Risks and Decision Making in Development of New Power Plant Projects

by

Ásbjörg Kristinsdóttir

B.Sc. Mechanical and Industrial Engineering, University of Iceland, 2002
M.Sc. Civil and Environmental Engineering, Massachusetts Institute of Technology, 2008
MBA, Sloan School of Management, 2008

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Author ....
Department of Civil and Environmental Engineering
August 10, 2012

Certified by ....
Fred Moavenzadeh
James Mason Crafts Professor of Civil and Environmental Engineering and Systems Engineering
Thesis Supervisor

Certified by ....
Olivier L. de Weck
Associate Professor of Aeronautics and Astronautics and Engineering Systems
Thesis Reader

Certified by ....
Gordon M. Kaufman
Morris A. Adelman Professor of Management, Emeritus
Thesis Reader

Certified by ....
Donald R. Lessard
Epoch Foundation Professor of International Management
Thesis Reader

Accepted by ....
Heidi M. Nepf
Chair, Departmental Committee for Graduate Students

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ABSTRACT

Power plant development projects are typically capital intensive and subject to a complex network of interconnected risks that impact development's performance. Failure to develop a power plant to meet performance constraints can come at great cost to the developer and other stakeholders involved. In order to develop an investment strategy plan based on their risk appetite, and manage risks effectively, developers must be able to identify and analyze project opportunity risks.

This dissertation is motivated by the need to study the nature and impact of risks on a power plant development project, and to demonstrate how proper management of those risks can help mitigate these impacts. The purpose is to feed that information into developer's investment strategy to be able to understand whether or not to participate in particular power plant development projects, and how to participate.

First phase of the dissertation is an analysis of power plant investment decisions and development process, followed by identification of risks across all stages of development. Through data mining of performance indicators of around 300 power plant development projects worldwide, clusters of geographical locations, energy technologies, and developer types are highlighted. This helps us understand which projects developers should consider for evaluation given performance trends of geographic locations, and energy technologies.

Our research then introduces a novel approach to power plant project risk analysis. We combine a System Dynamics model of the power plant development process with an Analytical Network Process model that enables identification of key relationships among risks and their impact on the development process. The models are used to construct project risk profiles. These three models work together to show how developers can make risk informed decision when selecting amongst power plant project opportunities, how they should best prepare projects to mitigate negative impacts of risks involved, and how they should react to changes in managing development performance over a project's lifetime.

Thesis Supervisor: Prof. Fred Moavenzadeh
Title: James Mason Crafts Professor of Civil and Environmental Engineering and Systems Engineering

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Elsku mamma og pabbi, þessi ritgerð er tileinkuð ykkur.

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LIST OF ACRONYMS

AHP	Analytical Hierarchy Process
ANP	Analytical Network Process
APPA	American Public Power Association
AWEA	American Wind Energy Association
AWWA	American Water Works Association
bps	Basis points
CAI	Country Attractiveness Index
CAPEX	Capital Expenditures
CAR	Construction All Risk
CBA	Cost Benefit Analysis
CCGT	Combined Cycle Gas Turbine
CDS	Credit-Default Swap
CHP	Combined Heat and Power
COD	Commercial Operation Date
Coop	Utility Cooperative
CRS	Congressional Research Service
CSP	Concentrating Solar Power
D/E	Debt to Equity ratio
EAR	Erection All Risk
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
ECA	Export Credit Agency
EPC	Engineering Procurement Construction
EUR	Euro
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GEA	Geothermal Energy Association

GHG	Green House Gas
GIS	Geographic Information System
GNI	Gross National Income
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IFC	International Finance Corporation
IOU	Investor Owned Utility
IPP	Independent Power Producer
IPR	Intellectual Property Rights
IRR	Internal Rate of Return
ISO	International Organization for Standardization
ITIG	International Tunneling Insurance Group
kW	kilowatt
kWh	kilowatt-hour
LCOE	Levelized Cost of Electricity
MAUT	Multi-attribute Utility Theory
MCDA	Multi-criteria Decision Analysis
MCDM	Multi-criteria Decision Models
MIGA	Multilateral Investment Guarantee Agency
Munis	Municipal Owned Utilities
MW	Megawatt
MWh	megawatt-hour
M&A	Mergers and Acquisitions
NABCEP	North America Board of Certified Energy Practitioners
NGO	Non-Governmental Organization
NUG	Non-utility generator
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
O&M	Operations & Maintenance
OECD	Organization for Economic Cooperation and Development
PCC	Pulverized Coal Combustion
PE	Private Equity
PERT	Program Evaluation and Review

POU	Public Owned Utility
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PRG	Partial Risk Guarantee
PRI	Political Risk Insurance
PV	Photovoltaic
RBS	Risk Breakdown Structure
RES	Renewable Energy Sources
RPS	Renewable Portfolio Standard
R&D	Research & Development
SD	System Dynamics
SEFI	Sustainable Energy Finance Initiative
SOC	Start of Construction
SWOT	Strengths, Weaknesses, Opportunities and Threats
S&P	Standard & Poor's
UNEP	United Nations Environment Programme
USD	United States Dollars
VaR	Value at Risk
VC	Venture Capital
WACC	Weighted Average Cost of Capital
WNA	World Nuclear Association

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Chapter 1: Introduction

Power plant development projects are typically capital intensive and comprise of a complex network of interconnected risks which can impact the development's performance. Failure to develop the power plant to meet the performance constraints can come at a great cost to the developer and other stakeholders involved. It is essential for developers to be able to analyze the risk in their project opportunities to develop investment strategy plan based on their risk appetite, and ability to manage the risk.

This dissertation is based on extensive data gathering, interviews with industry experts, and a database of around 300 power plant development projects. Through a novel approach built on a collection of models, the dissertation demonstrates how developers can make risk-informed decisions on their selection of power plant development projects, how they should best prepare the projects to mitigate the risks involved, and how they should react to changes throughout the project lifetime.

The following chapter will give a background to the motivation behind the research, as well as the gap that presented the research opportunity. It then highlights the key contributions, and follows up with an overview of the dissertation outline.

1.1 *Motivation and Research Opportunity*

Complexity of a power plant development project, and accordingly, evaluation of these projects is steadily rising. Changes to energy markets, and emerging energy technologies, introduce new players amongst developers, and new and established developers need to adapt to changing regulations and energy technologies through their power plant portfolio and market focus. These increasing criteria in evaluation of new power plant development opportunities change rapidly, making the overall assessment a complex undertaking. As the power plant development process requires a long management and execution process from site selection to plant start-up, there are many risks of time delays, cost increase, capacity output changes, and overall investment returns.

This dissertation is motivated by the need to study the nature and impact that these risks can have on a power plant development project, and to demonstrate how proper management of those risks can help mitigate the negative impact. Diagram 1.1 shows how this research approached key questions through literature review and data collection.

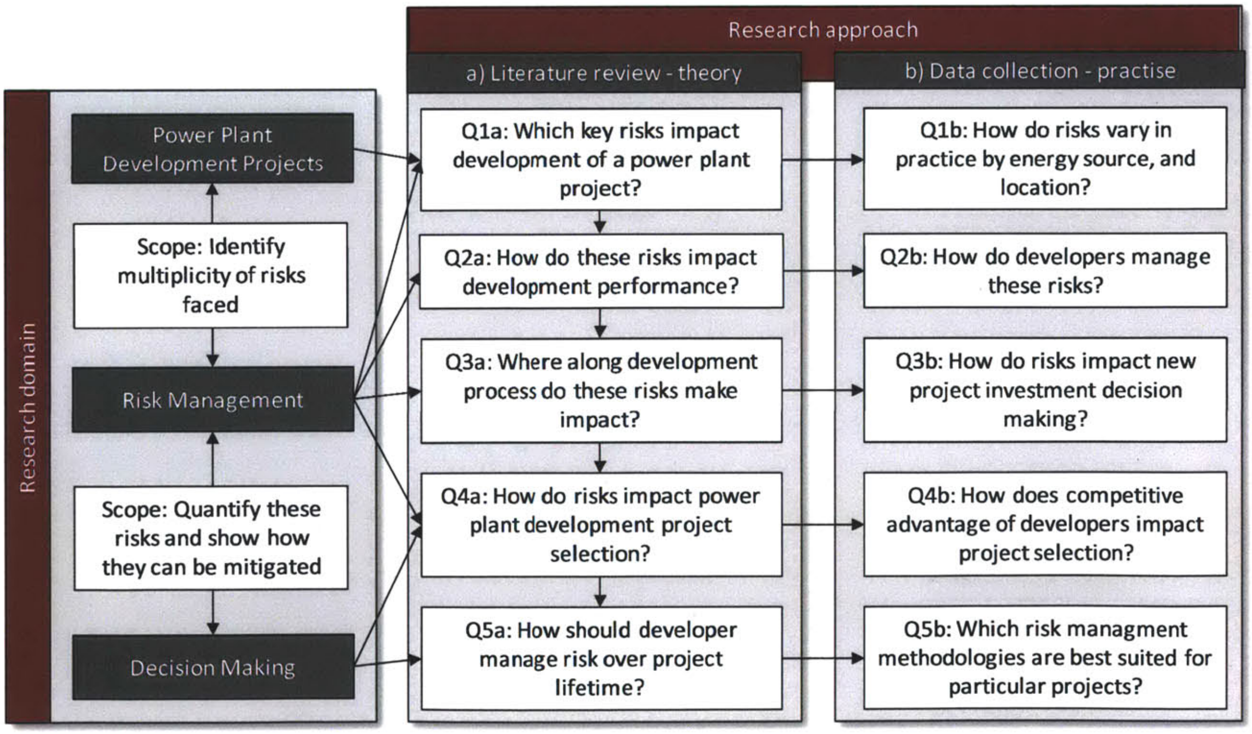

Diagram 1.1 Research overview and main questions

1.2 *Methodology and Contributions*

Several models are combined in order to identify key relationships among risks, how they impact the development process, and how companies choose among elements of a set of project development opportunities. Diagram 1.2 shows how the collection of models is deployed to answer key research questions. The diagram shows at a macro level how information is shuttled among our models. Taken together, the models allow us to answer risk oriented questions that cannot be adequately addressed by any one single model.

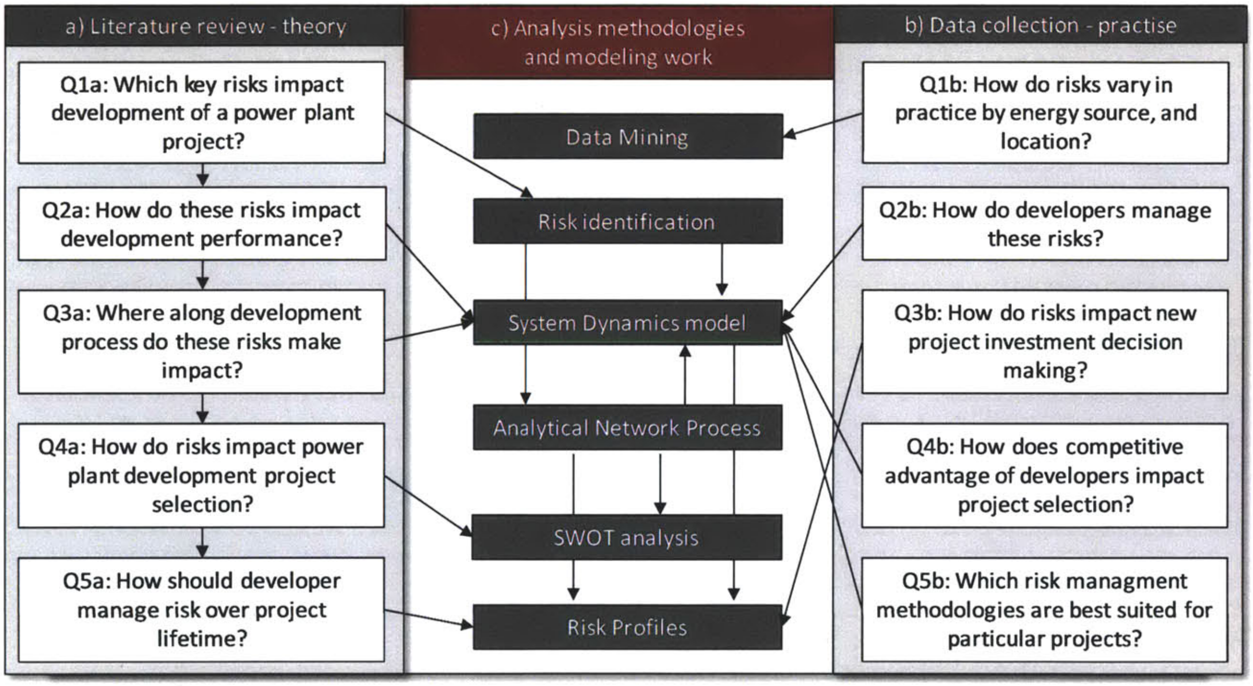

Diagram 1.2 Research approach and use of models and analysis methodologies

A System Dynamics model that captures feedback effects on cost, time, and scope of throughout a development process of a power plant project, is coupled with an Analytical Network Process model. The joint output of these coupled models is used to construct program development Risk Profiles. This in turn supports project selection. Coupled with a data mining analysis, this model framework can help a developer determine which project opportunities should be considered given their type, risk appetite, and competitive advantage. In sum, we are able to logically support answers to the following key questions:

1) Which project should be selected?

2) How should risk management efforts be allocated so as to mitigate impacts of risk on development performance?

3) How should risk management efforts adapt to observed changes in the project environment throughout the project's lifetime?

The first phase of the dissertation is an analysis of power plant project investment decisions and development processes, followed by risk identification and analysis of risk management methodologies across all stages of the development processes. A data mining analysis of performance indicators of around 300 power plant development projects worldwide, classified by of geographical location, energy technology, and developer type is highlighted. This helps us understand what projects and locations are best suited to a given developer type. *Classification Trees* provide insights into project selection, especially trends for how different project developers go for different project types, depending on location and energy technology. *Cluster Analysis* and *Logistic Regression* give insights into how project performance (time, cost, and scope) vary with location and energy technology.

This is followed with a demonstration of how a *System Dynamics* model can be used to track development of performance indicators (time, costs, and scope) of a power plant development project across the project lifetime. An *Analytical Network Process* (ANP) model that spans all identified risk criteria is used to identify risk weights which are, in turn, built into the System Dynamics model to control the severity of the risk impacts on the development performance. Factorial dominance matrix of the ANP model, generated by pairwise comparison of risk criteria, is deployed to generate System Dynamics model feedback loops. The System Dynamics model is coupled with the ANP model to construct project risk profiles. These models work together to show 1) which projects developers should consider for evaluation, 2) how to select amongst project opportunities, and 3) how to manage the development performance during the project's lifetime.

Finally *SWOT analysis* is used to analyze industry sector attractiveness due to importance of considerations for the developer's power plant portfolio in their new investment decisions. Through analysis based on strengths, weaknesses, opportunities, and threats of different sectors of the industry, the analysis can support developer's decision considerations for making a move into new sectors of the energy industry. Our research gives an example of how such analysis can be used to assess the conventional energy industry and the renewable energy industry. It also shows how that analysis can be combined with the ANP model to prioritize the individual SWOT factors.

1.3 Dissertation Outline

Chapter 1 is an introductory chapter on motivation behind the research, its approach, analysis contribution, and an outline for the following thesis

Chapter 2 identifies key characteristics of power plant development projects, and type of developers involved. Power plant investment strategies are discussed, along with a description of how developers approach development process, as well as key factors which impact new investment decisions. A typical project development structure is used as a template for discussion of different forms of project partnering. How project stakeholders impact development decision making is highlighted along with key investment drivers for a given market type. This section concludes with an overview of a typical financing structure, and investors' involvement.

Chapter 3 is devoted to discussion of risks involved in power plant development projects, how developers go about identifying those risks, and different approaches in classifying them. It then discusses general impact which risks can have on development's cost, time, and scope, as well as short term and long term effects. Risks general to power plant development projects are then detailed, categorizing them according to six different layers of risk, and identifying where along the development timeline those risks may occur. It then shows how magnitude of these risks can be used to display a project's risk profile. Following sections cover risks specific to renewables, risks general to power plant development projects, and those specific to each energy technology group. Following discussion of risk assessment, Chapter 3 highlights key risk mitigation instruments along with bearers of risk allocation. The chapter ends with discussion of risk transfer through third party contracts, financial architecture, and insurance.

Chapter 4 is devoted to models. Each model in this section is distinct. When brought together, however, they provide a system for enabling risk informed investment decisions for new power plant development. This section begins by discussing the pool of different strategic models, and their application for power plant developments. It then discusses the database created, and value of the parameters of the around 300 projects which are included.

Chapter 5 is a summary of main contributions of our model system, and proposes work for future research.

Chapter 2: Investment Decisions and Development Process

Power plant development projects follow a long process from initiation and execution of development to plant operation. This chapter identifies key characteristics of power plant development projects, and type of developers involved. It describes the development process with particular attention paid to key project selection considerations, and to important decisions points throughout the development, such as regarding construction permits and authorizations, and negotiations with stakeholders (including land owners, local and government authorities, and power supply companies). Power plant investment strategies are discussed, along with a description of how developers approach development process, as well as key factors which impact new investment decisions. A typical project development structure is used as a template for discussion of different forms of project partnering. How project stakeholders impact development decision making is highlighted along with key investment drivers for a given market type. This section concludes with an overview of a typical financing structure, and investors' involvement.

2.1 *Overview of Power Plant Development Projects*

Power plant development projects utilize one or more technologies, each of which is large scale industry of its own. Table 2.1 is an overview of energy technologies available for power generation, and demonstrates the breadth of technologies available to developers when selecting their energy technology focus (this table excludes energy storage, fuel cells, and ocean technology). This list was generated through literature review and although it's comprehensive it is not exhaustive, as new generation technologies are constantly in the pipeline waiting to become commercially feasible systems.

Category	**Power generation technologies**
Biomass	Pyrolysis-based biofuels, Lignocellulose sugar-based biofuels, Direct Combustion, Co-firing with Coal, Biomass Gasification, Municipal Waste, Pyrolysis, Landfill Gas, Anaerobic Digestion, Sewage Digestion
Geothermal	Dry Steam (Vapor), Flashed Steam, Binary Cycle, Petrothermal (Hot Dry Rock), Geothermal Preheat, Fossil Superheat
Hydro	Large (Pelton Turbine, Francis Turbine, Propeller Turbine, Kaplan Turbine), Small/Mini (Run of river), Micro, Hydrokinetic turbines
Nuclear	Nuclear Fission (Boiling Water Reactor, Pressurized Water Reactor, Pressurized Heavy Water Reactor, Advanced Gas-Cooled Reactor, High Temp Gas-Cooled Reactor, Gas Turbine Modular Helium Reactor, Breeder Reactors), Nuclear Fusion
Oil and Gas Thermal	Reciprocating, Natural Gas (Shale Gas), Simple Gas Turbine (Aero-Derivative Gas Turbine, With Recuperation, Humid Air Turbine, Cascaded Humid Air Turbine, Heavy Frame Gas Turbine), Combined Cycle, Coal (Pulverized, Atmospheric Circulating Fluidized-Bed, Pressurized Fluidized Bed Combustion, Integrated Gasification Combined Cycle, Integrated-Gasification Humid-Air Turbine, Direct Coal-Fired Combined Cycle, Supercritical & Ultra-Supercritical Coal Comb)
Solar	Solar PV (Crystalline silicon, Thin film, Amorphous Silicon, Thin film, Indium Diselenide, Flat Plate, High Efficiency Multi Junction), Solar Thermal (Trough, Tower, Dish, Salt Pond)
Wind	Onshore Wind Turbines, Offshore Wind Turbines, Higher-altitude wind generator, Wind kites

Table 2.1 Various power generation technologies

This research will cover all technology categories listed, as our underlying assumption is that a power plant developer's strategic investments are not limited by the choice of power generation technologies.

2.1.1 Project development categories

Power plant development projects can be classified in various ways. Within the types of power generation technologies listed in Table 2.1, commonly used categories to describe the characteristics of a project include the following:

- **Power plant size:** The generation output of the power plant.
- **Development type:** Whether this is a new plant, expansion or a version thereof.
- **Site characteristics:** Including if this is an undeveloped site or not.

In some cases, more than one type may be relevant for consideration. The following section describes these categories in more detail.

2.1.1.1 Power plant size

No commonly accepted classification is available to define what characteristics identify a power plant development project as being of a large or small size. In addition, such terminologies tend to be used differently depending on whether the project being developed is for a renewable or conventional energy source. The following list is a general description of a typical classification according to the project's scale (or the power plant's electricity generation size):

- **Mega Projects:** Mega Projects typically cost over USD 1 billion and attract public attention because of their substantial impact on communities, budgets, and the environment. Such projects suffer from a high risk of being derailed or cancelled entirely due to the difficulties of implementing such large, complex, and frequently politically as well as environmentally sensitive projects. Developers therefore face the risk of losing the initial investment as sunk cost after the project gets cancelled.
- **Large Scale Projects:** Large Scale Projects are typically grid connected or isolated grid projects. As for Mega Projects, Large Scale Projects face the risk of not reaching the implementation stage. Its impact on the environment and community may render it

infeasible or economically not viable, which in turn may block necessary regulatory approvals. It can also fail due to lack of financing.

- **Medium Scale Projects:** Medium Scale Projects, generally of the size 10 – 100 MW, can be grid connected centralized plants, isolated mini-grid projects for rural electrification, or captive projects for industry.
- **Small Scale Projects:** Small Scale Projects are typically less than 10 MW, and their application depends on energy source. Plants up to 1 MW are generally for self consumption for commercial or industrial buildings, and sale of extra energy (such as solar and wind). Such small scale stand alone systems are used in rural and semi-urban areas, where people have limited or no access to energy. Risks associated with such projects are significantly different from larger scale projects and project developers are equipment dealers or system integrators.

2.1.1.2 Development type

There are several different ways in which a power plant can be developed, ranging from developing an unproduced resource to expanding or converting an existing power plant. The following list summarizes the key groups of power plant development types:

- **Unproduced resource:** The development of a resource (hydro and geothermal) where levels of natural resource are sufficient to produce electricity and where development has not previously occurred to the extent that it supported the operation of a power plant.
- **Produced resource:** The development of a resource where levels of natural resource are sufficient to produce electricity but where development has previously occurred to the extent that it currently supports or has supported the operation of a power plant.
- **Expansion:** The expansion of an existing power plant and its associated resource area as to increase the level of power that the power plant produces. This can include adding power generation turbines or increasing efficiency of the existing plant.
- **Energy source co-production:** A power plant may be built as a side development to different resource utilization, such as when the produced fluids resulting from oil or gas field development are utilized for the production of geothermal power (GEA, 2011).

- **Energy source conversion:** A plant may need to be converted to produce energy using an alternative energy source, such as when a coal fired power plant is converted to use a biomass as a fuel to produce electricity.
- **Resource enhancement:** Development of resources needed to sustain power plant capacity, such as enhancing reservoir storage capacities for hydro power plants.

2.1.1.3 Site characteristics

Power plant development projects are referred to as being either Brownfield or Greenfield projects depending on whether or not they are being built on undeveloped land.

- **Brownfield:** Brownfield lands (or Greyfield lands) are areas that have been developed but are left abandoned or underused. Facilities which are modified/upgraded/redeveloped on Brownfield land are called Brownfield projects.
- **Greenfield:** Greenfield land is a term used to describe undeveloped land in a city or rural area either used for agriculture, landscape design, or left to naturally evolve. These areas of land are usually agricultural or amenity properties being considered for urban development. Greenfield projects are new power plants which are built from scratch on a Greenfield land.

