments which may seem impossible to apply real options approach in their valuation will be made easier by the aid of this research.
6. This thesis also contributes to academia and policy making as it has identified the major uncertainty (hindrance) of projects in Africa.

5.1.2 Recommendations

The research enables us to arrive at the following recommendations to academia, stakeholders and investors.

1. Real options analysis should be used to value projects before implementation.
2. Climate change related projects should first be valued before they are being undertaken. This helps to realize the areas of the investment in which much attention must be placed for the required results to be achieved.
3. The uncertainty identified (financial mismanagement) should not be taken lightly as it hinders the success of investments in Africa as a whole.
4. There should be close monitoring and supervision on projects and investments that involve huge financial commitment.
5. All African countries should strengthen institutions towards the reduction of financial mismanagement and corruption.

References

Abadie, L. M., & Chamorro, J. M. (2014). Valuation of wind energy projects: A real options approach. *energies*, *7*(5), 3218–3255.

Adenle, A. A., Ford, J. D., Morton, J., Twomlow, S., Alverson, K., Cattaneo, A., … others (2017). Managing climate change risks in africa-a global perspective. *Ecological Economics*, *141*, 190–201.

Africa, E. (2014). *Johannesburg, climate change, development and energy problems in south africa: Another world is possible.*

Awadzie, D. M., & Garr, D. K. (n.d.). The impact of corruption on economic growth in ghana.

Bartolomei, J., Cokus, M., Dahlgren, J., De Neufville, R., Maldonado, D., & Wilds, J. (2007). Analysis and applications of design structure matrix, domain mapping matrix, and engineering system matrix frameworks. *Massachusetts Institue of Technology*.

Brealey, R. A. (2001). *Fundamentals of corporate finance*. McGraw Hill.

Bryan, E., Deressa, T. T., Gbetibouo, G. A., & Ringler, C. (2009). Adaptation to climate change in ethiopia and south africa: options and constraints. *Environmental science & policy*, *12*(4), 413–426.

Buurman, J., & Babovic, V. (2016). Adaptation pathways and real options analysis: An approach to deep uncertainty in climate change adaptation policies. *Policy and Society*, *35*(2), 137–150.

Central Bank, G. (2022). *Treasury rate.* (https://www.google.com/search?client=firefox-b-dq=treasury+rate+in+Ghana+for+the+year+2014)

Ceseña, E. M., Mutale, J., & Rivas-Dávalos, F. (2013). Real options theory applied to electricity generation projects: A review. *Renewable and Sustainable Energy Reviews*, *19*, 573–

581.

Collier, P., Conway, G., & Venables, T. (2008). Climate change and africa. *Oxford Review of Economic Policy*, *24*(2), 337–353.

Commission, N. D. P., et al. (2010). Ghana shared growth and development agenda (gsgda)-costing framework,(2010–2013). *Volume II*.

Cox, J. C., & Rubinstein, M. (1985). *Options markets*. Prentice Hall.

Decision structure matrix. (n.d.). https://dsmweb.org/sequencing-a-dsm/.

Downing, T. E., Ringius, L., Hulme, M., & Waughray, D. (1997). Adapting to climate change in africa. *Mitigation and adaptation strategies for global change*, *2*(1), 19–44.

Ehrman, D. S. (2006). *The handbook of pairs trading: strategies using equities, options, and futures* (Vol. 240). John Wiley & Sons.

Eppinger, S. D., & Browning, T. R. (2012). *Design structure matrix methods and applications*. MIT press.

Fernandes, B., Cunha, J., & Ferreira, P. (2011). The use of real options approach in energy sector investments. *Renewable and Sustainable Energy Reviews*, *15*(9), 4491–4497.

Galderisi, A., & Colucci, A. (2018). *Smart, resilient and transition cities: Emerging approaches and tools for a climate-sensitive urban development*. Elsevier.

Gans, W., & Hintermann, B. (2013). Market effects of voluntary climate action by firms: Evidence from the chicago climate exchange. *Environmental and Resource Economics*, *55*(2), 291–308.

Glancy, D., Horn, M., Pryor, S., Shahinian, M., & Shopoff, G. (2007). Corporate strategies for addressing climate change.

Glanemann, N. (2014). *The optimal climate policy of mitigation and adaptation: a real options theory perspective*. WiSo-Forschungslabor.