2.1.2 Power plant developers

Although there are several different names used in the energy industry for entities that typically develop power plants, those entities can be grouped into three categories: Investor Owned Utilities (IOUs), Public Owned Utilities (POUs), and Independent Power Producers (IPPs)[1]. Utility categories vary depending on ownership and regulation. Both affect financing structure, electricity off-takers and rates. As a result, their power plant portfolio mix varies as their capability to manage project costs and risks varies. Conventional power plants, nuclear or combined-cycle power plants for example, require substantial investments only affordable by large power supply companies which can do financing off their balance sheets. By contrast, the investment required to develop smaller renewable energy power plants is considerably lower and thus affordable to smaller companies or even to individual investors.

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[1] Throughout this research whenever there is no need to distinguish between which type of entity develops the power plant the general term *developer* will be used.

Boundaries between these categories used to be clearer. However, in recent years utility mergers, redesigned holding structures, and establishment of non-regulated subsidiaries that own power plants and foreign owned utilities, have changed the nature of these boundaries. Many large utilities in newly deregulated markets have chosen to adopt a holding company structure to reduce the owner's risk. This structure allows the regulatory risk of having to divest to avoid regulatory conflicts, and restructure their assets for competition stimulation, to be mitigated.

All of this makes it difficult to keep track of utility names and to recognize utility subsidiaries or affiliates. Organizations such as the American Public Power Association (APPA, 2012) and Platts (Platts, 2012) still attempt to keep track of utility structures but definitions vary from one source to another. Following sections give a general overview of the typical characteristics of utilities (different financing structures are discussed in more detail in Section 2.5.).

2.1.2.1 Investor Owned Utilities

Investor Owned Utilities (IOUs) are commercial for-profit utilities. IOUs are usually subject to different regulations than POUs, and they pay taxes as corporate citizens. This industry consists of companies that provide consumers and businesses with electricity, natural gas, and water. Most of these companies are government sanctioned monopolies.

Typical Characteristics of IOUs

Also called	Private Utilities, Diversified utilities, Private Power Company
Ownership	Private investors.
Power Plant Portfolio	Have the financial resources and regulatory support to undertake large and expensive projects, such as coal and nuclear plants.
Electricity Rates	In many cases subject to government regulation of rates and conditions of service.
Electricity Off-takers	Have guaranteed service territories and face limited competition.
New Investment Decisions	State utility commissions must approve proposals by the utility to build new power plants.
Financing	Varies by company and project, typically have D/E ratio of 50/50.

Table 2.2 Typical characteristics of IOUs

IOUs finance power projects with a mix of debt and equity. Debt is more costly to these companies than to POUs because it is not tax exempt and because they usually have lower credit ratings. Investors expect private developers to make a significant equity contribution to a project.

2.1.2.2 *Public Owned Utilities*

Public Owned Utilities (POUs) maintain the infrastructure for a public service (often also providing a service using that infrastructure), but may include territories outside of city limits or don't necessarily serve the entire city. POUs can also be found in rural areas. POUs are subject to forms of public control and regulation ranging from local community based groups to country wide government monopolies.

Typical characteristics of POUs	
Also called	Utilities, Municipal Owned Utilities (Munis), Utility Cooperative (Coop), Electric Utility, State Owned Utility
Ownership	Citizens of the area served by the utility.
Power Plant Portfolio	Most POUs are small, provide only distribution service, and have limited financial and management resources. But larger and some smaller POUs also own and operate power plants, sometimes as co-owners of projects where an IOU or independent power producer is the lead developer.
Electricity Rates	Set their own rates or rely on energy subsidies[2].
Electricity Offtakers	Have guaranteed service territories and face limited competition.
New Development Decisions	Make their own decisions to build power plants.
Financing	100% Debt

Table 2.3 Typical characteristics of POUs

A POU will normally finance a project with 100% debt at a low interest rate. The rate is low because interest paid on public debt is exempt from federal or state income taxes, and because public entities have a far lower risk of default than private businesses.

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[2] The commitment to cost recovery from consumers isn't always there for POUs. Most state owned utilities in Africa being prime examples of regulated POUs that rely on subsidies rather than proper consumer pricing for cost recovery.

2.1.2.3 Independent Power Producers

Independent Power Producers (IPPs) are merchant developers and operators of power plants. IPPs face more financial risk than regulated utilities, but can also earn larger profits. IPPs may be privately held facilities and non-energy industrial concerns capable of feeding excess energy into the system.

Typical characteristics of IPPs

Also called	Non-utility generator (NUG), (Developer[3])
Ownership	Private investors
Power Plant Portfolio	IPPs often prefer to build and operate gas, wind, solar, and geothermal plants because of their scale and relatively low capital costs[4]. The most common current practice is for IPPs to develop renewable projects and sell the power to regulated utilities.
Electricity Rates	Need to compete with market price, but can sell power at whatever price the market will bear within the limits of pricing regulations (e.g. feed in tariffs for costlier renewables).
Electricity Off-takers	Sell wholesale power to utility and industrial buyers. They do not have guaranteed service territories and can face intense competition for power sales.
New Development Decisions	IPPs make their own decisions to build power plants.
Financing	Varies by company and projects, typically have D/E ratio of 60/40.

Table 2.4 Typical characteristics of IPPs

IPPs finance power projects with a mix of debt and equity. Debt is more costly to IPPs than to POUs because they typically face more competition and financial risk, are not tax exempt, and usually have lower credit ratings. IPP debt often falls in the speculative category and has a higher interest rate than IOU or POU (CRS, 2008). Debt providers therefore expect IPPs to make a significant equity contribution to a project.

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[3] Pure developers who sell off power plants once constructed have technically many of the characteristics of IPPs and therefore deserved to be included here within brackets. This should not be confused with the term Developer which is used throughout these chapters as a general term for any entity developing a power plant.

[4] For projects of larger scale and capital cost, IPPs will commonly form strategic partnership to undertake the development. As an example, ACWA Power is an IPP currently leading a consortium to develop a 4 GW gas plant in Saudi Arabia (estimated to cost USD 2.85 billion), which upon completion will be the largest IPP gas plant in the world (Reuters, 2011).

2.2 Project Development Process

Depending on the electric power system, development of new power plants is generally either in the hands of a regulatory authority (in centralized regulated systems), or the energy companies (in liberalized deregulated systems).

In centralized systems decisions related to the overall electric power operation, including new capacity expansion, are generally in the hands of a government coordinator. In emerging markets however (such as Ethiopia) it is common for the development to be in the hands of a state owned utility which operates at an arm's length from the regulator. The underlying criterion for the entire decision making process is maximization of social utility in the production and consumption of electric power (Pérez-Arriaga, Rudnick, & Rivier, 2008). Regulatory authorities of centralized systems face a problem with a set of influencing factors that are exogenous to the electric system that include demand growth, fuel prices, hydro inflows, technology evolution, and macroeconomics (Sánchez, Barquín, Centeno, & López-Peña, 2007).

In liberalized systems however, companies can independently develop power plants at their own risk under supervision of government regulatory authorities. These kinds of systems have become common in developed countries in recent years. The main decision criteria of those companies is to obtain the maximum profit, but other strategic concerns may be underlying, such as related to market share, generation technology mix, or political pressure. For liberalized systems analysis gets more complicated because of additional uncertainty sources that are endogenous to the system such as electricity prices, regulatory changes and competitors' decisions.

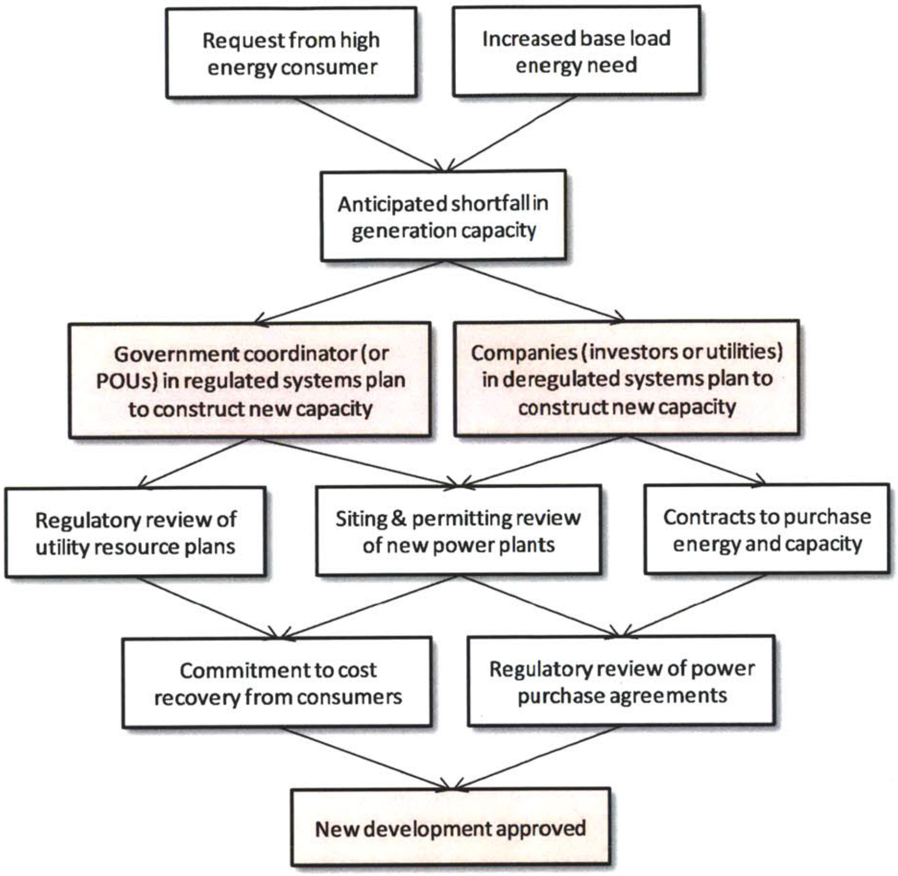


Diagram 2.1 Typical power plant investment decision process for regulated and deregulated utilities

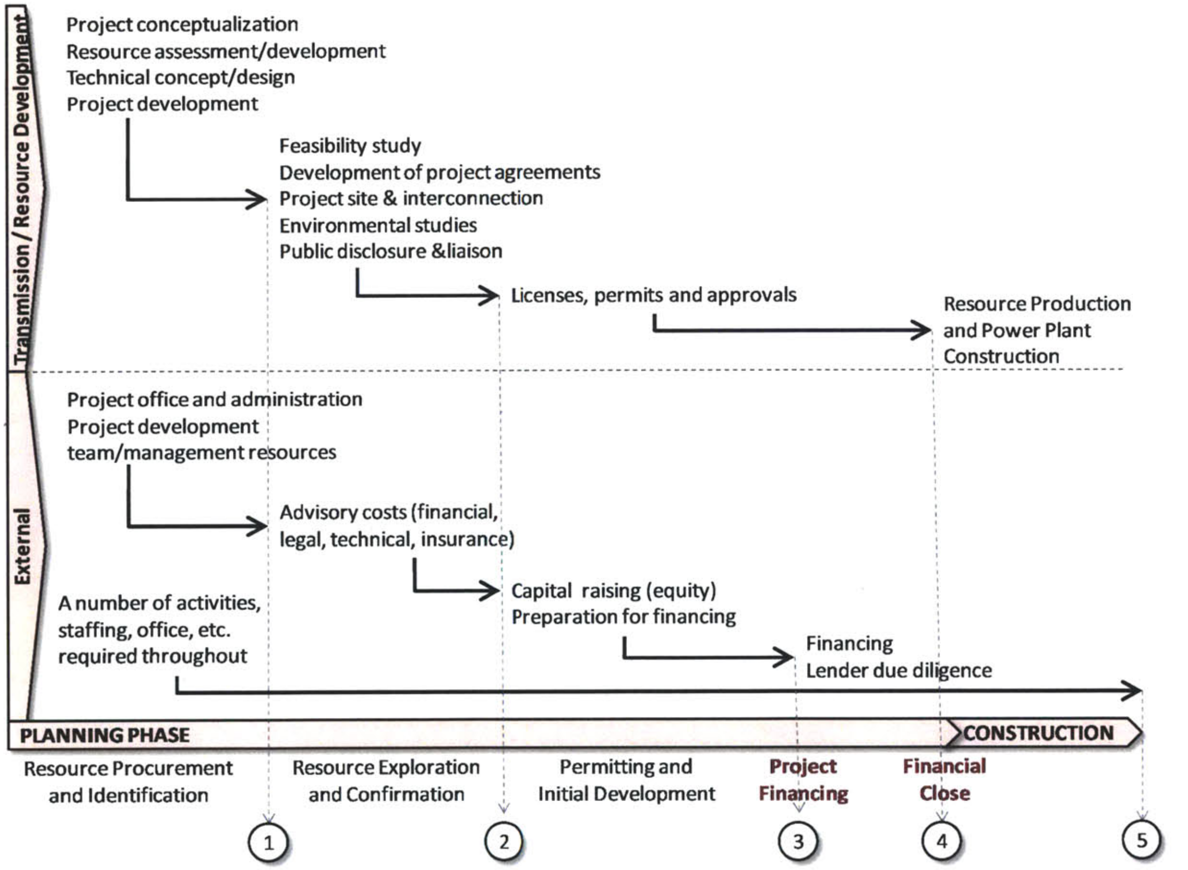
The following section will go through key phases of a power plant development project, and how they are evaluated.

2.2.1 Phases of development

The power plant lifecycle can be divided into the following general phases: 1) Planning phase, 2) Construction and commissioning phase, 3) Operation phase, and 4) Decommissioning phase. In preparing the power plant development project during the planning phase, there are several activities that need to be completed. These activities can be split into three sub-stages of development. The completion of the work at each of these stages is marked by a specific gate at which the progress and success of the development effort can be evaluated and a decision made to move on to the next phase. These sub-stages of development and corresponding gates are:

- Resource procurement and identification > Ready to make project commitment
- Resource exploration and confirmation > Ready with project development plan
- Permitting and initial development > Ready to invite bids for the development

Development activities within each of those stages can be categorized as either: i) resource or transmission development, and ii) external to resource development (acquiring access to land, permitting, signing PPA's and EPC contracts, securing a portion of project financing, etc.). Diagram 2.2 gives an example of some of the typical development activities for those stages of the pre-construction phase.



Gate 1:
Commitment ready
1) Scrutinize conceptual idea
2) Scrutinize opportunity
3) Review of objective and budget for next stage

Gate 2:
Development plan ready
1) Technical feasibility
2) Financial revenue
3) Review of objective and budget for next stage

Gate 3:
Ready to invite bids
1) Detailed technical feasibility
2) Business plan
3) Viable for financial closure
4) Review of objective and budget for next stage

Gate 4:
1) Permits available
2) EPC contract
3) Funding available
4) PPA, fuel supply, O&M contracts available
5) Construction risk management procedures

Gate 5:
1) Testing report
2) Commissioning report
3) O&M procedures
4) Operational risk management procedures
5) Review of financing objectives

Diagram 2.2 Project development activities and stage-gating

Details of the execution of a power plant development project, varies from one project to another depending on energy source, location, and size. Key development activities are similar for all equipment intensive capital projects, with some unique factors particularly related to environmental permits. Involvement of government and local authorities in that permitting process can add significant time to the project development schedule. Also, the larger the scope of the project the more extensive time needs to go into evaluating the economics and financing of the project, particularly for the high volatile inputs such as fuel source and power prices. Beginning with a letter of intent, Table 2.5 shows a realistic time frame for the planning and construction phase for an average power plant development project.

Energy Source	**Time to Construction (years)[5]**	**Construction Time (years)[6]**	**Plant Lifetime (years)[7]**
Biomass	1.0	4	40+
Geothermal	1.5	4	25+
Hydro	1.5	4	50+
Nuclear	2.0	6	50+
Oil and Gas Thermal	1.5	4	45+
Solar	0.5	2	30+
Wind	0.5	3	25+

Table 2.5 Average power plant development time and plant lifetime

2.2.2 Project evaluation

When it comes to identifying and selecting power plant development projects, methodologies used vary considerably from one developer to another, depending on scope of energy market considered, number of project opportunities identified, and developer's own selection criteria. As mentioned here above,

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[5] Source: Rough estimations based on the Project Database (see Chapter 4.2)

[6] Source: Lead time as presented by NREL on the Annual Energy Outlook dataset, representing the lag between the order date for a new plant and the date when the new plant is expected to go into service (NREL, 2010).

[7] Source: Average of Plant Lifetime as presented by NREL using information from the following datasets; AEO, GPRA, NREL-SEAC, MiniCAM, EPA, and MERGE (NREL, 2010)

developers' approach to project identification and selection can be broadly grouped as bottom up approach, or top down approach. The following sections describe those approaches in more detail.

2.2.2.1 Bottom up process

Many developers who do not have a set investment strategy can be classified as following the bottom up investment process. This approach is common for smaller developers, for those developers focusing on a narrow market, or when the developer lacks resources, experience, or financial capabilities to assess a broader range of project development opportunities. For such developers, this approach can be successful, and an efficient way to lower lead time. However, this approach lacks many of the important detailed project evaluation steps, and while the selection is based on profitable projects, this approach does not maximize the profit. As an example, a typical bottom up project evaluation process could be initiated using leads generated in one of these ways:

- **Landowner seeks developers:** Smaller developers (particularly wind farm developers) are often approached by landowners who want to build a plant on their land. The developer then begins feasibility analysis of the project, and looks for ways to connect to a nearby grid.
- **Referral and word of mouth:** Although not reported by developers as their tool of choice, lead generation often comes from referral and word of mouth.
- **Relationships and past customers:** Developers often successfully generate their leads from relationships between their companies and the community and past customers.

Commonly a developer using a bottom up approach to project identification may choose to use either simple Delphi technique or brainstorming to screen the most feasible project when prioritizing project leads.

2.2.2.2 Top down process

The key to the top down process for project evaluation is to identify projects where the developer has competitive advantage (meaning the developer has an advantage over its competitor, allowing it to generate greater profit). Before narrowing their selection down to a single project, a smart developer will initially do a thorough analysis of 1) the geographic location, 2) the energy technology, 3) the ideal site, and 3) the project specifics. The following describes some of the key considerations for that analysis:

1) Select geographic location:

When selecting geographic location a simplified approach would be to look up country risk and country attractiveness ratings using rating agencies and filter out countries which have risk above their country risk appetite (see Section 2.2.2.4 on avoiding project analysis bias when using those rating agencies).

A more thorough approach would be to select country based on developer's own criteria for country risk factors and country attractiveness. As this is a more time consuming approach to selecting geographic focus it is important to follow that process in a structured way. As methodologies for screening opportunities vary in complexity, one way is to apply them in stages of increasing depth of analysis, eliminating those along the way which don't meet the selection criteria. An example of such an approach is illustrated in Diagram 2.3 using the following steps:

Step 1: Eliminate projects using checklist procedure with restriction criteria

Step 2: Eliminate projects based on criteria ranking using weighted scoring models

Step 3: Conduct an in-depth analysis and eliminate projects using clustering, or portfolio analysis

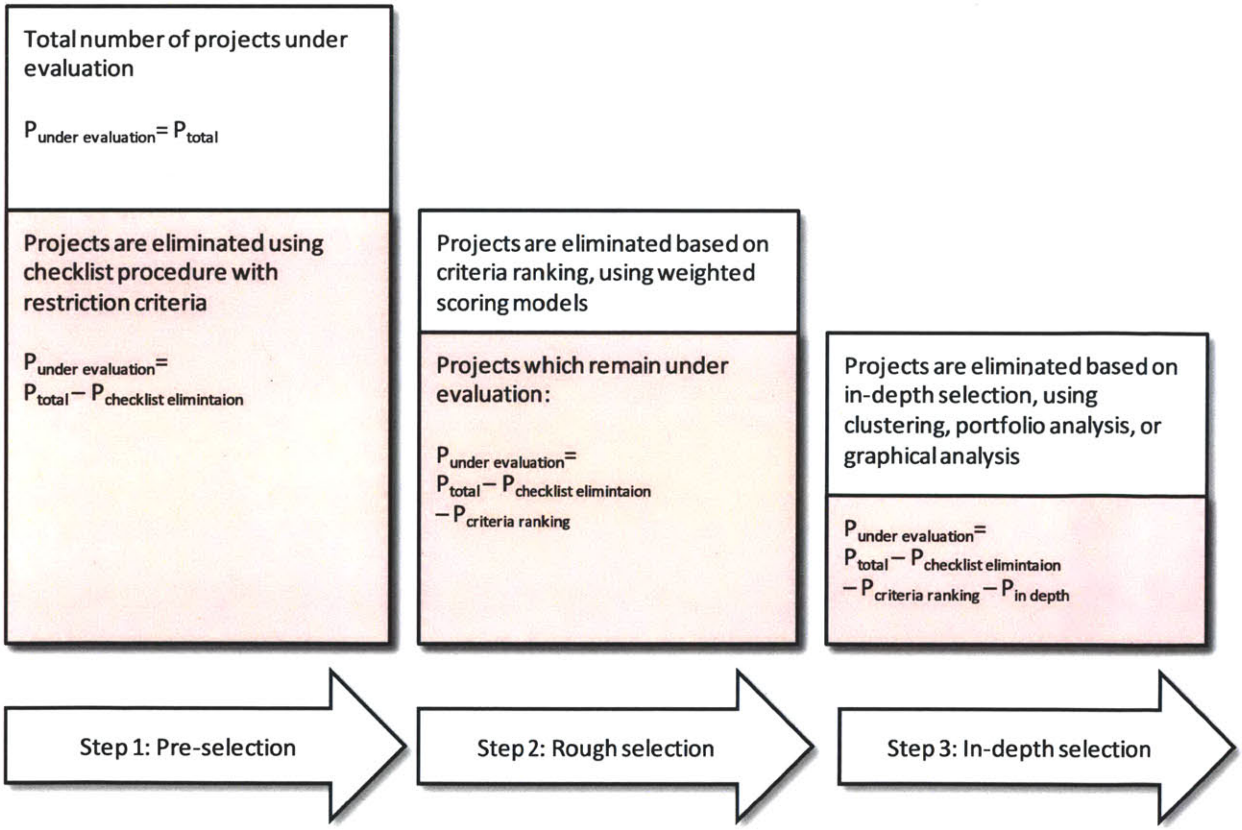

Diagram 2.3 Suggested stages of approach to screen projects based on geographic location

Key to step 2 is to generate a list of country risk and country attractiveness criteria. Criteria are then rated (an example of such rating is using a scale from 0 to 5, where 0 is most unfavorable and 5 is most favorable), given weight (such as average of all criteria), and ranked (from overall most favorable project to least favorable project), building a list of the top 10 – 15 projects still under evaluation. Diagram 2.4 shows how all these different factors work together to create country weight.

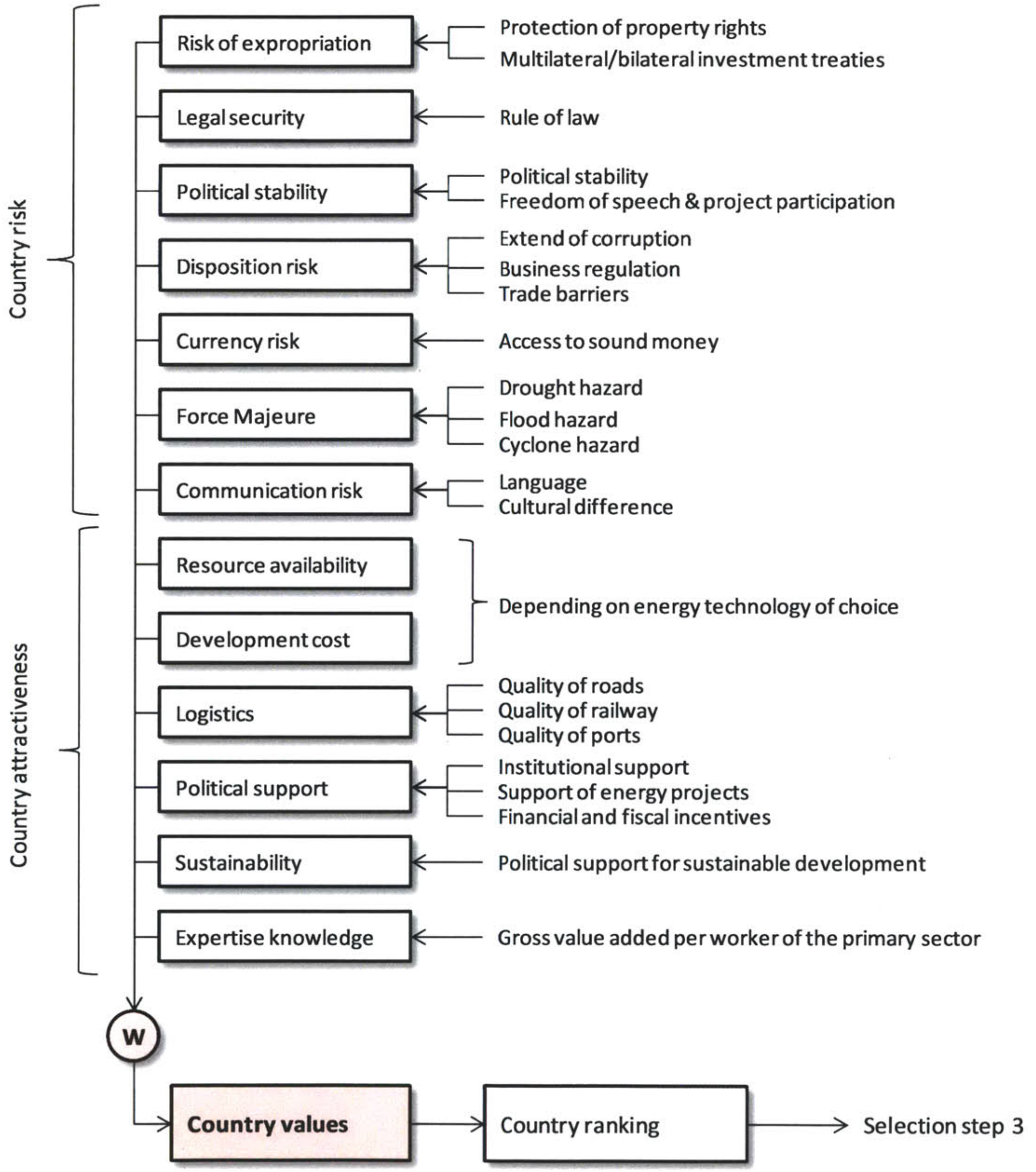

Diagram 2.4 Project selection criteria and indicators[8]

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[8] Source: This is based on various sources of information, including proceedings from an equity fund workshop (World Bioenergy Association, 2011)

Country risk considerations are discussed in more detail in Section 3.1. The following lists of some of key country attractiveness considerations that may impact choice of geographic location:

- **Developer's network in that geographic area:** Including trusted suppliers and prior experience of successful development.
- **Ease of development:** In addition to developer's network, other factors can make development undertaking easier and add to country attractiveness. Such factors can include cultural resemblance to the developer's home market, and language (which also cross boarders of being considered project risk factors, as cultural difference and language issues can be a communication risk factor).
- **Labor resource availability:** Increased availability of skilled labor in the area may lower risk related to hiring foreign contractors (including currency risk). However, the higher the skill level of labor in the area, the likelier it is for local labor to be more expensive.
- **Stakeholders' influence:** Developer's stakeholders may try to influence choice of their locational focus, such as when there's a holding company which wants to keep their subsidiaries within focused regions.
- **Political pressure**: Political pressure can come from various sources, such as influence from their local market's government on where it's appropriate for them to direct their foreign efforts.
- **Prior project commitments**: Developers may have received some benefits in their prior project participation in that area in return for their word for a continuous development in that area.
- **Level of expertise knowledge in that area**: Developer may want to participate in power plant projects in that area in order to learn from local experts in their field, as a way to train their own employers for future projects, or to bring the expertise knowledge back to their home markets. That will help the nation develop its own educational and training capabilities to better assure long term availability of crucial human resource and provide opportunities for its citizens.
- **Country's power plant portfolio mix and renewable energy targets**: Many countries have set themselves targets for increasing renewable energy generation in their power plant

portfolio. For developers of renewable energy plants this may be an opportunity to lower regulatory risk of the country, shorten development lead time, and invite a follow on project within the same country.

- **Government support:** In some cases countries will develop mutual agreements of cooperation to support power plant development efforts. This is common when countries are lacking expertise to develop their own resources, and would like to invite countries with that expertise to help them expand their generation capabilities as well as helping to build local knowledge[9].
- **Country's future outlook**: Many of the country's future outlook factors tie in with country risk of political stability, currency risk, risk of expropriation, etc. However, there can be some non risk related considerations for attractiveness of country's future outlook regarding ease of development, such as expected growth of gross domestic product (GDP), and government's overall support for the country's energy system.
- **Climate change strategy:** Some developers may have a climate change strategy which can factor into selection of geographic location. As impact of climate change is such an uncertain topic it is hard to get developers to go on record with their strategies. Currently those strategies are driven by the insurance industry's response to climate change threats. Where insurance industry has not yet adopted to climate change threats, neither have developers as they can still afford the insurances. That will change though as most energy technologies are expected to be impacted by climate change. For example offshore wind farms are expected to be at more risk of hurricanes, higher sea level may impact shore based fossil plants, and water scarcity may impact hydro power plants, as well as all other power plants reliant on water availability.

2) Select energy technology:

The process of selecting energy technology of focus goes alongside the process of selecting geographic focus as many of the criteria apply to both selections, ranging from various country risk considerations (such as political stability and support for energy development through subsidies or other means) to other less tangible sources attractiveness such as stakeholder's influence and political pressure. Other key factors include the following:

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[9] As an example, both Japanese and Chinese government authorities have had discussions with Icelandic authorities on mutual cooperation in the field of geothermal energy.

- **Perceived technology risk**: The smart developer will look at perceived technology risk for each energy source and compare that to their technology risk appetite. Energy technology risk can depend on its development maturity level, government support for R&D grants and energy subsidies, and analysis of expected future growth. Developer's appetite for the technology risk varies depending on factors such as expertise, and financing capabilities.
- **Competitive advantage**: When selecting project opportunities for evaluation, developers may focus primarily on their competitive advantage, such as their expert knowledge in developing a particular energy source. When they don't possess energy technology expertise, they are most likely to form strategic partnerships. In some instances expertise can be transferred from one energy technology to another such as with the oil and gas industry experts and the geothermal ones.

3) Select the site:

After selecting geographic focus and energy technology, developers will either analyze project opportunities already identified within that country (such as discussed in the Bottom up approach in Section 2.2.2.1) or will go to the country and search for idea project site. In order to find that the following maps need to be layered:

- **Connection points**: National utility can provide information on country's electricity network grid, which a developer can use to find ideal connection points. For larger power plants there may be need to invest in transmission structure to support additional generation load, but smaller power plant developers may want to avoid that by selecting a site that ensures grid connection points with adequate capacity to handle that load.
- **Resource availability**: Analysis of resource availability is a necessary map for renewable energy projects. For conventional energy sources this includes maps of water availability, and ease and access of fuel supply (such as harbor areas). For natural sources of heat sinks this can include proximity to sea, fast flowing rivers, or large natural and artificial reservoirs.
- **Land availability**: A map of land availability needs to be generated looking at both private and public land availabilities.
- **Accessibility:** Renewable power plants often need to be developed on mountainous terrain or in remote areas where there's adequate resource availability. Considering accessibility of operation may help developers considerably lower development cost of the plant. Having

roadway infrastructure in place can help ensure that site is safely accessible to workers, heavy equipment and emergency responders.

- **Environmental analysis**: It is important to consider all environmentally related analysis, such as environmental conservation areas, or impact on wildlife, endangered species or soil. Within those areas, development may be very expensive or even impossible to deal with.
- **Floods and earthquakes**: The site needs to be assessed for potential floods and earthquakes. Building a power plant in an area prone to these hazards can significantly affect the power plant's risk profile, and financing availability.

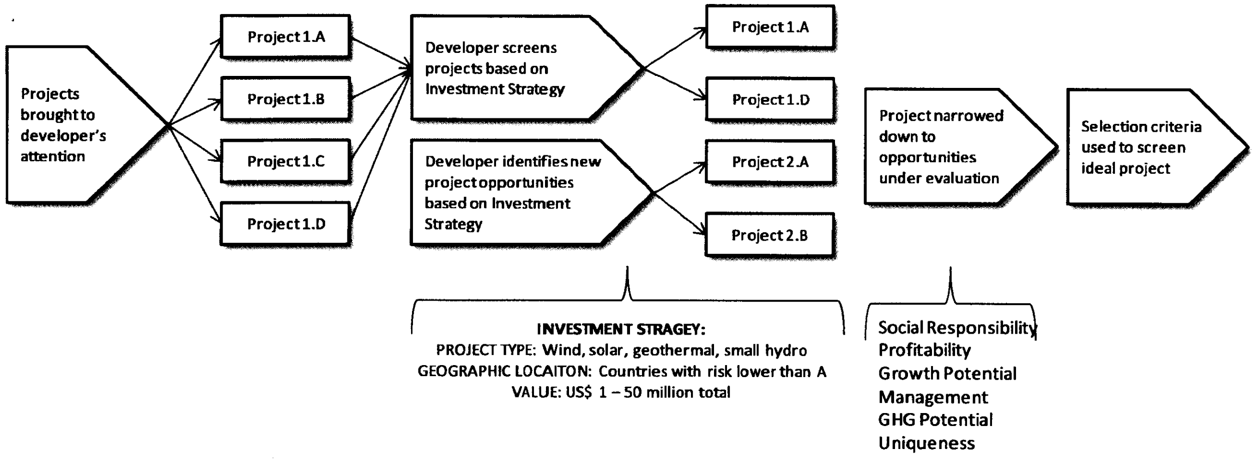
Once a developer has layered those maps the next step is to hire people who specialize in getting the land rights. The developer will assign them requirements based on analysis so that: i) connection is close and cheap, ii) land availability fits this project, and iii) there are no known issues.

4) Select the project:

After going through all these project evaluation steps, the developer now has a pool of projects to select from for which they may use one or a combination of the various project selection methodologies available (see Section 2.2.3). Once project has been confirmed, the developer can start applying for permits to develop the power plant.

2.2.2.3 Investment strategy

The skill of an experienced developer is not to find projects, but to know what they want, and know how to shape processes to get desired outcomes. Developers are often approached with ideas for new project opportunities. Unless they have set their own project investment strategy, such offers can lead them down the slippery slope of not doing full analysis themselves on the ideal projects they should be undertaking. When approached with project opportunities, the skill of the developer is to know beforehand exactly what they want based on their Investment Strategy, and to go screen out those projects that are fit to be evaluated further based on their selection criteria (see Diagram 2.5).



INVESTMENT STRAGEY:
PROJECT TYPE: Wind, solar, geothermal, small hydro
GEOGRAPHIC LOCAITON: Countries with risk lower than A
VALUE: US$ 1 – 50 million total

Social Responsibility
Profitability
Growth Potential
Management
GHG Potential
Uniqueness

Diagram 2.5 Example of project selection based on investment strategy

Some experienced developers refer to their Investment Strategy as the "shopping list", and give the analogy of going grocery shopping. If you have an upcoming dinner party and need to get groceries it'll save you both time and money to have a shopping list. Without a shopping list, chances are you'll be spending too much time at the grocery store not finding what you want, and eventually buying more than you need. If you however have your shopping list at hand you can go in and out of the grocery shop, and either have what you needed or not.

Developers' investment strategy is incorporated in the overall corporate strategy, and usually planned for the following 5 to 8 years. Investment strategy is based on developer's analysis on which markets and energy technologies will be their focus, and timing of their investments. As variables that such a strategy is based on consist of volatile predictions, the investment strategy must be flexible enough to be frequently reviewed to align itself to the fluid nature of the external environment, both outside and inside the corporation. With such investment strategy at hand developer can easily reject projects upon first review simply if they fall outside of the investment strategy for that period. Developers' investment strategy is generally a private document for competitive reasons. Developers may however publish parts of their strategic focus in order to invite being approached with the right projects. An example of such available investment strategy information is given in Table 2.6, and an example of how Investment Strategy is coupled with overall corporate strategy is given in Diagram 2.6.

Energy technology	Developer's publically available criteria for power plant leads
Solar	Project size of USD 25 million to over USD 1 billion
	Solar power plant land site has been selected or is owned
	Performance guarantee is in place
	Storage and transmission capability is key
Hydro	Project size of USD 25 million to over USD 1 billion
	Land site has been selected or is owned
	Performance guarantee in place
	Experienced, savvy management team selected
	Power purchase agreements are in place
Biomass	Project size of USD 25 million to USD 1 billion
	Geographical focus: Worldwide
Wind	Project size USD 25 million to USD 1 billion
	Geographical focus: Worldwide

Table 2.6 Example of a developer's publically available criteria for power plant leads

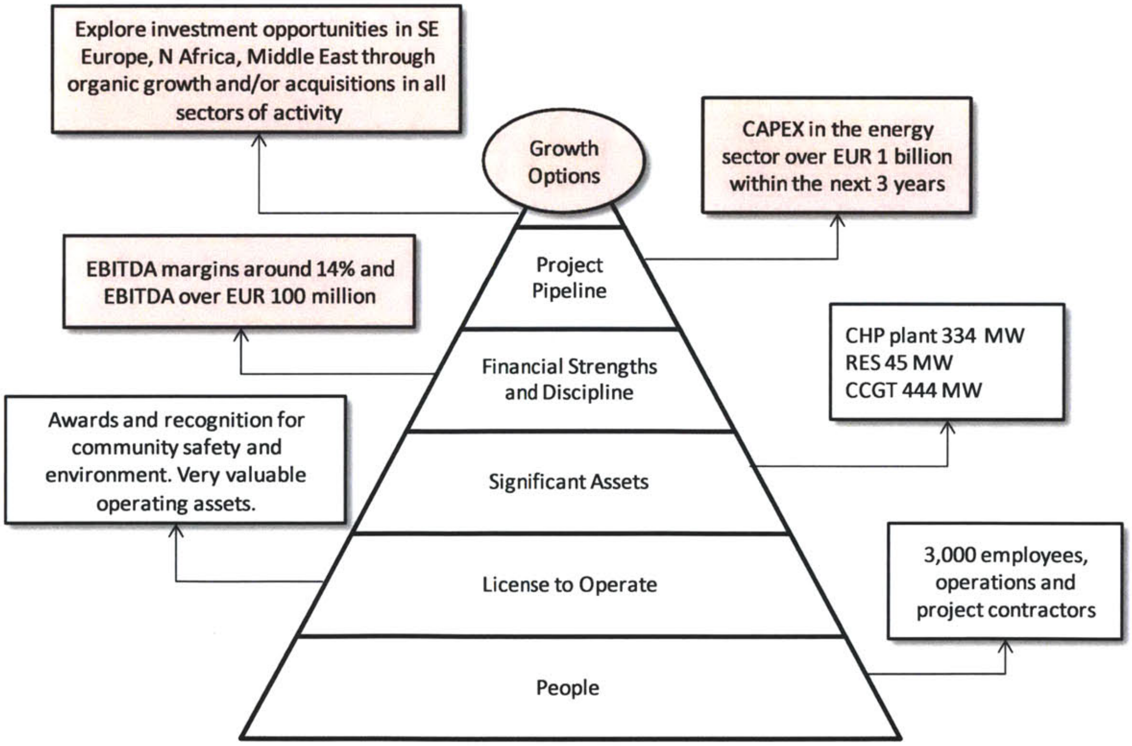


Diagram 2.6 Diagram of how investment strategy is coupled with overall corporate strategy[10]

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[10] Source: Adjusted from Mytilineos Holding company information

2.2.2.4 Analysis bias for project selection

An important thing to keep in mind while developing investment strategy is that many of the reports used to support that analysis are highly influenced by bias in the sources' data, and in some cases are also influenced by political pressure. In such instances it is important for the developer to take into consideration as many different analysis reports as possible, and derive appropriate average. Example of such analysis can be 1) country risk analysis, and 2) resource growth potentials.

1) Country risk and attractiveness rating bias

Nowadays there are dozens of rating agencies to choose from for country risk ratings and country attractiveness rating in various markets around the world. Most of the risk rating agencies publish their long term risk opinions using the same triple A through C rating symbols that have been the market standard since John Moody introduced them in 1909 (Moody's, 2011). But ratings are opinions about risk and attractiveness, not formulas, and vary significantly from one agency to another. Therefore, instead of relying on a single source the developer may need to check accuracy of ratings, by reading the research behind them, and examining its track record for accuracy.

2) Resource growth potential bias

When looking at the energy source growth potential, the different organizations will give different estimates depending on the organization's preference for that particular resource. For example Green Peace, American Wind Energy Association (AWEA), and the Oil and Gas industry are not going to give the same expected growth rate for wind energy. Green Peace is likely to give cautious numbers in order to promote environmental friendly decisions, AWEA is likely to give a positive message of future growth in support of their industry, and the Oil and Gas industry may have reasons to encourage less growth for their own benefit.

2.2.3 Project selection methods

After evaluating energy market and project opportunities as described in Section 2.2.2, the developer may have narrowed selection down to a pool of projects. Depending on the number and type of project opportunities under evaluation, the developer may choose to either use simple Delphi technique or brainstorming to screen most feasible project, select project based on financial models (such as based on the payback period, NPV, IRR, or options models), or to build a checklist model based on a list of criteria to possible projects. Checklists are valuable for recording opinions and encouraging discussion although more sophisticated methods build on top of that approach, by attempting to rank projects under evaluation based on their criteria of priorities under consideration, and objectives the project should meet. Those decision models are typically referred to as Multi-criteria Decision Models (MCDM). Literature review of published papers, as well as expert input, found that there are several different types of methods that are used for scoring, ranking, and deciding on project selection within the power plant development industry. Table 2.7 gives an overview of some of those methodologies, year that methodology was introduced, its advantages, and limitations.

Decision method	**Year**	**Application**	**Advantages (+) and limitations (-)**[11]
Analytical Hierarchy Process (AHP)	1980s	Construct a hierarchy of criteria based on weights generated by pairwise comparisons.	(+) Simple to apply. Scores are comparable. Useful when problem consists of many criteria. (-) Strict hierarchical structure can't handle complexities of influences.
Analytical Network Process (ANP)	1980s	Considers interdependence of decision criteria in generating weights based on pairwise comparison.	(+) Criteria are grouped into clusters. (-) Requires deep knowledge on interdependence of criteria.
ELECTRE[12]	1960s	Criteria are assigned weight based on importance, and alternatives are ranked to outperform each other based on criteria.	(+) Does not assume that performances of alternatives with respect to different criteria can be evaluated on basis of a common scale. (-) Each selection criteria needs to be given a weight, but no clear method is provided for generating that.
Goal Programming	1960s	The purpose is to set a priori target values for goals, and to minimize weighted deviations from these goals.	(+) Assumes little of decision maker. (-) Cannot produce a weak linear ordering of the alternatives.
MACBETH		Measuring attractiveness by a categorical based evaluation technique.	(+) Allows for the difference in value between any two alternatives to be quantified.

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[11] This table is a simplified overview of methodologies, highlighting only a few of the numerous advantages and limitations of their application.

[12] There exist different versions of the ELECTRE method, including ELECTRE I, ELECTRE II, ELECTRE III, ELECTRE IV, ELECTRE IS and ELECTRE TRI.

			(-) The qualitative scale used to assign a value to each pair of alternatives is ambiguous.
Multi-attribute utility theory (MAUT)	1940s	Derives a preference score for each alternative based on utility derived from its attributes	(+) Takes into account risks embedded in selection of alternatives. Useful when decision makers do not have enough information regarding occurrence of alternatives (-) Establishing a utility function is a difficult and lengthy process.
PROMETHEE	1980s	Preference ranking organization method for enrichment of evaluation.	(+) Does not require assumption that the set of criteria under consideration are commensurable. (-) Does not provide a clear method to assign weights to criteria.
Simple scoring model		Each project receives a score that is weighted sum of its grade on a list of criteria.	(+) Simple application. (-) Relative scores can be misleading, and are not comparable.

Table 2.7 Various MCDM models used for project selection

For some projects, a combination of models can be useful, such as when MAUT is used in conjunction with PERT, in conjunction with regression models, or when ranked criteria is presented in a profile model. In addition to these methods, the developer will also need to consider the Opportunity Cost of selecting the project, i.e. the cost of selecting that project measured in terms of the value of the next best alternative project that was not chose. Depending on their type, this collection of models can broadly be categorized as being either: 1) Financial Models, 2) Economic Models, or 3) Scoring Models, as illustrated in Diagram 2.7.

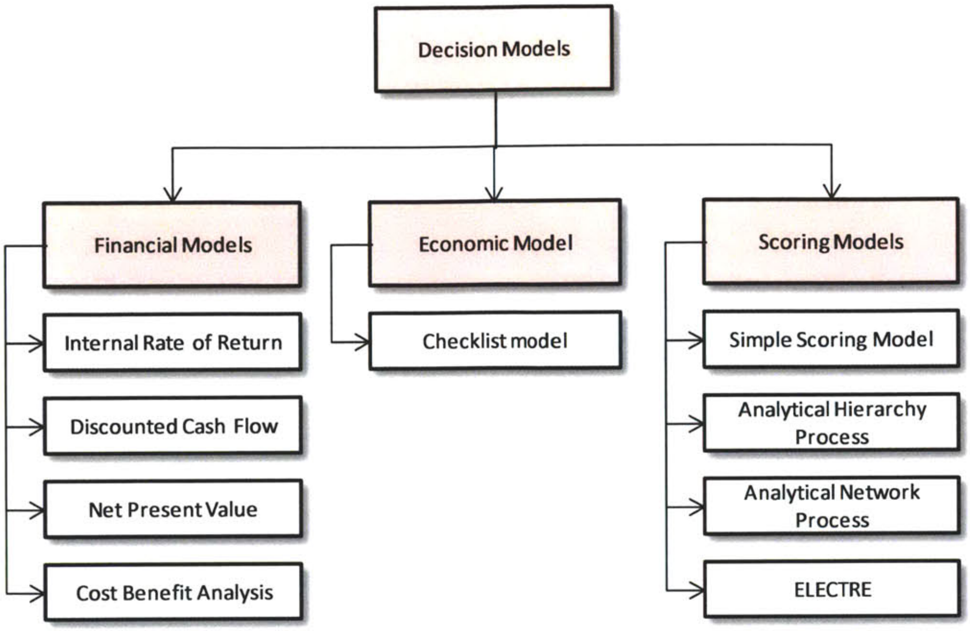

Diagram 2.7 Decision models for power plant development project selection

2.2.3.1 Risk Return Profile

Commonly, developers will use a combination of decision methodologies in their project selection. An example of such approach is the Risk Return Profile model. When constructing such a model, the developer analyses various factors which can influence success of the development project using a combination of financial models and simple scoring models. A summary of considerations for preparing such a risk return profile can be seen in Diagram 2.8.