Global, S. . P. . (2022). *S & p 500.* (https://www.google.com/search?client=firefox-b-dq=volatility+of+SP+500+in+2014)

Gould, D. J., & Amaro-Reyes, J. A. (1983). The effects of corruption on administrative performance. *World Bank Staff Working Paper*, *580*(2514).

Hamarat, C., Kwakkel, J. H., & Pruyt, E. (2013). Adaptive robust design under deep uncertainty. *Technological Forecasting and Social Change*, *80*(3), 408–418.

Hassanali, K. (2017). Challenges in mainstreaming climate change into productive coastal sectors in a small island state–the case of trinidad and tobago. *Ocean & coastal management*, *142*, 136–142.

Heydari, S., Ovenden, N., & Siddiqui, A. (2012). Real options analysis of investment in carbon capture and sequestration technology. *Computational Management Science*, *9*(1), 109–138.

Hilliard, R. (2000). Ieee-std-1471-2000 recommended practice for architectural description of software-intensive systems. *IEEE, http://standards. ieee. org*, *12*(16-20), 2000.

Hoffman, A. J. (2005). Climate change strategy: The business logic behind voluntary greenhouse gas reductions. *California Management Review*, *47*(3), 21–46.

Hull, J. C. (2019). *Options, futures and other derivatives.* Pearson.

Hussein, Z., Hertel, T., & Golub, A. (2013). Climate change mitigation policies and poverty in developing countries. *Environmental Research Letters*, *8*(3), 035009.

International, T. (2022). *Ghana corruption rank.* (https://tradingeconomics.com/ghana/corruption-rank)

Jeffery, M., Shah, S., & Sweeney, R. (2003). Real options and enterprise technology project selection and deployment strategies. In *Proceedings of the 7th annual conference in real options.*

Kalra, N., Hallegatte, S., Lempert, R., Brown, C., Fozzard, A., Gill, S., & Shah, A. (2014). *Agreeing on robust decisions: new processes for decision making under deep uncertainty*. The World Bank.

Karl, T. R., & Trenberth, K. E. (2003). Modern global climate change. *science*, *302*(5651), 1719–1723.

Kodukula, P., & Papudesu, C. (2006). *Project valuation using real options: a practitioner's guide*. J. Ross Publishing.

Kolk, A., & Pinkse, J. (2004). Market strategies for climate change. *European management journal*, *22*(3), 304–314.

Lander, D. M., & Pinches, G. E. (1998). Challenges to the practical implementation of modeling and valuing real options. *The quarterly review of economics and finance*, *38*(3), 537–567.

Lankhorst, M., et al. (2009). *Enterprise architecture at work* (Vol. 352). Springer.

Lee, H. (2007). Intergovernmental panel on climate change.

Lenssen, G., Arenas, D., Lacy, P., Pickard, S., Kolk, A., & Pinkse, J. (2008). Business and climate change: emergent institutions in global governance. *Corporate Governance: The international journal of business in society*.

McConnell, J. B. (2007). *A life-cycle flexibility framework for designing, evaluating and managing" complex" real options: case studies in urban transportation and aircraft systems* (Unpublished doctoral dissertation). Citeseer.

Meyer, E. L., & Odeku, K. O. (2010). Climate change, energy, and sustainable development in south africa: Developing the african continent at the crossroads. *Sustainable Development Law & Policy*, *9*(2), 17.

Michaelowa, A., & Jotzo, F. (2005). Transaction costs, institutional rigidities and the size of the clean development mechanism. *Energy policy*, *33*(4), 511–523.

Mikaelian, T. (2009). *An integrated real options framework for model-based identification and valuation of options under uncertainty* (Unpublished doctoral dissertation). Massachusetts Institute of Technology.

Mun, J. (2002). *Real options analysis: Tools and techniques for valuing strategic investments and decisions* (Vol. 137). John Wiley & Sons.

Myers, S. C. (1984). Finance theory and financial strategy. *Interfaces*, *14*(1), 126–137.

Nightingale, D., & Rhodes, D. (2007). Mit esd-38j enterprise architecting. *Course Notes*.

Nightingale, D. J., & Rhodes, D. H. (2004). Enterprise systems architecting: Emerging art and science within engineering systems. In *Proceedings of the esd external symposium* (pp. 1–13).

Park, T., Kim, C., & Kim, H. (2014). Valuation of drainage infrastructure improvement under climate change using real options. *Water resources management*, *28*(2), 445–457.