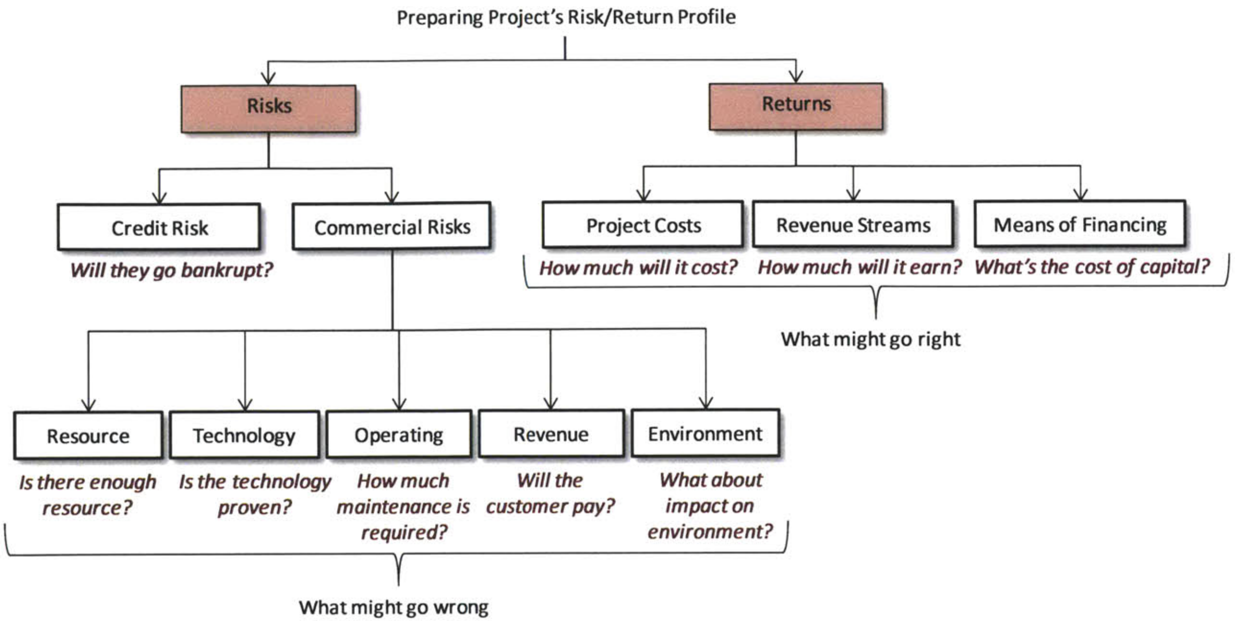

Diagram 2.8 Preparing a project's risk return profile[13]

Once projects have been rated on their expected risk and return, they are plotted on a graph with the developer's efficient frontier, as demonstrated Diagram 2.9.

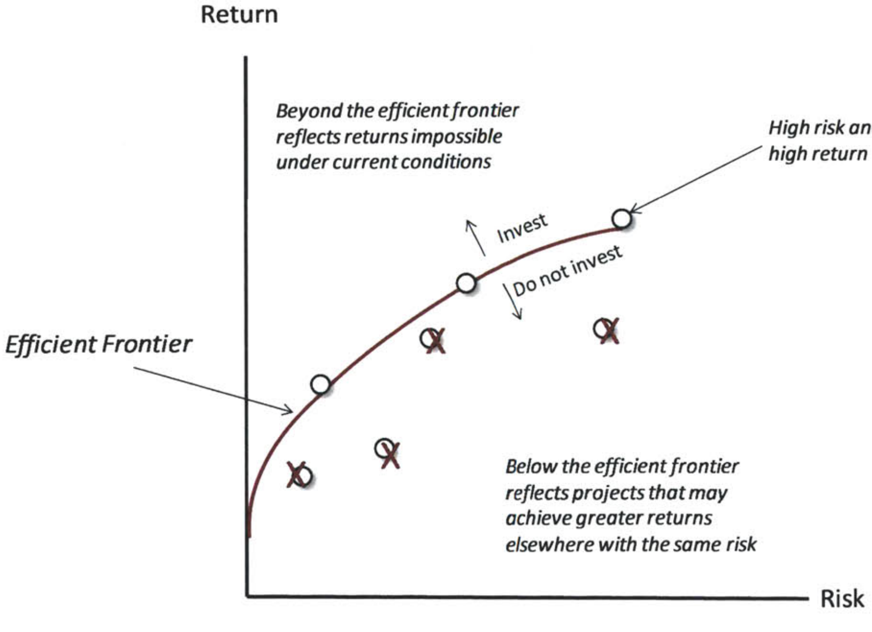

Diagram 2.9 Efficient frontier for risk return profile of a selection of projects under evaluation

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[13] Adjusted from diagram presented in the report *Scoping Study on Financial Risk Management Instruments for Renewable Energy Projects* (SEFI, 2004)

2.2.3.2 Cost Benefit Analysis

Another common approach to project selection combining different methodologies is Cost Benefit Analysis (CBA). This method summarizes positive aspects of the project (benefits), and deducts negative aspects (or costs) from the benefits. Benefits and costs are expressed in money terms, adjusted for time value of money. The CBA gives both 1) justification of investment feasibility, and 2) a basis for comparison of other project opportunities. The following is a list of steps that comprise a generic cost-benefit analysis (Boardman, 2006).

- List all alternative projects.
- List stakeholders.
- Select measurements and measure all cost and benefits elements.
- Predict outcome of cost and benefits over relevant time period.
- Convert all costs and benefits into a common currency.
- Apply discount rate.
- Calculate net present value of project options.
- Perform sensitivity analysis, and adopt recommended choice.

Risk associated with project outcomes is usually handled using probability theory. This can be factored into the discount rate (to have uncertainty increasing over time), but is usually considered separately. Uncertainty in CBA parameters (as opposed to risk of project failure etc.) can be evaluated using a sensitivity analysis, which shows how results respond to parameter changes. Alternatively a more formal risk analysis can be undertaken using Monte Carlo simulations.

2.3 Project Development Structure

An overview of a typical project development structure based on a top down project evaluation process, and involvement of key stakeholders can be found in Diagram 2.10. As the diagram shows, Technical Analysis, Social Impact Assessment, and Environmental Impact Assessment are conducted concurrently. When done sequentially it can be time consuming, especially since approving authorities often ask for additional information, necessitating further detailed analysis which can delay project approval even more. Highlighted on the diagram in diamond shape, are the following key approval milestones:

- Environmental Impact Assessment approved: Whether project adhere to all environmental regulations.
- Administrative approval: Whether project is capable to achieve business objectives.
- Approval of local authorities: Whether project is in line with overall sector plan.

A more detailed list of the key development activities can be found in Appendix 1.

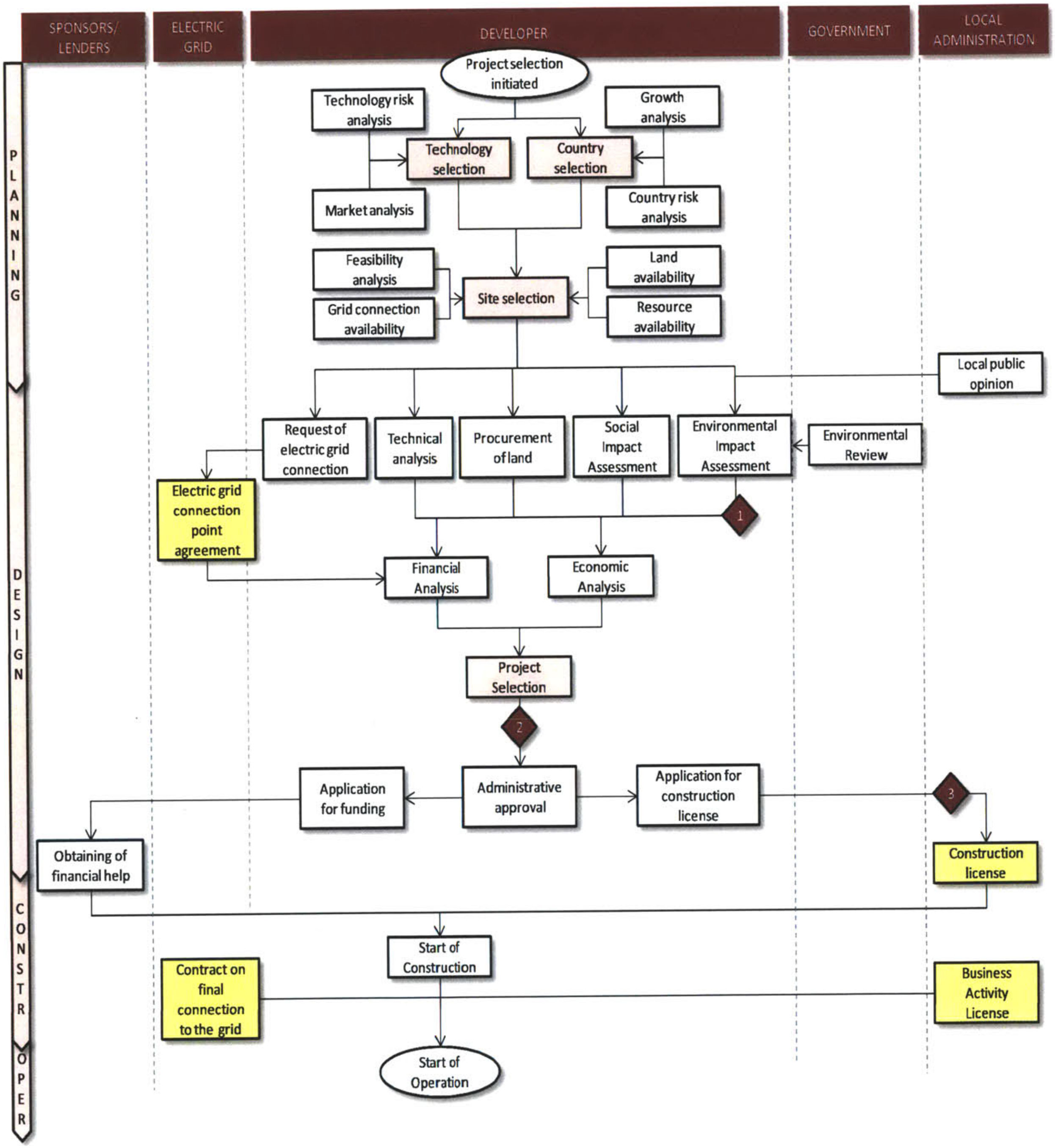

Diagram 2.10 Strategic top-down investment process for a power plant development project

2.3.1 Project participants

Some of the key stakeholders of a power plant development project are highlighted in Diagram 2.11.

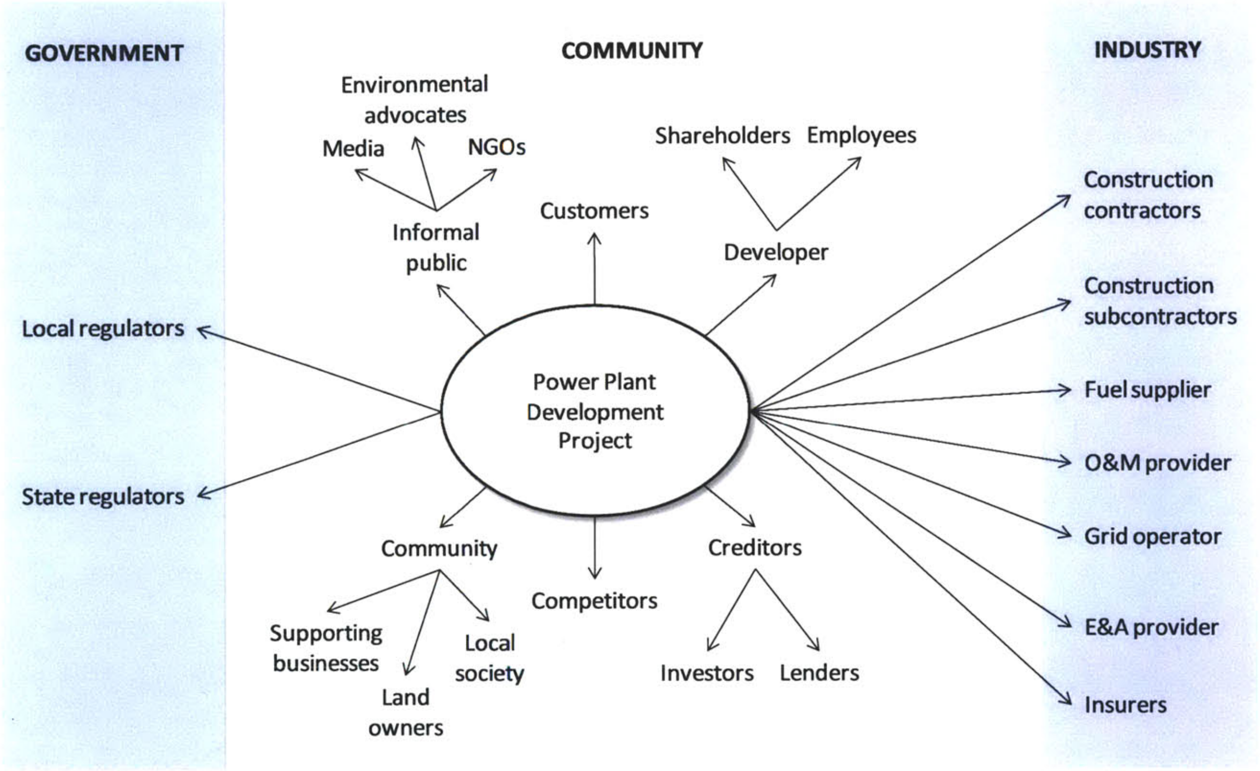

Diagram 2.11 Stakeholders of a power plant development project

Development of a power plant requires knowledge and skills across most scientific and engineering disciplines to purchase, properly construct, license, operate, maintain and comply with regulations of a power plant. Much of the general knowledge required is the same across any large power plant development. Specific energy technologies require additional knowledge, such as nuclear construction (to ensure operational safety, security, and radiation protection). The developer will generally develop entities within the organization which are directly involved in the development, such as a group in charge of providing project funding and make relevant strategic decisions, Project Management group, and O&M group. The following describes types of teams at work in the development project during phases of project analysis, project selection, and design and construction.

Project Analysis Team

Core of Project Analysis Team should be selected based on their experience and past performance, and have representatives of a design group (civil, electrical, and mechanical), a planning group, an implementation group, an operations group, and a finance group. This group identifies the project stakeholders, determines their concerns, and involves them in analysis in order to reduce lead time of the project analysis process due to iterations and rework. In addition this team will seek input from specialists for impact assessment on social and environment (such as geologists, wildlife biologists, archeologists, and hydrologists), as well as general advice from adjudicators, lawyers, and paralegals. Also, depending on project type, there is need for input from specialists on feasibilities studies, including engineers, geologists, geophysicists, geochemists, GIS specialists, sample analysts, consultants, clerical staff, and management staff.

Project Selection Team

The team that makes decision on project selection is likely to be a group of highly experienced executives, who establish a common consensus for project selection methodology through group decision making. Disagreements are usually resolved by reasoning and collecting more information.

Design and Construction Teams

Design and Construction Teams depend on the energy technology. In general construction team will need engineers, power plant designers, document controllers, project managers, administrative support, construction managers, project engineers, field engineers, safety managers, inspection personnel, and other specialists (such as welders, steel erectors, concrete placers, and assembly mechanics). For contractors, winning a project generally requires a combination of expertise knowledge, and track record. With growth in renewable energy development, increasing demand for skilled engineers[14] has encouraged identifying transferrable skills from other industries, using creativity to put people in the right positions, and offering dual-ladder career paths. Examples of transferable skills can be from aerospace turbine design to wind industry and from automotive mechanics design to mechanics design in the renewable industry.

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[14] Example of a skill requirement is the "gold standard" for PV and solar heating installation certification by The North American Board of Certified Energy Practitioners (NABCEP), a credentialing body in the United States formed to set competency standards for professional practitioners in the fields of renewable and sustainable energy.

2.3.2 Forms of partnering

Different stakeholders of power plant development may form partnerships in which partners co-labor to increase likelihood of each achieving their mission and to amplify their reach. By undertaking the project with another firm, part of the risk is transferred through equity. Most partnerships stand to amplify mutual interest and success, and share the development's profits and losses. A developer will typically seek partnership when that will combine expertise or other business assets that will mutually benefit the partners for one or a combination of the following reasons:

- **Partner's experience:** Developer may want to learn from another developer or EPC partner that have a successful, proven track record of installing utility scale power plants ("big names" in the power plant development industry), and a significant experience in developing and financing projects as well as securing energy power purchase agreements.
- **Size of project under development:** Some project opportunities are simply too large for a single developer to undertake, which may provide an opportunity to partner with another developer. Those developers seek mainly partners which are a good fit for them, trusted partners who are committed to the project, or who might be a good fit for future projects as their investment strategy aligns. Such partnership is common for partnering of POUs in developing large hydro power plants.
- **Risk management:** A developer may want to form a partnership when that partner is more capable of managing specific risk characteristics of the project.

Some of the common forms of partnering for power plant developers include the following:

- **Strategic Partnerships:** A developer may choose to develop strategic partnership as a formal alliance without forming a legal partnership.
- **Public Private Partnership:** A public private partnership (referred to as PPP, P3 or P^3) is a partnership of government and one or more private sector companies.
- **Joint Ventures:** Joint Ventures do not need to be permanent, the shares of the partners may evolve over time and the Joint Venture may eventually be dissolved.

2.4 Investment Drivers

The following section discusses methods for assessing attractiveness of international investments, as well as some of the common drivers investing in new markets, including a section on considerations for investing in emerging markets.

2.4.1 International investments

Heat maps are commonly used to cluster countries by their attractiveness for international investments. In practice, there are many different approaches to generating such heat maps. Some of those are shown in the following diagrams.

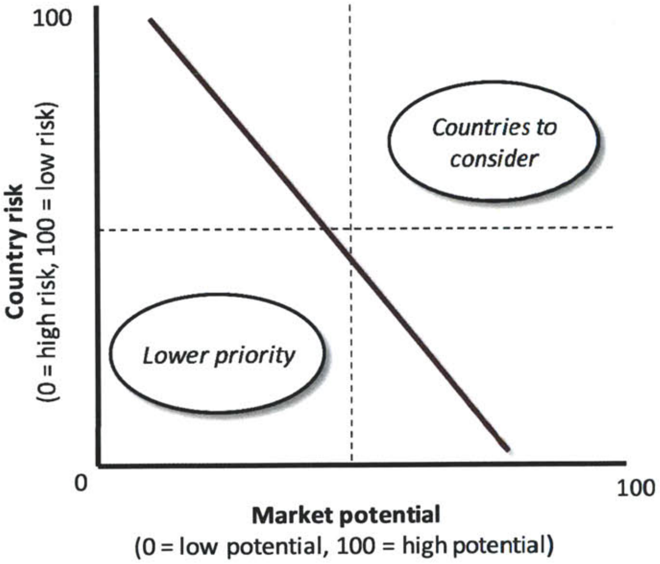

Diagram 2.12 Country risk/Market potential heat map

Diagram 2.12 shows a typical representation of a heat map for mapping country risk against market potential. Countries which are considered to have high market potential and low risk are clustered as countries which are more attractive to invest in. The scale can be either based on values as perceived by investor (considering their own constraints and competitive advantages), or it can be based on values perceived to represent these scales well, such as Diagram 2.13 and Diagram 2.14 show.

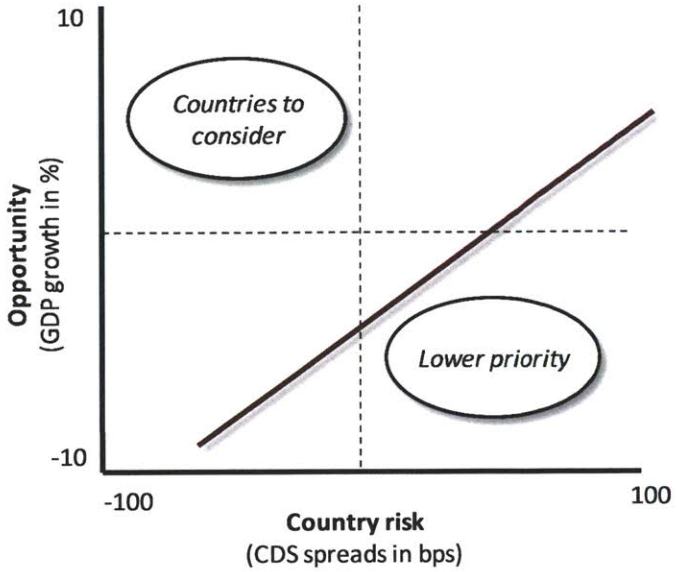

Diagram 2.13 Country risk/Opportunity heat map

Diagram 2.13 shows a heat map where country risk measured as credit-default swap (CDS) spread (which is roughly the cost of insuring debt against default), is mapped against perceived opportunity measured as Gross Domestic Product (GDP) growth in %. The higher the opportunity, and the lower the risk, the more attractive a country is to invest in.

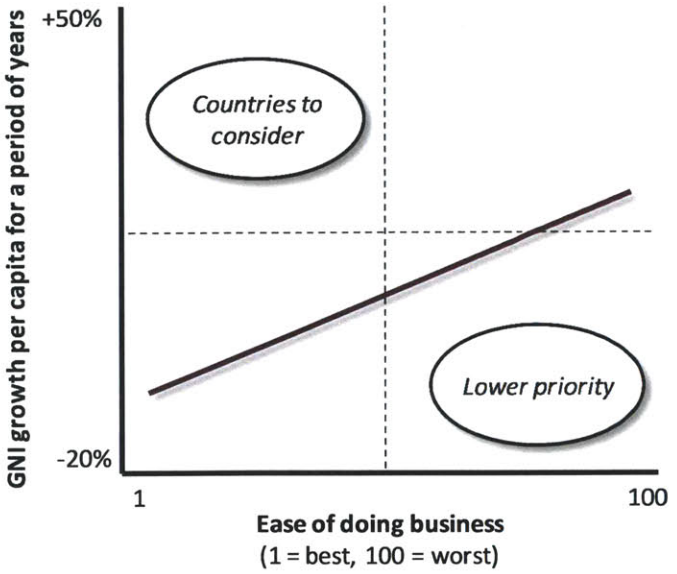

Diagram 2.14 Ease of doing business/GNI growth heat map

Diagram 2.14 shows a heat map where Gross National Income (GNI) growth is mapped against global ease of doing business index that is created by the World Bank. The most attractive countries in the short term will be those in top-right corner of the chart. This may be because they have made sustained improvements in creating wealth and opportunities while providing the proper legal and political environment for business to develop.

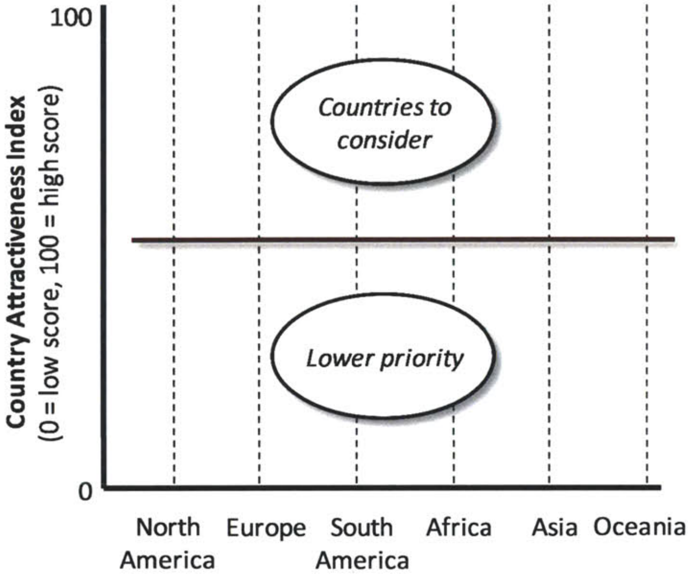

Diagram 2.15 Country Attractiveness Index

Finally, Diagram 2.15 shows a graph based on a single scale, the Country Attractiveness Index (CAI) generated by a rating agency (such as the index generated by Ernst & Young). The score is displayed on a graph ranked against countries within the same continent. The higher the score, the more attractive a country is.

In addition to countries' attractiveness, developers need to consider restrictions which countries may have against foreign investment. Commonly, foreign investments may need to meet certain requirements, such as being beneficial for country's economy and society, in terms of job creation, rural development, export, and tax revenues. However, in return approved investment projects may receive benefits, including derogations from taxes and charges. Investment projects can also be eligible for exemption from customs and excise duties on importation or domestic purchase of construction materials, machinery, and equipment for building and operation of the investment project.

2.4.2 Investment drivers into new markets

Some key drivers for a developer to look for power plant development projects into new markets include the following:

- **Country's limitations:** A developer may look abroad for project support because domestic economy can't provide the technical expertise, manufacturing capability, or financial support needed. Countries entering a recession may scale back in power plant development as a result of lowered energy consumption, and less electricity demand from other industries. Countries can also reach a point where new project development is limited due to land resource limitations. Risks encountered for those developers include lowered credit rating that affects financing of the project.
- **Talent growth:** Established developers, whose biggest resource is their manpower, may reach a point where it is important for the developers' sustained growth to start looking at projects in new markets. They may be driven by the need to further develop their manpower's talent with exposure to projects in new markets, with different challenges.
- **Organizational balance:** A developer can decide to enter global competition for projects to diversify risks in their power plant portfolio.
- **Developer's expansion:** Developers may decide to participate in projects in new markets as a part of their M&A activities, entering into a fast expanding market, etc. Those developers may be impacted by risk factors associated with partnering organizations.
- **Market attraction:** Developers may be attracted to a certain market which may drive them to look at project developments there for a certain period of time. Examples are large project developments, such as in China and in Saudi Arabia.

Those companies can have several financial risk factors in common, including foreign exchange risk, interest rate risk, liquidity risk, revenue risk, funding risk, and counterparty risk. Other risk areas include engineering, procurement, governance, contractual arrangements, contractors'/consultants' performance, geo-technical considerations, construction works, force majeure, environmental and social risk (see discussion on risks in Section 3.1).

2.4.3 Investment in emerging markets

Investing in emerging markets is largely riskier than in developed countries, and generally provides lower returns than investing in developed countries (Allen, Myers, & Brealey, 2006). Key characteristics of the energy market in emerging economies can be summarized as follows[15]:

- **Key players:** Dominant actors in the energy sector in emerging markets tend to be large utility companies. In most developing economies this is typically a national utility that has historically held dominant position in generation, transmission, and distribution of energy.
- **Market structure:** Energy sector in most developing economies is heavily regulated.
- **Pricing:** Pricing is usually set by public planners based on cost assumptions associated with existing long life capital stock.
- **Drivers for new technology:** Pricing structure does not factor in elevated learning costs of deploying new technologies or approaches, and therefore drivers for innovation and new technology uptake are poor.
- **Regulatory environment:** In developing countries policy frameworks that price environmental and social cost associated with conventional fossil fired power plants are often absent or still evolving.

Based on a survey which was conducted on behalf of the Multilateral Investment Guarantee Agency (MIGA) by the Economist Intelligence Unit, senior executives from multinational enterprises investing in developing countries considered the following to be the major constraints on investment in emerging markets (listed in decreasing order of importance) (MIGA, 2011): 1) Political risk (including in increasing order of importance: Breach of contract, transfer and convertibility restrictions, was and civil disturbances, non-honoring of government guarantees, other adverse regulatory changes, expropriation, terrorism, and restrictions on FDI outflows in home countries), 2) macroeconomic instability, 3) access to financing, 4) corruption, 5) access to qualified staff, 6) infrastructure capacity, 7) limited market opportunities, and 8) increased government intervention.

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[15] Source: Summarized from the report *Addressing the lack of early stage capital for low carbon infrastructure in developing economies* (UNEP, 2011).

2.5 Funding and Financing

Funding and financing requirements for a power plant development project are generally very large. Depending on project type and developer, it may be financed on a stand-alone project-finance basis, or directly by public or private sponsor. In either case, a range of financing instruments can be used, including equity and debt financing, different forms of risk mitigation, and carbon finance. Table 2.8 shows the collection of debt and equity financing instruments available.

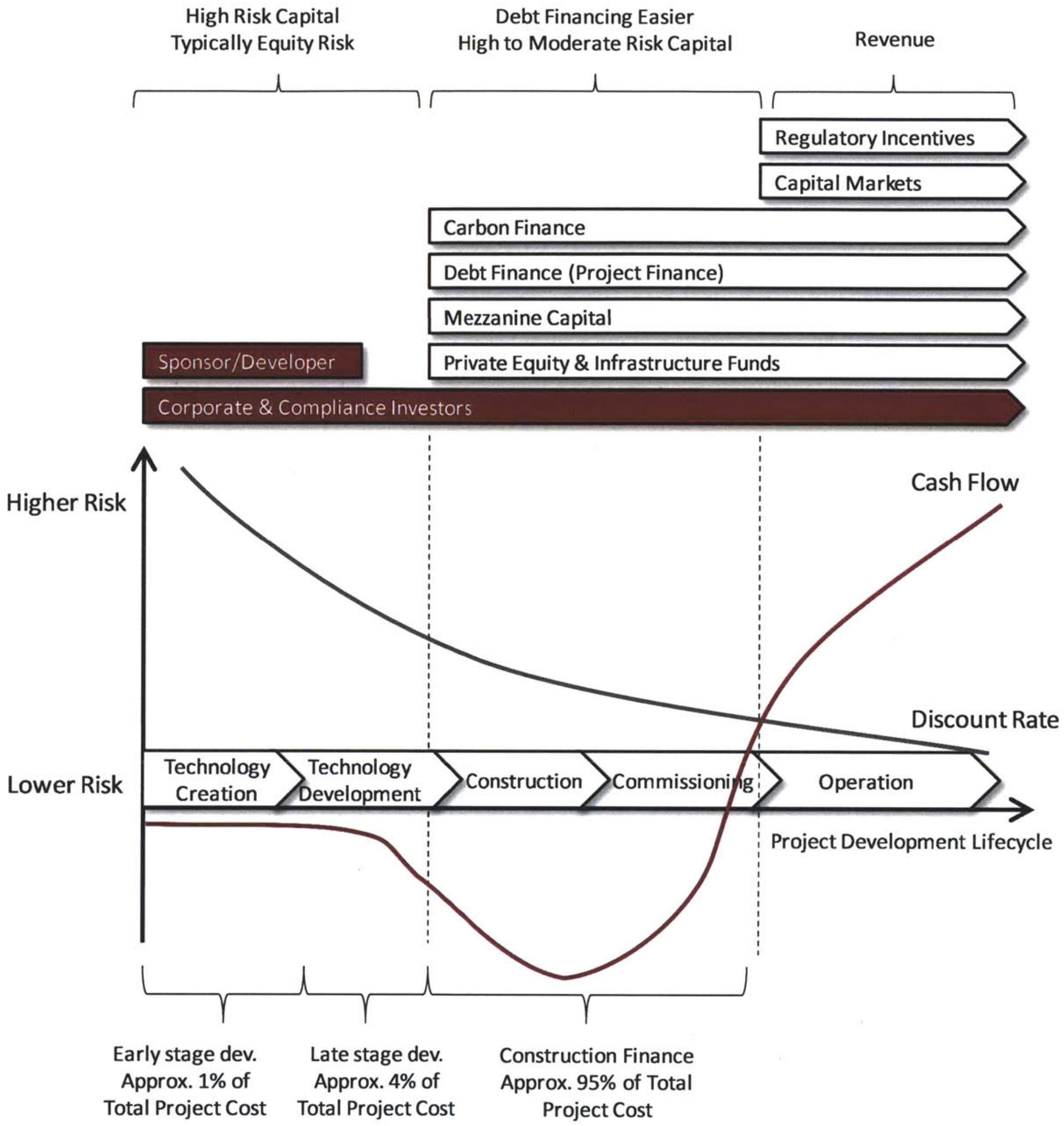
Instrument	Form of financing	Source of finance	Investor
Equity	*Ordinary shares*	Risk capital from developer or sponsor.	Sponsor
	Preference shares	Senior to ordinary shares, typically from tax investor; sometimes providing a cumulative dividend.	Institutional Investors Investment Funds Tax Investors
	Grants	From public sector, often designed to help a project developer share cost of early stage development.	
	Risk Capital	Equity investment that comes from venture capitalists, private equity funds or strategic investors (e.g. equipment manufacturers).	
	Private develop Finance	From personal savings or bank loans secured by private assets	
Debt	*Mezzanine Finance*	Groups together a variety of structures positioned in the financing package somewhere between high risk/high upside equity position and lower risk/fixed returns debt positions.	Lenders specializing in mezzanine debt
	Syndicated loans	Loan provided by two or more lenders, governed by a single loan agreement. May have different agreements for construction and operating phase of project. Provide long-term finance.	Banks

	Senior debt	Large unsecured loans are only available to creditworthy corporations. Banks tend to limit their risk to 5 - 10 years.	Commercial banks
	Development loan	Financing provided during development of project to a sponsor with insufficient resources.	Lender with project experience. World Bank (only if project cannot secure borrowing at reasonable rates from any other sources). Vendor
	Intermediary Loan	Export-Import bank lends to a financial intermediary (commercial bank), which in turns lends to the project.	Export Credit Agency
	Private Placement	Direct sale of long-term debt / equity	Sophisticated investors including insurance companies, pension funds, trading companies
	Eurobond	Issued in amounts averaging USD 100 million without prior registration or approval by any particular government. Terms usually range from 10 - 15 years. Loans may be made in any currency, fewer covenant than syndicated bank loans, and accessible through a large and liquid market. However, a credit rating for the project entity is required which could be both costly and time-consuming to obtain. Also, bond issues tend not to allow changes to the underlying project.	Capital Markets
Guarantees and other risk finance structures	*Exchange Rate Risk*	A commercial lender provides a loan to a project entity (importing entity), at below market interest rates. Export-Import bank provides compensation for the difference between commercial rate and below-market rate.	Export Credit Agency
	Risk Finance/ Insurance Structures	Are used to transfer or manage specific risks through commercial insurers and other parties better able to underwrite risk exposures and smooth revenue flows.	Commercial insurer

	Political Risk	Limited protection against risks of sovereign non-performance and against certain Force Majeure risks.	Word Bank
Tax relief	*Tax Credits* *Tax Holidays* *Duty exemption*	Individual governments may offer tax incentives.	Host governments

Table 2.8 Sources for financing new power plant development projects

Graph 2.1 gives a simple illustration of typical financing sources available to a power plant development project, and how those main capital providers engage along the project development lifecycle (note that this graph does not give an exhaustive list of capital providers). It also illustrates how discount rate changes to reflect less risky nature of the project in later stages of development, which is reflected in internal rates of return expectations of the capital providers (see Table 2.11). Their different risk appetite is again reflected in stages of their involvement along the development lifecycle. As cash flow on the graph shows, revenue isn't generated until in operation phase of the project. There are no fixed rules for allocation of project costs to different phases of the development lifecycle, as it depends on project type and scale, but as a general rule spending is lower at earlier stages when risk is relatively high. As project development matures and the project moves into financing phase, development spending increases to cover financing activities and preparation for construction start. Majority of the total project cost (approximately 95% for smaller projects) is incurred during construction phase of the project. Investing in projects whilst they are still in early stages of development carries significant risk until certainty can be achieved that the project is feasible and will reach financial close. Although the investment requirements are modest at early stages of project development, third-party financing remains almost non-existent, leaving financial burden to project developers themselves (UNEP, 2011).



Graph 2.1 Typical financing structure of a power plant development project[16]

The larger the project is on scale of cost, time, and risk involved, the harder it is to get initial funding. Medium-scale projects are typically funded through corporate finance route, where a significant portion of project risk is assumed by project sponsor, thereby making credit worthiness of the project sponsor critical. Larger projects, such as nuclear power plants, are mostly reliant on government sources for initial activities until the project has developed confidence of the financial community, and can

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[16] Source: Graph is put together based on several different sources of information, including (UNEP, 2011)

demonstrate stable and continuing determination to competently manage construction, licensing, and operation of the power plant (IAEA, 2007). Geothermal power plants are another example of a project with a unique risk profile, with high upfront risk (as a result of high exploration risk at the pre-feasibility stage) and very long lead time. They commonly struggle to guarantee successful initial funding, until all (or most of) these factors align: geothermal resource, sector regulation, contractual framework, and cost competitiveness (IFC, 2011). As a result, substantial upfront equity outlay is required prior to debt financing. More generally, funding for power plant development projects is more available if the following project characteristics are aligned[17]:

- Strong public and government policy in support of development of the energy source.
- Established credit worthiness of sponsor.
- Reasonable degree of stakeholder involvement.
- Complete legislative framework supportive of the use of the energy source and of any financial guarantees necessary to support specific financial approaches.
- Competent regulatory framework with funding sources to fulfill its responsibilities and maintain its existence.
- Fully funded security and safeguards programs (particularly for nuclear power plants).
- Plans in place to fully finance long-term operation and decommissioning.
- Structure for the electricity rates and tariffs that is sufficient to ensure a return on capital investment.

2.5.1 Investors

Three parameters in particularly control which investors are willing to finance power plant development projects: 1) Stage of maturity of the energy technology, 2) capital requirements of the plant, and 3) expected Internal Rate of Return (IRR) of the project. Table 2.9 gives an overview of typical values of those key parameters for different energy technologies. As the table shows investment cost is generally lower the more mature the energy technology is. Typically mature energy technology projects will have

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[17] Source: Adjusted from various literature sources and expert inputs, including (IAEA, 2007)

an IRR of around 8% whereas newer renewable energy technologies need to be higher than 10% to justify higher risk associated with these investments.

Energy technology	Investment cost (2010 USD/kW)[18]	Stage of maturity[19]	IRR[20]
Biomass	2,500	Demonstration	10 – 12%
Coal (PCC)	2,100	Mature	7 – 8%
Gas	2,400	Mature	7 – 8%
Geothermal	2,400 - 5,500	Deployment	10 – 12%
Large Hydro	2,000	Mature	8 – 10%
Nuclear	3,000 - 3,700	Mature	10 – 12%
Oil	800	Mature	7 – 8%
Small Hydro	3,000	Diffusion	8 – 10%
Solar PV	3,500 - 5,600	Deployment	10 – 12%
Wind	1,450 - 2,200	Diffusion	10 – 12%

Table 2.9 Investment cost for different energy type projects

The IRR is used to measure and compare the profitability of investments. It is not used as an investment decision tool to rate mutually exclusive projects, but rather to decide whether a single project is worth investing in. The minimum IRR which investors require on a power plant investment is called the hurdle rate. The hurdle rate varies depending on risk appetite of the equity investor, difficulty of the project, and market. More risky projects have higher cost of capital and demand higher returns. It is important for investors to look at unlevered IRR as often the capital structure is not known or finalized until after development is completed.

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[18] Source: Energy technology investment cost figures are based on an estimate by IEA in 2010 USD/kW (IEA, 2010)

[19] The different stages of technology maturity of utility scale utilization of the energy technologies, from early stage and through different growth stages, can be defined as: 1) Research and Development (R&D), 2) demonstration, 3) deployment, 4) diffusion, and 5) commercially mature.

[20] Source: IRR rates are adjusted from IEA analysis based on discussions with various financial institutions (IEA, 2010)

Historically, early stage energy technologies have been funded by the public sector from R&D through demonstration. Private equity and project finance debt capital have however historically funded energy technologies once they're commercially proven. As a result, there has been lack of financing available to capital intensive new technology projects at commercial scale. This has been termed the "commercialization valley of death", referring to projects which sit between venture capital and project finance worlds (McConville & Valentine, 2010). They are too capital intensive for venture capital and too risky for private equity in that they require investors to bear technology and scale-up risks. Diagram 2.16 shows how different investors get involved at different maturity stage of the energy technology.

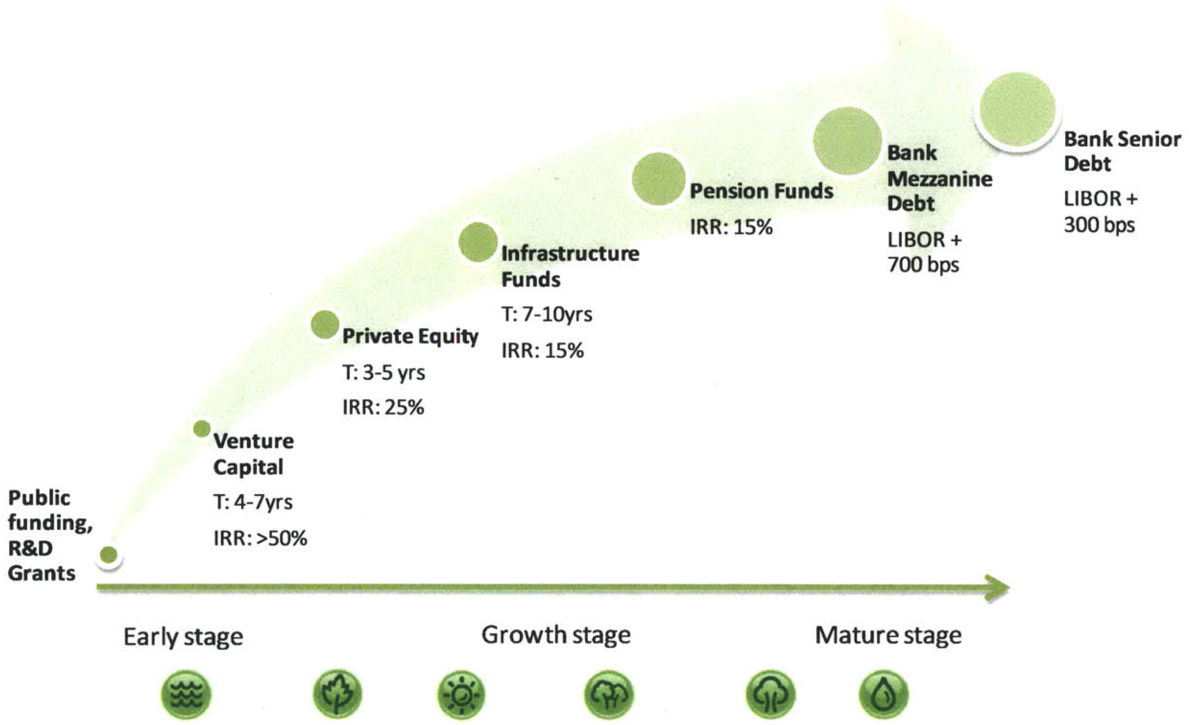

Diagram 2.16 Investors involvement depends on stage of technology development

The different types of investors can be grouped as financial and non-financial investors, i.e. providing equity and debt financing respectively, which will be discussed in more detail in the following sections.

2.5.1.1 *Non-financial investors*

Non-financial investors, providing debt financing, include developers, project sponsors and corporate or compliance investors (e.g., utility companies). Non-financial investors typically play a role beyond providing capital, such as to secure the power off-take or the carbon credits from the project.

- **Corporate and Compliance Investors:** Large utility companies have traditionally invested in the conventional energy sector but to lesser extent in the renewable energy, due to the relatively smaller transaction size and perceived higher risks (and development costs), particularly in countries with evolving policy environments.
- **Sponsors:** Other non-traditional project developers, such as local entrepreneurs and/or companies without an energy sector background or experience and which often have limited capital resources. They are generally prepared to accept greater risk in evolving policy environments and therefore respond more quickly to expected shifts in investment.

Table 2.10 gives an overview of these sources of debt financing, their risk appetite, investment horizon, and required IRR.

Sources of financing	Risk appetite	Investment horizon	Required IRR[21]
Corporate Investors	Medium – High	Long term	15 to 20%
Sponsors	High	Long term	30 to 40%

Table 2.10 Sources of debt financing

2.5.1.2 *Financial investors*

Financial investors, providing equity financing, include third-party investors and lenders. Equity investments are direct investments made in exchange for a share of the ownership in a company or project. As Graph 2.1 shows these investors typically enter projects when construction is ready to begin. Traditionally, financial investors rely on non-financial investors to complete the project development activity up to that point.

- **Angel investors**: Individuals who provide capital for business startups, usually in exchange for a stake in the company. Angel investors invest their own capital.

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[21] Source: These rates are based on source (UNEP, 2011)

- **Venture Capital**: Equity which is raised from a wide range of sources, and is typically used to finance new technology development. Their focus is on early-stage company development and funds are provided in exchange for equity in the company.
- **Private Equity**: Equity which is raised from a wide range of sources, and is used to finance more mature technology, demonstrator companies or under performing companies.
- **Mutual funds**: Professionally managed collective investment schemes that pool money from different shareholders for investments in a variety of instruments.
- **Sovereign wealth funds**: State owned investment funds from countries with large foreign reserve surpluses. These funds invest in a wide range of financial assets aimed at increasing return on their excess foreign reserves.
- **Infrastructure funds**: Equity which is raised from institutional investors and pension funds to invest in essential assets with long life spans, such as power plants. These investments typically provide low risk, and stable cash flows.
- **Insurance funds**: Represents insurance premiums paid and are invested by insurance institutions in order to meet the liability at maturity. The majority of these funds are from long term insurance policies.
- **Pension funds**: Pooled assets from contributions to pension plans. Investments are made in a wide range of instruments including public equity via stock markets, corporate and government bonds, real estate, and other assets.

Table 2.11 gives an overview of these sources of equity financing, their risk appetite, investment horizon, and required IRR.

Sources of Financing	**Risk Appetite**	**Investment Horizon**	**Required IRR**[22]
Angel investors	High	5 – 7 years	High, at least 10 times the initial investment
Venture Capital	High	4 – 7 years	50% to 500%, because of high risk
Private Equity	Medium	3 – 5 years	Relatively high, 18 to 50%
Mutual funds	Low/Medium	Medium to long term	Around 15%

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[22] Source: These rates are based on source (UNEP, 2011)

Sovereign wealth funds	Low/Medium	Medium to long term	Around 15%
Infrastructure funds	Low	7 – 10 years	10% or 15%
Insurance funds	Low	7 – 10 years	Around 10%
Pension funds	Low	7 – 10 years	Around 10%

Table 2.11 Sources of equity financing

2.5.2 Weighted average cost of capital

The way developers finance their investments through combination of equity and debt is called capital structure or Debt to Equity (D/E) ratio. Developers generally want higher D/E ratio. Equity financing is more expensive than debt financing for corporations as the associated risks, and therefore the required returns, are higher for equity than for debt. Relative weight of each component of the capital structure determines the weighted average cost of capital (WACC), i.e. the rate they are expected to pay on average to all its security holders to finance its assets. Developers can then use their WACC to see if the investment projects available to them are worthwhile to undertake. Table 2.12 shows the typical capital structure for the different utilities. In general, POUs have a lower WACC and can therefore go for projects with lower expected IRR.

Developer	Capital Structure	WACC
IOUs	50% debt at 6%, 50% equity at 14%	6.8%
POUs	100% debt	5.1%
IPPs	60% debt at 8%, 40% equity at 17%	9.8%

Table 2.12 Typical financing opportunities for power plant developers[23]

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[23] Source: These financial factors are from the report *Power Plants: Characteristics and Costs* which was prepared for members and committees of Congress (Kaplan, 2008).

2.5.3 Financing structures

Several different financial structures are used for power plant development projects, which vary in type of participants, source of financing and allocation of benefits. A typical project financing structure for conventional power plant development project can be found in Table 2.13

Sources of financing	Percentage of total capital cost	Tenors
Foreign Export Credits	40% total project costs, and/or 85% equipment costs	12 years, 3 years grace, slightly concessionary rates
Multilateral Agencies	10-15% credits & loan guarantees	12 – 15 years
Commercial Bank Debt	10% loans, 5 – 15 member bank syndicate	5 – 12 years
Multilateral Co-Financing Facilities	10% loans, umbrella for commercial banks reduces risks; participation limits may require co-financing	12 – 15 years
Local Bank Debt	10% loans in local currency for working capital	5 – 8 years, 2 years grace, usually higher interest rates
Private Placements	10% loans, beyond what may be available for commercial banks	5 – 12 years

Table 2.13 A typical project financing structure for a power plant development project[24]

The simplest form of financing is corporate financing, when one corporation develops the power plant, finances all costs, and bears all risks (see Diagram 2.17)[25]. That may be a subsidiary of the corporate parent, but holds 100% ownership with no other investors or lenders involved. This is a common financing structure for POUs, but rare in the renewable energy sector.