Prins, G., & Rayner, S. (2007). Time to ditch kyoto. *Nature*, *449*(7165), 973–975.

Program, U. N. D. (2021). *Climate change learning strategy in ghana: Background report.*

(https://UNDP$_{G}H_{S}USDEV_{C}CLEARN_{B}ackgroundReport_{C}CLearningInGhana_{F}inalDraft$)

Puig, D., Olhoff, A., Bee, S., Dickson, B., & Alverson, K. (2016). The adaptation finance gap report.

Ransom, P., Ribeiro, G., et al. (2018). Terminal evaluation of the un environment/gef project: Mitigation options of ghg emissions in key sectors in brazil.

Rautenberg, W. (2010). Incompleteness and undecidability. In *A concise introduction to mathematical logic* (pp. 215–268). Springer.

Roelich, K., & Giesekam, J. (2019). Decision making under uncertainty in climate change mitigation: introducing multiple actor motivations, agency and influence. *Climate policy*, *19*(2), 175–188.

Rubin, E., & De Coninck, H. (2005). Ipcc special report on carbon dioxide capture and storage. *UK: Cambridge University Press. TNO (2004): Cost Curves for CO2 Storage, Part*, *2*, 14.

Sæverud, I. A., & Skjærseth, J. B. (2007). Oil companies and climate change: inconsistencies between strategy formulation and implementation? *Global Environmental Politics*, *7*(3), 42–62.

Saleh, J. H., Mark, G., & Jordan, N. C. (2009). Flexibility: a multi-disciplinary literature review and a research agenda for designing flexible engineering systems. *Journal of Engineering Design*, *20*(3), 307–323.

Schwartz, E. S., & Moon, M. (2000). Rational pricing of internet companies. *Financial analysts journal*, *56*(3), 62–75.

Sharman, D. M., & Yassine, A. A. (2007). Architectural valuation using the design structure matrix and real options theory. *Concurrent Engineering*, *15*(2), 157–173.

Singh, N., Finnegan, J., Levin, K., RICH, D., SOTOS, M., TIRPAK, D., & WOOD, D. (2016). Mrv 101: Understanding measurement, reporting, and verification of climate change mitigation. *World Resources Institute Working Paper, August.(http://www. wri. org/publication/mrv-101-understanding-measur ement-reporting-and-verification-climate-change-mitigation).*

Smit, H. T., & Trigeorgis, L. (2012). *Strategic investment: Real options and games*. Princeton

University Press.

Sousa, P., Caetano, A., Vasconcelos, A., Pereira, C., & Tribolet, J. (2007). Enterprise architecture modeling with the unified modeling language. In *Enterprise modeling and computing with uml* (pp. 67–94). IGI Global.

Trigeorgis, L., et al. (1996). *Real options: Managerial flexibility and strategy in resource allocation*. MIT press.

VijayaVenkataRaman, S., Iniyan, S., & Goic, R. (2012). A review of climate change, mitigation and adaptation. *Renewable and Sustainable Energy Reviews*, *16*(1), 878–897.

Vincent, K. (2004). Creating an index of social vulnerability to climate change for africa. *Tyndall Center for Climate Change Research. Working Paper*, *56*(41), 1–50.

Walker, W. E., Haasnoot, M., & Kwakkel, J. H. (2013). Adapt or perish: a review of planning approaches for adaptation under deep uncertainty. *Sustainability*, *5*(3), 955–979.

Wang, T., & De Neufville, R. (2005). Real options in projects 9th real options annual international conference. *Paris, FR*.

Watch, C. (2010). The clean development mechanism (cdm) toolkit: A resource for citizens, activists and ngos. *Brussels: CDM Watch*.

Wende, W., Bond, A., Bobylev, N., & Stratmann, L. (2012). Climate change mitigation and adaptation in strategic environmental assessment. *Environmental Impact Assessment Review*, *32*(1), 88–93.

Winkler, H. (2005). Renewable energy policy in south africa: policy options for renewable electricity. *Energy policy*, *33*(1), 27–38.

Woodward, M., Kapelan, Z., & Gouldby, B. (2014). Adaptive flood risk management under climate change uncertainty using real options and optimization. *Risk Analysis*, *34*(1), 75–92.

Yang, M., & Blyth, W. (2007). Modeling investment risks and uncertainties with real options approach. *International Energy Agency*, *23*.