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[24] Source: This table is from the report *Global Infrastructure Financing: Sources & Structures* (Cobb, 2010)

[25] Source: The diagrams of the different financing structures in this section are adapted from information from Green Rhino Energy Ltd. (Green Rhino Energy, 2012)

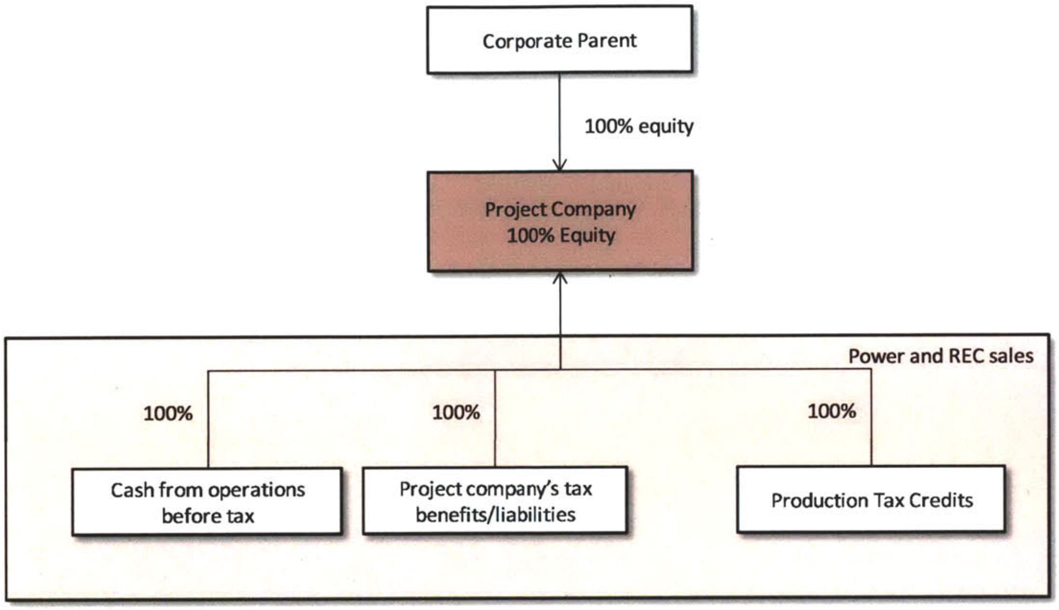

Diagram 2.17 Typical corporate financing structure

Another commonly used structure is when developer acquires lease and land rights, permits, interconnection agreements, power purchase agreements, and any renewable certificates or feed-in-tariffs (see Diagram 2.18). The developer sells the developed project to a strategic investor and receives a development fee from the investor. The strategic investor constructs the project on its balance sheet or arranges bridge finance for the construction. The strategic investor owns and operates the plant. The developer's risk is limited to the development capital.

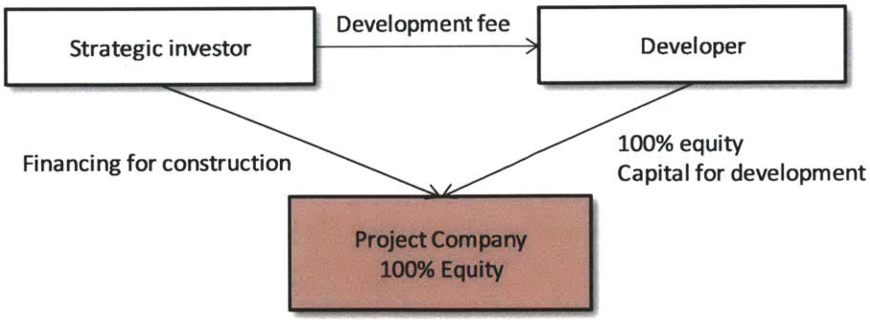

Diagram 2.18 Financing structure of sale before construction

When the developer seeks bridge finance from lenders to finance a power plant development project with 100% equity, the type of bridge finance determines repayment structure. Diagram 2.19 gives an example of a loan structure using construction loan, Cash Equity Bridge, and Tax Equity Bridge. For the construction loan the bank is repaid in full at completion of construction (alternatively the bridge is converted into long term loan). For the Cash Equity Bridge the bank is repaid at completion of construction with funds from sponsor (developer may provide limited guarantee for cash equity). For the Tax Equity Bridge the bank is repaid at completion of construction with funds from tax investor, who will only come in once the plant produces tax credits.

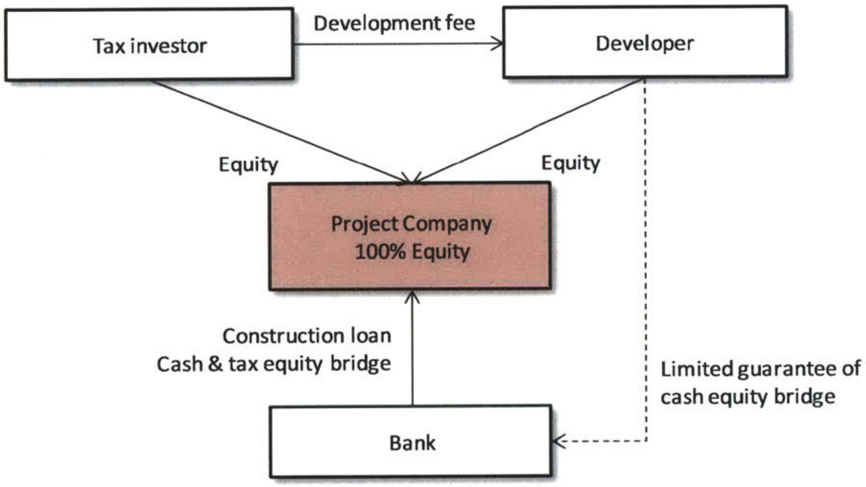

Diagram 2.19 Financing structure of sale after construction

Some financing structures change throughout the project lifetime. An example of those is the investor ownership flip structure (see Diagram 2.20) which is important when tax credits or other tax benefits are key elements of the project's economics. In this structure the investor contributes almost all of the equity and receives a pro-rata percentage of the cash and tax benefits prior to a flip in allocation. At a given level of IRR, the ownership flips back to the developer, after which most of the cash and tax benefits are allocated to the developer. Only the production tax credits will continue to go to the tax investor even after the flip. If the investor is a tax investor rather than a strategic investor, the pre-flip allocation may not be pro-rata and all tax benefits may go to the investor instead.

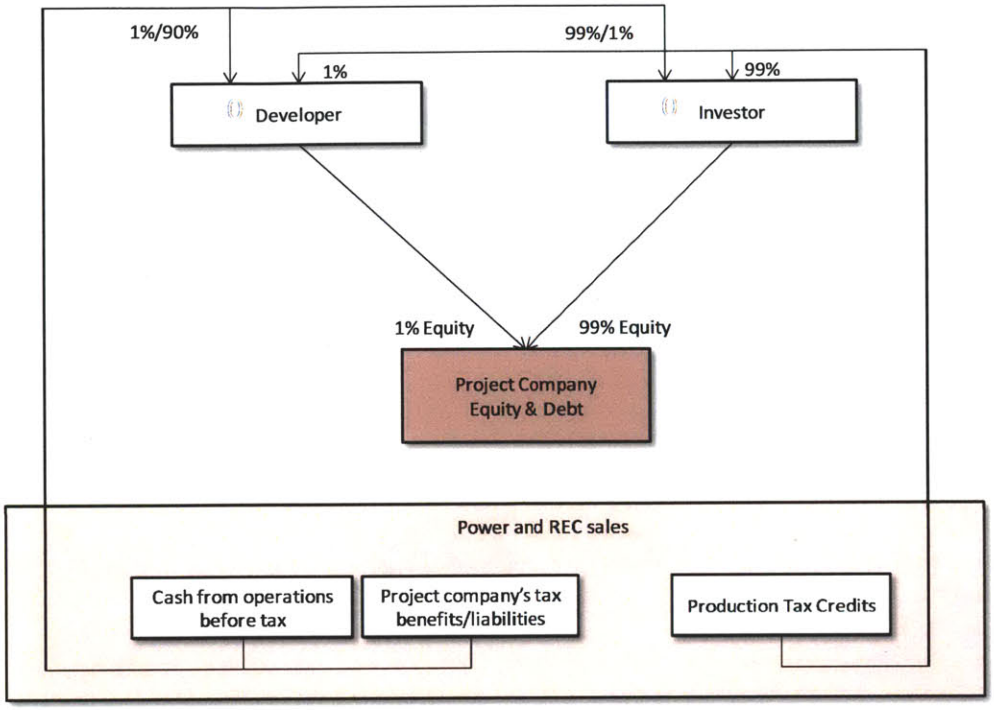

Diagram 2.20 Investor ownership flip (pre-flip/post-flip)

The most common project finance structure is the so-called leveraged ownership flip and pay-as-you-go, or PAYGO (see Diagram 2.21). The tax investor makes contributions before production begins, though a portion may be deferred until the project receives production tax credits, which are initially allocated to the tax investor, though a high percentage is paid to the developer as an equity contribution. The leverage is at project level with long term debt of up to 18 years, based on the power purchase agreement. This structure also includes a return based flip in allocations. As the term for the production tax credits is usually, an additional loan may be secured against those flows.

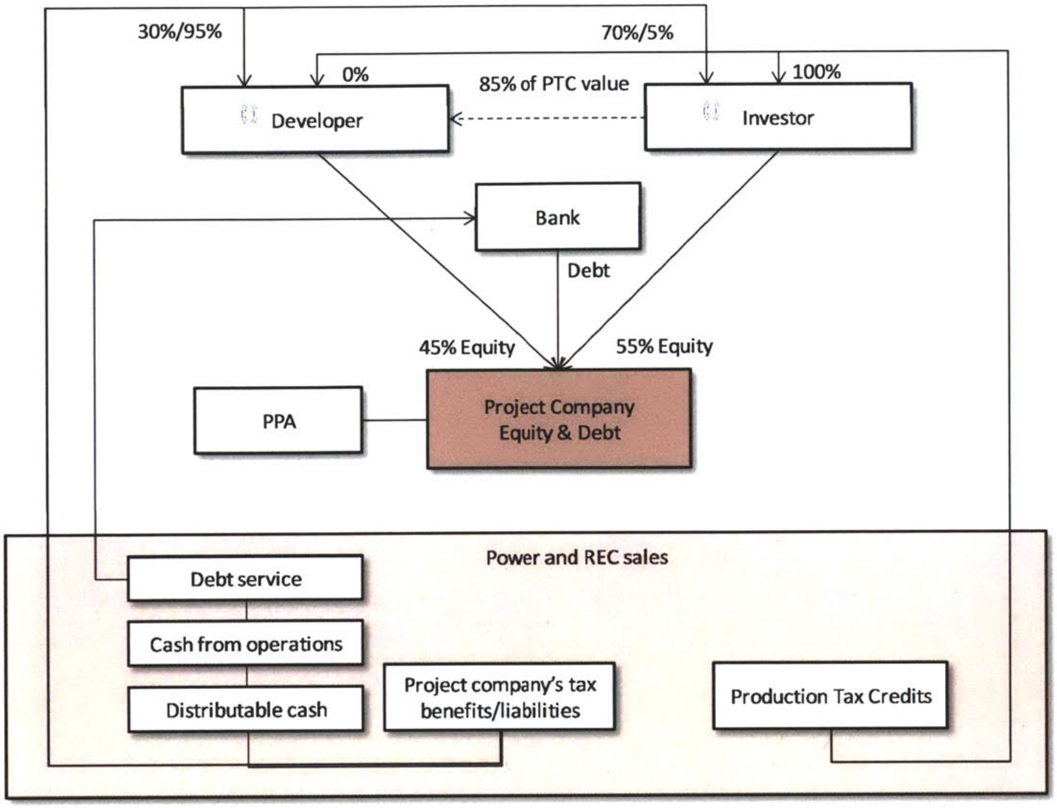

Diagram 2.21 Leverage ownership flip and pay-as-you-go (pre-flip/post-flip)

Another similar financing structure is the back leveraged structure where the developer is leverages its equity stake in the project using debt financing, and the tax investor commits equity upfront (see Diagram 2.22). In this example 100% of the cash goes initially to the developer until return of investment (similar to a development fee), after which 100% goes to the investor. The flip happens upon the investor's pre-agreed IRR is reached (typically 7% - 10% depending on project risk). After that the ownership and cash flow allocations go back to the developer, including most of the tax benefits.

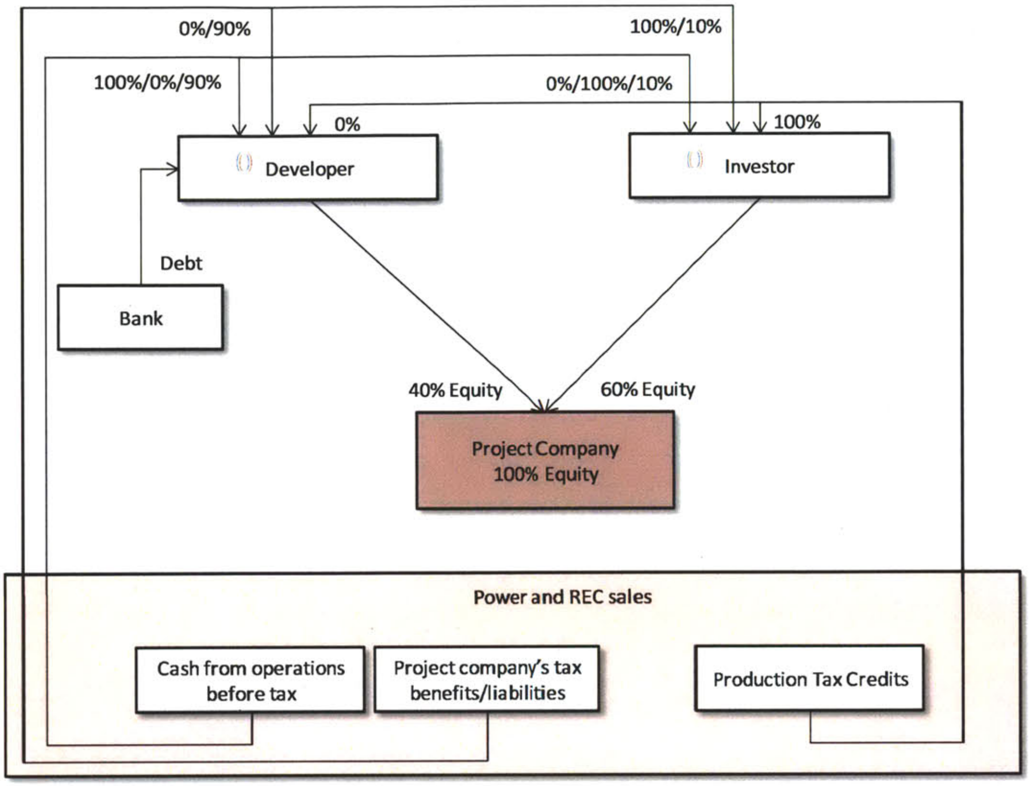

Diagram 2.22 Back leveraged structure

For a leveraged lease financing structure, the construction is funded by sponsor equity and a construction loan (see Diagram 2.23). Once constructed, the sponsor sells the project to the investors that have formed a trust and immediately leases it back. The developer repays the construction loan from the sale proceeds. The trust is financed with cash equity and a non-recourse term debt. Lease payments are likely to be assigned to a lender. For tax purposes, a minimum of 20% equity is usually required. Leasing generates a time value of money cost saving achieved by deferring tax payments. It also improves cash flow.

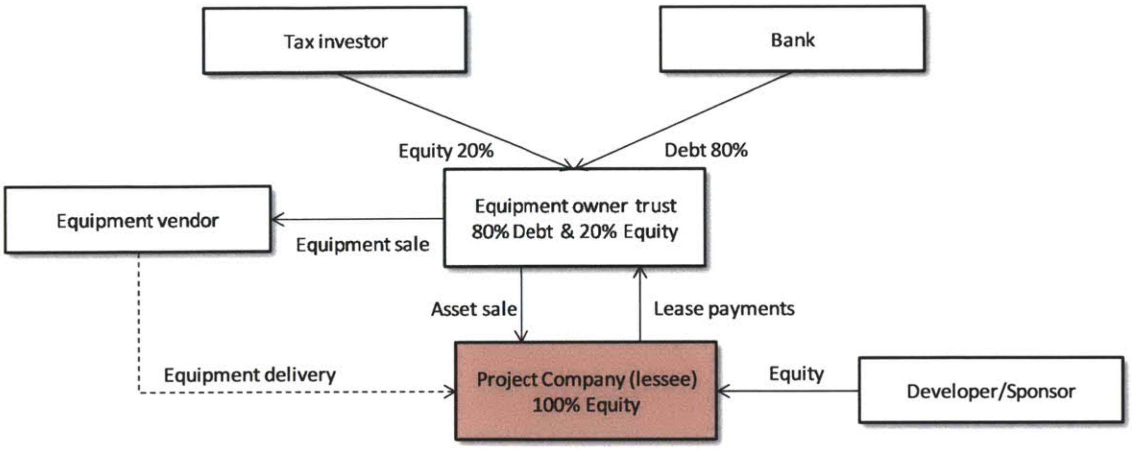

Diagram 2.23 Leveraged lease

In addition, power plant development projects are often financed as standalone entities (Project Finance) rather than as part of a corporate balance sheet (Corporate Finance). The main advantages of project finance are:

- **Non-recourse/limited recourse financing**: There is no or only limited recourse to the project sponsor's assets for liabilities of the project. Thus, the project preserves sponsor's debt capacity. Also, lenders will be keener to participate in a workout.
- **Risk Sharing**: By setting up a separate legal entity, project risk is isolated and can be allocated to parties that can best control, understand and mitigate the risks involved. Consequently, incentives for all involved are optimized. This includes political or country risk.
- **Favorable Tax Treatment**: Project Finance structures allow tax benefits to be allocated to entities that can make use of them.
- **Improved Financing Terms**: The project may obtain more favorable financing term than it would based on the sponsor's credit profile alone. This way projects can be carried out that would be too big for one sponsor.

However, all of these benefits come at a high transaction cost, higher interest rates and insurance coverage. In general, choice of financing structure depends on several considerations regarding the project, and participants. Table 2.14 gives some of the criteria that can be used to select the most suitable financing structure.

Consideration	Context	Most suitable structure
Project size	If project's value is less than USD 50 million, transaction costs of Project Finance will outweigh benefits.	Corporate
Developer can use tax benefits	If developer wants to use tax benefits, project needs to be on its balance sheet. However, often, developers are much smaller than the projects they develop and have no capacity to use all the tax benefits.	Corporate
Developer can fund project costs	If developer can fund project costs.	Corporate PAYGO
Low project IRR	If project's projected IRR is low, increasing debt levels will help increase equity holder's rate of return.	Leveraged structure
Developer wants early cash distribution	Due to large capital expenditure there are no early cash distributions available if developed on own balance sheet. Developer either needs to sell early or device a structure whereby the developer receives a large proportion of cash.	Project Sale Back-leveraged PAYGO
Re-financing	If project already exists, but just needs re-financing, possibly after construction, options include a pay-as-you-go structure or leasing.	PAYGO Leveraged Lease

Table 2.14 Selecting financing structure based on project criteria[26]

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[26] Source: This table is based on information from Green Rhino Energy Ltd. (Green Rhino Energy, 2012)

Chapter 3: Risk in Power Plant Development Projects

As was discussed in Chapter 2, a developer will select the power plant development project based on a wide range of analyses. Many of the factors which go into that analysis are uncertain at the time the decision is made, or are likely to change throughout the development timeline. In assessing these uncertain events the developer will seek to find out:

1) What potential changes can impact the development of the project?

2) How likely are these events to happen?

3) If they do happen, what would be the consequences[27]?

Depending on the type of event, their potential outcome and likelihood of occurrence will fall somewhere along the range of these three levels:

Level 1: The single view of the future is clear.

Level 2: There is a limited set of possible future outcomes, one of which will occur.

Level 3: There is a range of possible future outcomes.

Level 4: There is true ambiguity, not even a range of possible future outcomes.

Conventional risk assessment is based on the ability to define probabilities for an expected set of outcomes, i.e. outcomes falling into level 2. In level 3, the developer is no longer assessing risk events but uncertain events, and is unable to estimate the probabilities of the known possible outcomes. However, many of the factors the developer needs to assess fall into level 4, leaving the developer faced with a complete "ignorance"[28] of not having the slightest idea about possible outcomes (such as impact of extreme risk events like nuclear disasters, earthquake and tsunamis impact, human errors, etc).

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[27] It important to note here, that uncertain events can have a positive effect on the development project (see further discussion on positive risk impact in section 5.2).

[28] Ignorance in the risk assessment and risk management sense is defined as (i) ignorance expressing the same as uncertainty, i.e. lack of knowledge, (ii) ignorance expressing a situation where a poor basis exists for the assignment/estimation of probabilities, and (iii) ignorance expressing a situation where the definition of a complete set of outcomes is problematic (Aven & Steen, 2010).

The conventional approach to the risk management process can be broken into five steps:

- **Risk identification:** Identifying all possible risks exposures relative to the power plant development project.
- **Risk assessment:** Assessing each risk exposure identified, classifying them according to their level of certainty of potential outcome and likelihood of occurrence (certainty, risk, uncertainty, and ignorance), and quantifying the costs associated with the risks.
- **Risk management methodologies**: Once risks have been identified and assessed, the project needs to be prepared to mitigate negative impact on development, potentially caused by these risks, by using one of the risk management techniques: Avoid, control, accept, or transfer.
- **Implementation:** Risk management techniques selected are then implemented, with the underlying principle being to minimize the costs.
- **Review:** The potential risk management exposure and their management techniques continue to follow a dynamic feedback process throughout the development lifetime, in which decisions have to be constantly revised.

The following section discusses risk management process in more detail. Section 3.1 identifies some of the key factors which can impact performance and return of a power plant development project. This section will not discuss probabilities of the event occurring, and therefore does not distinguish between whether the event is a risk, uncertainty, or "ignorance" according to the definitions mentioned here above. For simplifications these events will be referred to as *risks*, as it is important for the developer to take the wide range of events into consideration in their project assessment. Section 3.2 discusses approach to risk assessing, and Section 3.3 discusses key instruments for risk management.

3.1 Risk Identification

When a power plant development project goes wrong there can be several things to blame, ranging from inexperience at the hand of the developer, to site specific problems, technical issues, regulatory problems and permitting issues, all of which affect financial and technical viability of the project. Failure to develop a project can come at a great cost to the developer, and other stakeholders involved. The process of identifying those risks varies from project to project. During pre-selection phase, initial risk identification may be developed by specialized groups on behalf of the developer or the developer themselves depending on in-house knowledge. Once project has been selected, effective, ongoing risk identification requires input from the entire project team and from others outside it, such as owner's representatives, contractors, and internal and external consultants or advisors.

Data gathering for risk identification can be based on a) historical information and knowledge that has been accumulated from previous similar projects and from other sources of information, b) interviewing of experienced project participants, stakeholders and experts based on their intuition/pure gut feel, c) expert audit using formal scoring methods, d) through brainstorming of the project team usually with experts, or e) through surveys. To reduce bias in the data and to keep one person from having too much influence on the outcome, data may be collected using Delphi method. A facilitator then uses a questionnaire to solicit ideas from experts about important project risks. Responses are summarized and are then sent back to experts for further comment. Consensus may be reached in a few rounds of this process. Empirical data can also be combined with expert judgments using Bayesian statistical tools.

The following section highlights the risks which can impact a power plant development project. Section 0 focuses on the risks that are general to most power plant types, and shows where along the development timeline those risks can occur. Section 3.1.2 focuses on risks that are specific to renewable energy projects, and Section 3.1.3 highlights key risks specific to a power plant's energy technology.

3.1.1 Risks general to power plant development

An integrative part of risk identification is risk classification. That is, provide a coherent descriptive structure for classification and analysis of diverse risks affecting a project. Many approaches have been suggested. El-Sayegh used a Risk Breakdown Structure (RBS) to categorize the risks depending on if their source was internal or external to the project (El-Sayegh, 2008). Zhi focused on risks at a project level, categorizing them into five main categories: risks generated by the owner, risks relating to the architect, risks caused by direct labor and subcontractors, risks caused by materials and equipment suppliers, and risks arising from internal activities of the company (Zhi, 1995). Chapman and Ward presented nine categories of risk for any infrastructure project as being technical, construction, operating, revenue, financial, force majeure, regulatory/political, environmental, and project default (Chapman & Ward, 2003). Perry and Hayes presented a list of factors extracted from several sources, which were divided in terms of risks retainable by contractors, consultants and clients (Perry & Hayes, 1985). Cooper and Chapman classified risks according to their nature and magnitude and grouped risks into primary and secondary categories (Cooper & Chapman, 1987). Merna and Smith categorized risks as "global" or "elemental", global risks being those that are normally allocated through the project agreement and typically include political, legal, commercial and environmental risks, whereas elemental risks being those associated with the construction, operation, finance and revenue generation components of the project (Merna & Smith, 1996). In general, there are many ways to classify the risks associated with projects, and the rationale for choosing a method must serve the particular purpose of the research (Nik, Zegordi, Nazari, Sakawa, & Honari, 2011).

The following risk classification is based on Lessard, who categorized risks in six different layers corresponding to the responses to these risks (Lessard, 2003). The risks are summarized in Table 3.2[29], using the following six layers[30]:

- World system risk: Risks which are not specific to the project or development site location but have to do with volatile global factors, which the developer has no control over.
- World price risk: Risks which result from volatile prices of commodities, or result from international dealings of workers and equipment which are subject to exchange rate risks.

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[29] Source: This table was developed through literature review and expert input, including (WNA, 2008), (Lindlein & Mostert, 2005), (El-Sayegh, 2008), and (Zhi, 1995)

[30] The categories are listed here from the outermost layer of risk to the innermost layer.

- Country risk: Risk factors which are specific to the country of choice. These risks are not in control of the developer, who is likely to choose a country which best compares to their selection criteria for ideal development environment and their risk appetite.
- Institutional and regulatory risk: Risks which are related to the regulatory authorities and institutions whose decisions impact the development project.
- Industry and competitive risk: Risks related to changes outside the project but which impact the energy industry, such as infrastructure which the project relies on, development of competing technologies, or advancement of this energy technology, supply or demand.
- Project risk: Risks which may result from within the project structure, such as due to failure of contractors, or poor management.

Table 3.2 does not indicate which risk factors may potentially impact development time, cost or scope, as it can generally be assumed that impact on one of those dimensions will have an effect on another[31]. Table 3.1 describes what this impact can be, and how the development project is likely to react to that short term (immediate or near-term actions) and long term (affecting the development lifetime). Risk management methodologies that appropriately prepare the development project for those potential risk impacts are discussed in Section 3.3.

	Impact	**Short term effect**	**Long term effect**
Cost	Power plants are capital intensive, and a significant cost increase may result in a decreased return on investment and uncertainty of timely capital recovery	Depending on financing availability, cost increase may require additional capital input or design changes	If development cost increases considerably, the developer may need to scale down the project or abort it overall
Time	Construction delays, regulatory delays, and delays from public intervention bring risk to several stakeholders of the project, including the developer and electricity buyer	When time goes beyond schedule, cost always increases (only depends on who needs to bear that cost) as a result of penalties for delay, need for additional workers, etc.	When the overall development completion date goes over schedule the project may become at risk of expiring government support mechanisms, and added fees or contract breach with the electricity buyer

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[31] In project management this is often referred to as the Iron Triangle, where cost, time, and scope sit on each side of the triangle. One side can't be changed (increased/decreased) without affecting the other two (PMI, 2009).

Scope	Impact on scope can be measured as changes to performance and expected generation output of the plant, or quality impacts such as impact on environmental compliance, or safety standards	Depending on when discovered, quality or performance impacts generally require costly and time consuming rework, additional resources or design amendments	Depending on severity of scope or quality changes and time of discovery, the plant may require design amendments, being relocated, or overall project may be aborted

Table 3.1 Impact on development time, cost, and quality and their short term and long term effects

Although risk factors listed in Table 3.2 can all be classified as Development Risks, they may occur at different stages of the development lifetime and thereby impact different stakeholders of the project. The table reflects that using the following development phases (characteristics of each phase were outlined in Section 2.2.1):

i. Planning risks: Risks that can impact power plant development project at pre-construction phase, such as the plant's design, permitting, financing, etc.

ii. Construction risks: Risks that can impact power plant development project during construction phase of the plant.

iii. Operation risks: Risks of unscheduled closure of the power plant due to lack of resources, equipment damages, etc.

iv. Decommissioning risks: Risks which can impact plans to remove the power plant from service.

	Risk factor	Description	Development phase[32]
World system risks	*Political conditions*	Instability in worldwide political conditions, such as war	P C O D
	Trade regimes	Tariffs, quotas or other restrictions used to protect domestic industries	C O
	International geopolitics	Relations with third countries, and how they will react to this project	P C O D
	Nature catastrophe	Extreme weather conditions and other Act of God events (such as hurricane, flooding, earthquake, volcanic eruption, etc.)	C O D

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[32] Abbreviations for risk occurrence at different development phases stand for:
P = Planning phase, C = Construction phase, O = Operation phase, and D = Development phase.

	Climate changes	Impact of climate changes on future operation of the plant, such as due to higher ocean level[33]	P		O	
	Financing	Risk of insufficient access to investment and operating capital	P	C	O	D
	Resource availability	Risk of changes in electricity generation due to lack of resource availability[34]	P		O	
	Global demand	Changes in global electricity demand can influence the development, such as worldwide reactions to nuclear catastrophes, or increased focused on energy efficiency	P		O	
World price risks	*Commodity prices*	Changes in the price of commodities needed for development which are variable with world economic conditions		C	O	
	Exchange rates	Currency fluctuation or inconvertibility	P	C	O	
	Interest rates	Fluctuations in interest rates	P	C	O	
Country risks	*Political stability, terrorism, civil unrest*	Risk that power plant will be subject to damage or operational halt due to political violence, terrorism, civil unrest, or labor strikes		C	O	
	Financial, economic stability, inflation	Instability in country's financial or economical structure	P	C	O	
	Transparency	Transparency of business dealings	P	C	O	D
	Ethics	Potential reputational risk resulting from corruption or bribe	P	C	O	D
	Sabotage or theft	Risk that all or parts of power plant will be subject to physical damage as a result of sabotage or theft		C	O	
	Local investment	Increasing local investment can be negative for power plants competing over same resources, or if they deplete the regulatory authorities' tolerance over environmental issues	P			
	Social acceptance	Some project locations risk to be impacted by the spillover effects of another nearby development, such as poorly managed or environmentally unsafe plant development which can impact social acceptance	P			

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[33] Researchers at MIT and Yale have found that proliferating greenhouse gases are likely to increase hurricane storm related damage impacting power plants located on the coastline (Emanuel, 2012).

[34] Such as when wind doesn't blow for wind farms, sun doesn't shine for solar plant or snow covers the panels for long periods of time, water is insufficient in the reservoirs for hydro plants, etc.

	Growth rate	Decreases in GNP or incompatible GNP per capita can impact economic and financial situation			O	
	Local protectionism	Economic policies which contrast free trade and can impact import of equipments and service needed for the development		C		
	Culture and language	Conflicts due to differences in culture tradition, resulting from a language barrier, or even religious inconsistency	P	C	O	D
	Pandemic	Impact of an epidemic affecting a large proportion of the population or a fatal epidemic decease (pestilence), both of which would impact availability and efficiency of workers of the project		C	O	
	Expropriation	Risk of a government taking a privately owned plant to be used for benefit of the public			O	
	Taxation	Risk of a country imposing new taxes which can affect the power plant		C	O	
	Repatriation policies	Foreign investments may be of risk of government imposing policies on repatriation, restricting capital flow from that country to the country of origin			O	
Institutional and regulatory risks	*Permitting policies*	Changes in policies related to permitting or complex permitting procedures	P	C	O	
	GHG legislation	Development of GHG legislation can impact competitiveness of energy technologies	P		O	
	Regulatory incentive mechanisms	Changes or uncertain development of RPS targets or incentive mechanisms, such as government grants or loan programs	P		O	
	Contract enforcement	Regulatory review or renegotiation of a contract	P	C	O	
	Network regulations	Changes in regulations regarding interconnection	P		O	
	Regulatory rate allowance	Changes in market price of electricity or any pricing restrictions resulting in changes in rate of electricity generated	P		O	
	Administrative capacity	Constrained staffing levels in government institutions prevent a larger policy and regulatory response	P		O	
	Environmental compliance	Risk stemming from both existing environmental regulations and uncertainty over possible future regulations	P	C	O	D

	Legal stability	Status, procedures and maturity of legal system	P	C	O	
Industry and competitive risks	*Own energy technology growth/demand rate*	As demand for energy technology being used grows, or as it matures further it can greatly impact technology component availability and cost, ease plant expansion on current site, increase developer's experience with a given technology thereby lowering capital cost, etc.	P	C	O	
	Other energy technology growth/demand rate	As other energy technologies grow in maturity or demand, it can have both positive impact (such as reaction in technology advancement of mechanical parts or workers' know-how) and negative impact (such as increased competition over same resources) on the project	P	C	O	
	Supply conditions	Shortage, delay, poor quality of equipment availability and material supply, or other supply chain disruption		C	O	
	Fuel supply	Risk that fuel supply will be unreliable, resulting in inability to generate energy in a predictable and dependable manner			O	
	Costs	Risk of changes in cost for key input factors such as labor, modules or construction material costs		C	O	D
	Distribution	Transmission system access or reliability			O	
	Credit	Inability of developer or electricity off-taker to meet payment obligations	P	C	O	
	Fuel prices	Risk that price of fuel used to generate electricity will exhibit variability resulting in an uncertain cost to generate electricity			O	
	Infrastructure	Risk related to reliance on transport routes to site, such as roads, ports, as well as stability of electricity availability during construction of the plant	P	C	O	D
Project risks	*Developer expertise*	Risk resulting from performance of project developer, such as related to key personnel (lack or departure of qualified staff), project management, and technical ability to execute on plans	P	C	O	D
	Contractor performance	Risk of having to intervene (through renegotiation of contract, added workers, or increased supervision) as contractor (or sub-contractor) turns out to lack expertise in development, has low productivity, imposes human errors, or otherwise does not perform as per contract		C		
	Design quality	Risk of power plant design, drawings and specifications not being issued on time, being defected, frequently changed, or scope incorrectly defined	P	C	O	

Safety	Risk of accidents during construction or other safety issues during operation		C	O	
Operator performance	Risk of the O&M contractor not managing the facility as per contract (counterparty risk), or staff burn-out which will result in low efficiency and increased risk of accidents and equipment damage			O	
Technology performance	Unpredicted technical problems in construction or risk of components generating less electricity over time than expected		C	O	
Site conditions	Unforeseen site conditions resulting in increased site preparation or power plant construction work		C		
Environment	Risk of environmental damage caused by the power plant (pollutions or nuisances), including any liability following such damage		C	O	D
Communication	Inefficient operational communications or co-ordinations amongst all stakeholders, or poor communications with public can result in unexpected delays	P	C	O	D
Reputation	Any project stakeholder may suffer reputational risk if their brand names are associated with project related damages or perceived mismanagement		C	O	
Contract negotiation, partner conflict/failure	Risk of delays in resolving disputes or contractual issues, or that a party to the contract will default on the contract, for example by entering into bankruptcy		C	O	
Design changes from owner	Unclear requirements, or the need for developer and constructor to adjust to design changes requested by owner after contract has been agreed upon		C		

Table 3.2 Risks general to power plant development projects[35]

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[35] Source: This table was built using empirical and secondary data, input from various industry experts, and literature review on risk. Sources of references include the report *Financing Instruments for Renewable Energy* (Lindlein & Mostert, 2005).

As Table 3.2 shows, nature of risks in a power plant development project is influenced by many factors, ranging from project design to economic and financial situation worldwide. Each year different surveys are done to try to highlight which are key risks of concern. Often these surveys are supported by major insurance companies concerned that risk managers may not be aware of various liabilities, and may not be adequately covered for them. As insurers cover companies against losses ranging from property damage to performance failures to litigation, they have an interest in understanding their clients' level of awareness and identifying opportunities for education on these risks (Ceres, 2010). By understanding risk concerns and how clients anticipate risks, insurance industry is in a better position to adapt and develop products to provide more specific and comprehensive coverage against these losses. Results of surveys like these need to be taken with precaution, as they tend to be highly biased towards information the respondents choose to reveal. Respondents who chose to participate in surveys as these may be those individuals with the greatest personal interest in the results or those who have "nothing to hide", or responses may be driven by political pressure not to reveal information sensitive to their corporation.

As was discussed in Section 2.2 the risk profile for the power plant development project varies considerably depending on factors such as project's size, location and energy technology used. Diagram 3.1 shows how different risks are distributed throughout the development lifecycle and which risk factors will depend on type of energy technology used[36]. The shape of the line that indicates the risk profile throughout the development lifecycle will vary considerably from one project to another, as magnitude of risks at each development phase varies (see further discussion on modeling of a project risk profile in Section 4.6).

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[36] Note that the diagram shows at which phase risk is likely to impact the development project, not in which phase these risk factors impact decision making regarding the project execution.

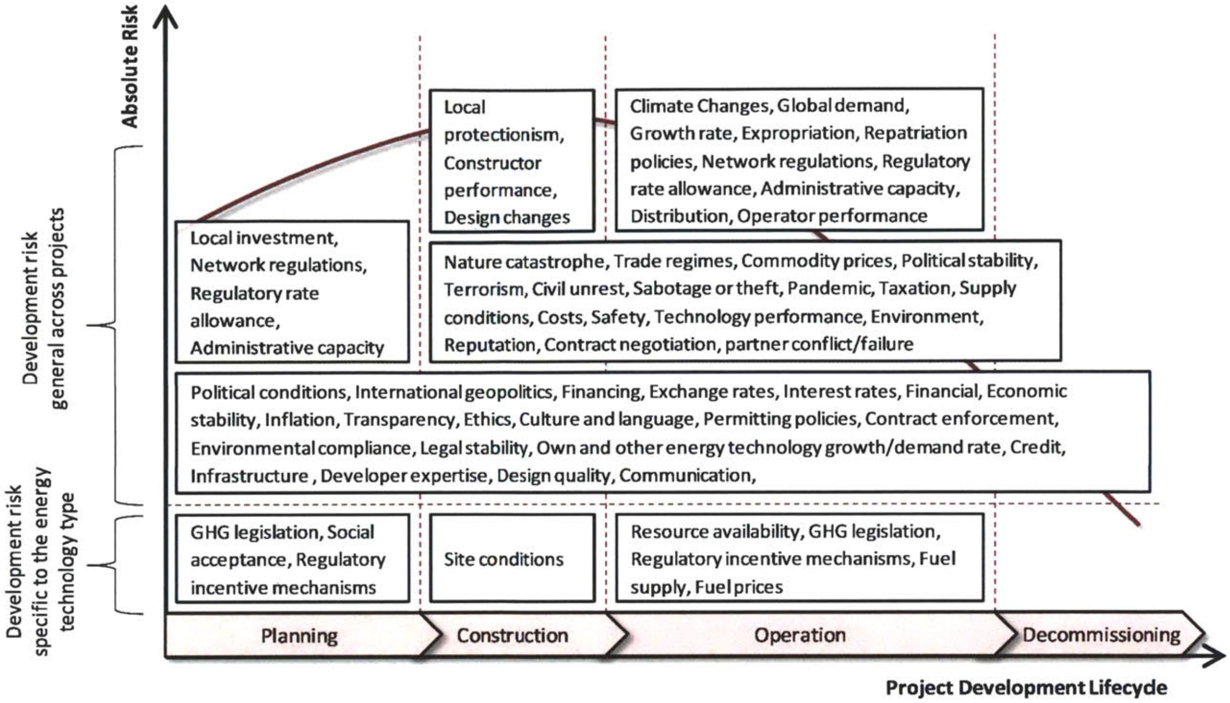

Diagram 3.1 Distribution of risks throughout development lifecycle

The following sections will discuss in more details how choice of energy technology will shape development risk profile of the project.

3.1.2 Risk factors specific to renewables

As was discussed in Section 2.1.1 renewable energy projects are in many ways different from conventional energy projects. They're dependent on localized resources which tend to be in remote locations, and require a long permitting process. Their risk profile is quite different as well, usually with a high risk at pre-construction phase, which coupled with lower financial returns can cause financing difficulties. Followed are few of the key characteristics of renewable energy projects that generally differ from conventional energy projects, and change the development risk profile:

- **Remote location:** Renewable energy projects are often located in remote locations because of their dependence on localized resources. This can increase cost and complexity of the projects due to development related cost (such as high Engineering, Procurement and Construction (EPC) costs where labor must be flown in and accommodated in construction camps), as well as cost of transmission and other infrastructure. This can also introduce challenges due to environmental impact (visual impact or disturbance of land and wildlife) which can make social acceptance difficult.

- **Resource availability:** Renewable energy projects need to rely heavily on resource availability data in their project planning. It can bring a considerable risk to the project if resource availability turns out not to be as measurements for feasibility studies indicated.
- **High capital cost:** Renewable energy projects are more capital intensive per unit of output (though they have lower operating costs). They are smaller in scale than conventional energy projects and yet require significant development resources i.e., they have a higher ratio of development cost-to-total project cost (UNEP, 2011). For that reason, some countries still view renewable energy projects as being off their budget, and others are quick to abort any plans to support those projects when budget is low.
- **Regulatory environment:** Most renewable energy projects are highly reliant on stable regulatory environment, and governmental support mechanisms, and can suffer a substantial damage from regulatory changes during development of the project.
- **High administrative costs:** Renewable energy projects are generally smaller in scale in terms of physical size as well as financial returns, and tend to be unattractive prospects for commercial lenders and insurer because of the administrative costs associated with risk assessments, loan processing and insurance for such projects (SEFI, 2004).
- **Financing difficulties:** Financing renewable energy projects can be challenging. According to the Sustainable Energy Finance Initiative, attracting the financial interest of international lenders and insurers generally requires a minimum project size of EUR 10 million, particularly when the project location is a developing country (SEFI, 2004).
- **Intellectual Property Rights (IPR):** Some of the early stage renewable technologies may be concerned about protection of IPR, especially for projects in developing economies where legal frameworks continue to evolve and enforcement of IPR remains patchy (UNEP, 2011).
- **Social acceptance:** Some of the institutional risks faced by renewable energy projects are difficulties in social acceptability, such as for large hydroelectric power projects, large wind and solar farms.

3.1.3 Risk factors specific to energy technology

As Diagram 3.1 shows, degree of exposure of some general risk factors varies considerably given the energy technology. Table 2.3 gives an example of variation of perceived exposure of some of the key risk factors.

	Exposure to risk					
Energy technology	Fuel price	Permitting and licensing	Grid connection	Construction time	Social acceptance	Technology risk
Biomass	H	L	L	M	L	M
Geothermal	N	L/M	M/H	H	L	M/H
Hydro small	N	L	M	L	M	L
Hydro large	N	H	L	H	H	L
Nuclear	H	H	L	H	H	H
Oil and Gas Thermal	H	H	L	M	H	L
Solar	N	L/M	M	L	L	H
Wind	N	M	H	M	H	M

Degree of exposure is labeled as such: H = High, L = Low, M = Medium, N = None

Table 3.3 Degree of project exposure to common risks for various energy technology types[37]

The following sections describe in more details main risks which are specific to the energy technology of the power plant. They also discuss key risk management approaches which are available to avoid, control or transfer that risk or if that risk is generally accepted (risk management methodologies are discussed in more detail in Section 3.3).

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[37] This table is developed using empirical and secondary data. The degree of perceived exposure to these risks varies from one project to another. This table should therefore only be used as a general example.

3.1.3.1 Biomass

By the end of 2010 an estimated 62 GW of biomass power capacity was in place globally, with significant increases seen in a number of European countries, the United States, and in China, India, and several other developing countries (REN21, 2011). The main risks specific to a power plant using biomass to produce electricity include:

- **Fuel supply availability:** Many projects have had to be cancelled as a result of risks directly connected with the supply of biomass material in a stable and sufficient way (SEFI, 2004). One of the reasons for interruption to the biomass fuel supply chain is related to costs of transporting.
  - Risk control: Rather than relying on one large supplier of biomass fuel, developer should use medium sized, regionally located companies.
  - Risk transfer: Fuel supply risk can be transferred through contractual agreements entered into at the planning phase.
- **Resource price variability**: Fluctuations of biomass fuel price impose risk to operation of the power plant through instable variable cost. Environmental liabilities associated with fuel handling and storage can also pose a risk to a biomass power plant.
  - Risk transfer: Fuel price risk can be transferred partially or completely through long-term contracts with fixed prices with suppliers.
- **Siting issues:** There is variable awareness and understanding of biomass in different regions. This can cause local push backs in the power plant permitting process which needs to be managed in order to minimize cost and time commitments.
  - Risk control: The local community needs to be educated and their benefits and drawbacks need to be managed. Local information should be integrated into project design.

3.1.3.2 Geothermal

Geothermal energy is an inexpensive reliable source of clean renewable energy, developed mainly where there's high grade resources and sufficient policy support. Unlike other renewable energy sources, geothermal power plants serve as base load power. There are however large entry barriers to geothermal development, due to unique risk profile and high upfront cost. Therefore, despite advantages over other renewable energy sources, it is challenging to finance geothermal projects before resource has been fully verified. Geothermal power plants have a relatively long lead time from concept to production. This long lead time, coupled with the high upfront risk, makes it hard for geothermal energy to compete with other green energy sources at times of low gas prices and with wind and solar having considerable lower lead times. Because of these long lead times geothermal developments rely less on government incentive as those are generally short term. That makes geothermal investments less vulnerable to the regulatory risk of changes in energy subsidies than other renewable projects which have become more reliant on such support, such as wind projects. The main risks specific to geothermal power plant developments include:

- **Exploration risk:** The most critical risk for geothermal power plants is at the exploration phase when determining the availability of the resource and feasibility of the project. The exploration risk is the risk of not successfully achieving economically acceptable minimum levels of thermal water production (minimum flow rates) and reservoir temperatures. Before drilling begins, there can be high uncertainty about the quantity and temperature of geothermal resources, and as a result there is high uncertainty about drilling cost. According to the United Nations Environment Programme, it is estimated that detailed surface exploration studies leading to the pre-feasibility stage, may result in expenditure up to USD 1 million, which is at risk (30% probability of failure) through not identifying a useable heat resource (UNEP, 2007). Due to the risks associated with the assessment of resource size and production capacity, planning approvals can be difficult to obtain.
  - Risk transfer: The risks associated with exploratory and drilling cost have in some cases been transferred through partial risk guarantees and contingent grant facilities (this has been done successfully in markets such as Germany). Insurance companies have also developed a product called Discovery Risk Insurance to address this risk. Insurance products available for geothermal exploration risks are not always applicable, as they

are often adapted from conventional oil and gas exploration risk insurance which is quite different.

  - Risk control: This risk can be minimized (although not eliminated) if sufficient time is spent with specialists during pre-planning of the project. Quality of the expertise is of critical importance and experienced partners have to be involved to evaluate the adequacy of the project location (SEFI, 2004).
  - Risk control: In cases of smaller developments it may be applicable to use fewer or less costly shallower wells, to reduce overall cost associated with exploration risk.
  - Risk control: Stimulation technology is still unproven but can reduce exploration risk.
  - Risk control: By incorporating real options in design of a geothermal power plant, the project is better prepared to meet risk of inaccurate resource assessment.

- **Drilling technology risk:** Technology risk is mainly associated with the geothermal drilling which unlike the drilling risk in the oil and gas industry poses an added risk on account of the higher temperatures, corrosive fluids, harder rocks, unproven stimulation technology, and technical elements of integration of geothermal electricity. Seismic surveying used in the oil and gas industry is therefore not always transferable to geothermal resources making technology risk assessment harder for investors and insurance companies.
  - Risk transfer: These risks are generally transferred through partial risk guarantees and contingent grant facilities. Insurance companies have also developed a product called Discovery Risk Insurance to address this risk.
- **Experience technology risk:** In different locations technology risk may be higher due to lack of long term experience of certain aspects of the technology, which can impact availability, reliability, spare supply, and maintenance capabilities.
  - Risk control: This risk can be reduced by strategically partnering with more experienced developer, or by seeking consulting input from industry experts.
  - Risk acceptance: Most of that risk needs to be accepted, although it’s important to review and adjust given market environment.

3.1.3.3 Hydro

Hydro power plants are the most technologically mature source of green power, and tend to be only moderately difficult on the engineering side. Risks associated with a hydro power plant development vary greatly depending on size and location. Smaller hydro power plants (or run-off-the-river plants) are more socially acceptable for typically being environmentally benign, for not altering river flows or impacting existing ecosystems. They may however suffer from operational risk factors, such as flooding or drought. Large hydro power plants however pose far more challenges in development, can be more controversial, often alter water availability downstream of the dam, may need relocation of nearby population, and can impact existing ecosystems. Main risk considerations for hydro power plants in general include the following:

- **Resource availability risk**: Hydro power plants need to rely on availability of water resource, which can be highly variable given season and site location. This risk applies to plants of all sizes although its nature and management differs. Run-off-the-river plants typically don't store their water supply, and are therefore highly vulnerable to seasonal fluctuations. Large hydro power plants typically dam the water flow, creating a reservoir, therefore reducing risk of variable water flow. However, their control of the water flow may be regulated, enforcing them to let water pass for downstream needs regardless of the impact on the power plant operation.

- **Social acceptance risk**: Social acceptance varies depending on the plant's impact on the environment and society. Impact of that risk depends on location, but can typically result in public opposition ranging from protests affecting development progress, or damaging developer's reputation, to failure of securing appropriate development permits and approvals.

  - Risk control: Social acceptance risk is addressed in various ways depending on applicability. Community outreach programs are an important factor in keeping society informed and avoiding misperception of the project's impact.

3.1.3.4 Nuclear

Nuclear projects are large technically complex and capital intensive projects, and have a uniquely high risk profile. They have long lead time, and pose high financial, social, and institutional risks. Market risks tend to be lower because sponsors are usually network operators that can forecast and have a need for power (Lessard & Miller, 2001). Main risk considerations for developers of nuclear power plants include the following:

- **Project delivery risk:** Nuclear projects have a long lead time and pose high financial risk. Occurrence of an incident causing loss or permanent shutdown of the facility during any stage of development, and accompanying substantial damage liability, bring risk of a complete loss of investment. Political support and public acceptance are key requirements for implementation of nuclear energy programs, but complex regulatory environment may with a clear and stable commitment to nuclear energy in national energy policy. Nuclear plants also tend to be subject to extensive public scrutiny which can increase project delivery risk. The project construction leaves little room for innovation, so construction risk is mainly downside.
    - Risk control: Standardized design can reduce project delivery risk (WNA, 2008).
    - Risk control: Stability in regulatory process is vital to successful project delivery (WNA, 2008). Project delivery risk which can result from political or societal risk factors can be mitigated through public debates and hearings, by gaining cross party political support, by emphasizing environmental advantages of nuclear or by developing waste management policy with government (WNA, 2008).
    - Risk control: To reduce risk related to delays and cost increase resulting from on site operation and delivering of material the developer can consider investing in the supply chain infrastructure near the site.
    - Risk transfer: Downside construction risk can be allocated through debt financing. Commercial insurance solutions are also well established.
- **Operations risk**: Safety in operation is an important risk aspect to a nuclear plant. Operator needs to have right skills and attitude, following a management system that deals with safety, health, environmental, security, quality and economic requirements through lifetime of the facilities. Although primary reliance is placed on the operator to ensure safety, a legal

structure as a foundation is needed, and regulatory staff needs to be competent with appropriate access and support (IAEA, 2007). In addition, operation can be greatly impacted not only by nuclear events of the plant, but nuclear events elsewhere[38].

  - Risk control: There is an urgent need to strengthen the nuclear workforce to meet future demands, by investing in education and training (IEA, 2010).
  - Risk control: The risk can be reduced by using internationally accepted designs, and building on existing nuclear sites (WNA, 2008).

- **Financing risk:** Financing the very large investments needed to build nuclear power plants is a major challenge, which in most cases requires government support (IEA, 2010).

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[38] A recent example is the Fukushima Daiichi nuclear disaster that followed earthquake and tsunami in Japan on March 11, 2011. This triggered a slowdown of nuclear power development worldwide, making it harder for developers to make the case for building new plants, not only because of public opinion on safety, but also because of low price of natural gas. According to Professor Steve Thomas, from 2008 to 2010, construction work began on 38 reactors around the world, but in 2011-12, there were only two construction starts.

3.1.3.5 Oil and Gas Thermal

Oil and Gas Thermal is mostly a mature energy technology, and depending on source of fuel poses little or no technical risk, but can face difficulties mitigating regulatory risk, and uncertainty in impact of various emission controls, the Kyoto protocol, carbon trading, etc. Main source of risks for these types of power plants is linked to choice of fuel, whether fossil fuel (coal, oil, conventional gas) or more environmentally friendly fuel (such as natural gas and biogas). Source of fuel may also pose political risks where fuel supply chain is influenced by geopolitical balance in the market. In addition, these projects are increasingly becoming more at risk of demand changes, due to competitiveness with renewable energy, as more alternative energy sources are developed, support/stimulus is given to renewable energy providers, uncertain development of carbon trading, Kyoto protocol, etc.

- **Environmental compliance risks**: All thermal plants face environmental compliance risks, stemming from both existing environmental regulations and uncertainty over possible future regulations. These are divergent risks and take different strategies to overcome or to mitigate.
- **Social acceptance risk**: Fossil fuel plants typically face social acceptance risk from environmental conservatives, due to their carbon emission.
  - Risk control: Projects can be designed to be socially acceptable if they provide central heating to cities or come with regional development packages (Lessard & Miller, 2001).
  - Risk control: Risk of social acceptance can be controlled through choice of fuel, such as using natural gas or converting conventional fossil fuel plants to use renewable sources of fuel such as biomass.
- **Fuel source risks:** Common to all these plants are risks related to the fuel, such as fuel price risk (price variability and uncertainty over future costs), and their supply and demand which can be controlled by managing exposure through diversification.
  - Risk transfer: When project is viewed in a closed system those risks are out of control of the developer, and most dominant methodology in managing it is through hedging.
  - Risk control: When project is viewed in an open system, much of supply and demand risks is broad, systematic, but controllable, and can be managed by diversifying exposure through portfolios or projects. Some of external risk on demand and supply are interconnected.

3.1.3.6 Solar

Utility-scale solar projects are generally categorized in one of two basic groups: concentrating solar power (CSP) and photovoltaic (PV), with PV projects making up the majority of operational plants, as well as plants under development (NREL, 2012).

- **Operational risk due to force majeure events**: Once a site for a large scale solar plant has been selected the meteorological data has been analyzed which should leave little or no resource risk to the project. The plant can however be impacted by weather damages, or force majeure events.
  - Risk transfer: Weather risks can be mitigated using weather futures.
- **Operational risk related to technology**: Solar plants may experience operational risk due to failure arising from the technology novelty, breakdown of panels or other components, or loss of efficiency, which can result in an uncontrolled downtime of electricity generation.
  - Risk transfer: The risk of operation being affected due to panel breakdown is typically covered through a performance guarantee (e.g. up to 25 years) or other forms of warranties provided by the solar panel manufacturer.
  - Risk avoid: The risk of operation being affected due to component breakdowns can be eliminated by using standard components with easy substitution.
- **Theft or vandalism**: Though manufacturers offer solar panels warranties and can even guarantee their electricity generation, increasingly some form of physical protection that prevents panel removal is needed. Indeed, some insurers now demand that security measures are in place before they will cover an installation (Lawson, 2012).
  - Risk control: Involving the local community is the best way to prevent theft and vandalism, according to a recent study by the Alliance for Rural Electrification (Lawson, 2012). Bringing all the stakeholders together is fundamental to any sustainable, successful and secure solar installation in a remote location where they can enforce the rules and prevent vandalism and other damage.

3.1.3.7 Wind

According to the American Wind Energy Association (AWEA), prices for wind are mostly fixed by 20 year PPAs, and are therefore not subject to price risk as a result of lowering market prices (such as due to low gas prices) and even when prices for wind get a little higher the utilities still want to keep wind farms in their power plant portfolio (Bode, 2012). When land availability is plentiful, there is a trend toward increasing size of individual wind projects driven mainly by cost considerations, including infrastructure such as substations or grid connection points as well as licensing and permitting costs (REN21, 2011). As wind farms are not subject to changing fuel prices their production cost is quite predictable. According to International Energy Agency, wind power can now be competitive where resource is strong and when cost of carbon is reflected in markets, but as technology develops further, and deployment and economies of scale improve, cost is expected to decrease by as much as 23% to 2050 (IEA, 2010). As wind technology matures, so does technology reliability. Some main component breakdowns (such as control unit, electrical parts or the pitch control) still occur, which can be of risk to the operation (SEFI, 2004). The following highlights key development risks for wind farms:

- **Operational risk related to resource availability**: Critical to wind farm operation is resource availability, which impacts economic efficiency of the plant.
  - Risk transfer: Holding a portfolio of base load and peak load power plants reduces the financial uncertainty, as well as the variability of energy production in a physically connected system.
  - Risk control: It is essential to base site selection on a good quality resource availability analysis on wind frequency. Resource risks can be minimized if wind measuring systems are installed early enough (data gained during a one-year period is not sufficient) or historic data is available over a long-term analysis period (SEFI, 2004).
- **Political and regulatory risk of changing energy subsidies**: Biggest uncertainty for wind farms is related to political and regulatory stability, such as risk of losing tax breaks[39]. Such risk can urge developers to speed up development which can be costly and introduce other risks, resulting from design oversight, push backs from local communities, or failure to secure permits.

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[39] Bloomberg New Energy Finance estimate that as wind credits in the United States expire (scheduled by the end of year 2012), it may result in installations of wind turbines to fall as much as 95% to 500 MW (Bloomberg, 2012).

  - Risk transfer: Wind farm developers need insurance to address the unique exposure of political and regulatory risks they face, covering both physical property and potential liability exposures.

- **Societal acceptance resulting in siting issues:** Wind farms have in recent years started facing increased opposition from local communities who complain over unexpected side effects to their health which they blame on nearby wind farms. Many studies have been conducted as a result of those claims, yet no proof has been found. Visual impact of wind farms has also faced opposition with diverging views on landscape preservation.

  - Risk control: When site location that has been agreed upon faces opposition in permitting, it is important to adapt to local context, manage local benefits and drawbacks, and involve local residents in the process (Raven, Mourik, Feenstra, & Heiskanen, 2009).

3.2 Risk Assessment

With a list of risks that have been identified as potentially affecting a power plant development project, the next step is to assess magnitude and seriousness of each identified risk (such as risk probability assessment, risk impact assessment, and risk time frame assessment). As the list of risk assessment tools in Appendix 2 shows, majority of the risk assessment that is carried out for power plant development projects is qualitative or semi quantitative, and relies extensively on expert judgments.

3.2.1 Quantitative Risk Assessment

Quantitative risk assessment is best done by combining observed historical data and expert judgment. It is evident that assessment quality depends highly on quality of the data. Often data can be challenging to locate or not available, and can be subject to heuristics, biases and/or anchoring[40]. This applies particularly to new energy technologies, and projects in developing countries. Commonly used quantitative risk assessment tools are subjective probabilities coupled with event tree analysis (fault trees, probability trees), as well as additive models. Sensitivity analysis is also a useful tool in determining which variables have greatest influence on risks. It however, does not reflect diversification, says nothing about the likelihood of a change in a variable, and ignores relationships among variables.

3.2.2 Qualitative Risk Assessment

For power plant development projects, a qualitative risk assessment approach is often an easier and a more practical tool because of access to experts in the field. Some of the simple qualitative tools include classifying risks by grouping them based on their shared characteristics, which shows the relationships among risks. This can identify duplicate risks as well as help simplify the list of risks. It can also be useful to use Pareto Diagrams to prioritize risks. The diagrams show sources of risk in descending order which makes explicit those activities that have greatest effect on project completion date or cost, and that

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[40] Anchoring is a cognitive bias that describes the common human tendency to rely too heavily, or "anchor," on one trait or piece of information when making decisions.

therefore require greatest management attention. Simple stratification methods, such as heat map or risk matrix, can then be used to assign the risk on a green/yellow/red or high/medium/low rating scales, which can be used to assess likelihood and consequence so that the two values can be multiplied together to get a risk score.

The Analytical Hierarchy Process (AHP) is effective in power plant development projects, because risk factors are many, and the ability of humans to assess many factors at the same time is very limited. Therefore, it is necessary to break down the numerous risk factors into small groups, so that people can easily assess these small group risk factors step by step, and then combine them to obtain the whole risk assessment. The AHP method assesses relative priority or importance of each risk factor by pairwise comparison of all factors with respect to certain criteria.

Graphical representations of relationships and interrelationships between a risk and its associated causes are also very useful in these projects. Influence diagrams, and graphs analyzing cause and effects (Ishikawa, fishbone diagrams) can provide additional insight into their dependencies, as it encourages consideration of all possible causes of the risk, rather than just the ones that are most obvious. Setting up a system or process flow chart can also show how various elements of system interrelate and mechanism of causation. This can sometimes help identify a risk that may have slipped through the cracks. Risks can then be fully examined through strengths, weaknesses, opportunities, and threats (SWOT) analysis and with the help of stochastic simulation (Monte Carlo).

Commonly used methodology to assess the risk related to cost of the project, is Value at Risk (VaR), which is based on basic methodologies: historical simulation, delta-normal approach, and Monte Carlo simulation. The VaR methodology attempts to summarize downside risks using a single number which represents worst possible monetary loss over a target horizon with a given probability. Another tool commonly used to determine risks in project completion time is Program Evaluation and Review Technique (PERT) chart. PERT charts are dependency and probability schedules that can be used to analyze impacts of changes in risk status and mitigation plans.

It is very important for these projects not to forget to assess risks of group enactments or team operation. This can be done through project simulations, in which managers and other project participants perform project activities in a virtual environment before undertaking them on the project. This type of simulation may or may not be supported by computers; emphasis is not on computer models but rather on interactions of participants and effects of these interactions on project outcomes.

3.3 Risk Management

Correct response to risks is the most important stage in risk management. Each risk should be allocated to the party that can best control or manage it. Boundaries between different channels that risk management procedures can be directed to are often a little blurred, but can be generally grouped into these categories: Avoid, control, accept, and transfer.

- **Avoid:** Risk avoidance includes not performing an activity that could carry risk. It may seem the answer to all risks, but avoiding risks also means losing out on the potential gain that accepting (retaining) risks may have allowed. Risk avoidance is generally recognized to be impractical as it may lead to projects not going ahead or contractor submitting an excessively high bid for a project.

  Risk management terms of this category: *Avoid, eliminate*

- **Control:** Risk control may span a wide range of methodologies, such as the use of alternative contract strategies, use of training programs, different methods of construction, prototyping, project redesign, more detailed and further in-depth site investigation, and technical due diligence.

  Risk management terms of this category: *Control, reduce, shape, mitigate*

- **Accept:** Relative superiority in risk bearing may arise from any of these three reasons, a) some parties may have more information about particular risks and their impacts than others, b) some parties or stakeholders may have different degrees of influence over outcomes, or c) some investors differ in their ability to diversify risks. These risk bearing abilities will differ from one location to the other, as players may have strategic advantage in a certain location due to a successful prior experience there so they can better estimate and plan for that risk factor. In other cases, risk retention becomes the only option where risk prevention or transfer is impossible, avoidance is undesirable, possible financial loss is small, probability of occurrence is negligible and transfer is uneconomic. True self insurance falls in this category. Risk retention is a viable strategy for small risks where cost of insuring against risks would be greater over time than total losses sustained. All risks that are not avoided or transferred are retained by default.

This includes risks that are so large or catastrophic that they either cannot be insured against or premiums would be infeasible.

Risk management terms of this category: *Accept, retention*

- **Transfer:** Various contracts can be used to transfer risks to be borne. Different players can hedge their currency and interest rate exposure, enter into long-term purchase or supply agreements, require guarantees, and purchase various forms of insurance.

  Risk management terms of this category: *Transfer, hedge, shift, allocate, outsource, insure*

Table 3.4 gives an overview of some of the typical risk control and transfer instruments that can be associated with risks that were identified in Section 3.1. This table leaves out those risks which were identified, but are typically left for the developer to accept. That includes risks resulting from international geopolitics, lack of transparency, ethics, culture, and language.

This is a comprehensive yet not a complete overview of those risk management instruments available, as environment for managing risks continues to change, and new approaches emerge as experience brings to the market a better understanding of how to best manage risks. Availability of instruments listed here also varies from one project to another, depending on various factors such as energy technology, site location, and type of developer. In general, it can be said that these risk management instruments are similar regardless of the size of the project, in particularly for risks which can be mitigated through financial risk management instruments (such as completion risk, performance risk, financial risk, political risk, and force majeure risk). The difference is mainly with respect to magnitude of respective risks.

	Risk factor	**Risk control instrument**	**Risk transfer instrument**	**Bearer of risk allocation**
World system risks	*Political conditions*		Political risk insurance	Commercial insurer
	Nature catastrophe		Weather insurance, force majeure insurance, catastrophe bonds	Commercial insurer
	Resource availability	Resource modeling, resource sourcing	Resource availability insurance	Commercial insurer

World price risks	*Commodity prices*	Diversify through portfolio of projects[41]	Commodity markets (e.g. futures market) can be used to absorb commodity price risk	Commodity markets
	Exchange rates	Diversify through portfolio of projects	Financial markets can be used to hedge currency risk, e.g. exchange rate SWAP	Financial markets
	Interest rates	Diversify through portfolio of projects	Financial markets can be used to hedge interest rate risk, e.g. interest rate SWAP	Financial markets
Country risks	*Political stability, terrorism, civil unrest*	Strategic partnering	Investment guarantee	Government (MIGA)
			Political risk insurance	Commercial insurer
	Financial, economic stability, inflation	Involve influential investors, such as the World Bank	Investment guarantee	Government
			ECA cover	Export Credit Agency
	Sabotage or theft	Community involvement, local partners	Standard insurance	Commercial insurer
	Expropriation or taxation		Investment guarantee ECA cover	Investment Guarantee Export Credit Agency

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[41] If there is high correlation across countries it suggests that when international portfolios are well diversified, the risk factor component of overall risk will be effectively diminished.

Institutional & regulatory risks	*Permitting policies*	Due diligence process		
	Regulatory incentive mechanisms	Adopt non-subsidy driven business models		
	Regulatory rate allowance		Long term PPAs Guarantee by Government	Grid/Power Distributor Government
Industry & competitive risks	*Supply conditions*		Commodities derivatives	
	Fuel supply		Delivery guarantees	Commercial Insurer
	Credit		Guarantee funds	
	Fuel prices		Standard derivative products	
Project risks	*Contractor performance*	Use contractors with previous construction experience	Completion guarantee; risk is transferred through monetary damages for delay in completion	Contractor
		Use strong project management, incentivize good performance, penalize bad	Turnkey contracts; fixed price and scope, with contractors accepting much of the capital cost overrun risk	Contractor
			Certain delay risks can be covered by insurance, such as Construction All Risks (CAR), Erection All Risks (EAR), or Surety Bonds	Commercial Insurer
	Operator performance	Use incentives for good performance and penalties for bad	Long-term O&M contract; operators may need to contractually guarantee minimum performance levels	Operator

	Use experienced creditworthy service providers	The insurance markets may cover the risk of certain events affecting operating performance.	Commercial insurer
Technology performance	Use a proven technology	Supplier performance guarantee	Commercial Insurer
	Use a proven technology provider	Warranties; risk is transferred through monetary damages for performance shortfall	Supplier

Table 3.4 Risk control and transfer instruments[42]

However, as is to be expected for any development project, evidences show that there is a gap between the existing risk management techniques and their practical application. The implication is that the project participants either fail to or have no incentive to undertake research as part of the strategies to reduce the risks associated with their activities. The following sections give an overview of commonly used instruments to transfer the risks, namely a) third party contractual instruments, b) financial architecture instruments, and c) insurance instruments, as well as use of capital and operational reserves.

3.3.1 Third party contractual instruments

It is important for developers, especially with projects in unfamiliar markets, to consider whether risk can be transferred through forms of partnering, such as through Strategic Partnerships, Public Private Partnerships, Joint Ventures, or by use of Foreign Direct Investment (see discussion in Section 2.3.2). By undertaking the project with another firm, part of the risk is transferred through equity. Joint Ventures do not need to be permanent, the shares of the partners may evolve over time and the Joint Venture may eventually be dissolved.

For wholly owned projects, any transfer of risk is limited to that which can be achieved through contracts. Innovative contractual structures can transfer risks between the project, its sponsors and

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[42] Source: Information in this table is derived from secondary and primary sources, namely: a) through interviewing energy and power plant development experts and practitioners, and b) literature review, including (Lindlein & Mostert, 2005), and (Lessard D. , 1996)

contractors, loan and debt providers, equity holders, the government, insurance agencies, and in some cases, multilateral organizations. Table 3.5 gives an example of how developers can use third party contractual arrangements to help distribute the various risks.

Type of contract	Risk transferred	Risk barrier	Description of risk transfer
Facility Management Contract	Completion risk	Contractor	Includes guarantees that the project facility will be completed on time and that it will be built and operated to desired specifications.
Working Capital Maintenance Agreement, or Cash Deficiency Agreement	Capital risk	Lender	Lending banks ensure adequate funding for the project in its early years.
Turnkey Contract	Construction risk	Contractor	Specifies a fixed price and penalties for delays, and usually requires the contractor to post a performance bond.
Long Term Supply Contract (such as Fuel Supply Agreement)	Supply risk	Supplier	Contract purchase price will often be fixed, or indexed to inflation or some other variable that affects project revenues.
Long Term Sales Contract (such as Power Purchase Agreement)	Revenue risk	Customer[43]	These contracts often include a take or pay clause or throughput agreements that oblige the customer to make some minimum use. This gives customers incentive to estimate their demand for the project's output as carefully and honestly as possible.

Table 3.5 Third party contractual methods to transfer project development risk

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[43] This revenue risk transfer applies in particularly when there are only a few customers for the power plant, such as when main electricity off-taker is a high energy consuming industry facility. The type of customer will guide the price structure of the contract. Prices are often indexed to power plant's costs, and where there is considerable currency uncertainty, prices may also be indexed to exchange rates, or to key commodity prices which customer may be reliant on.

3.3.2 Financial architecture instruments

Project financing is another way to shift a variety of project risks to those parties best able to appraise and control them. It involves creating a separate legal and economic entity with primary role of setting up an organizational structure and obtaining necessary financial resources to develop and manage a project. The main, and crucial, distinction from conventional financial structures is that repayment to debt and equity providers depends solely on the capacity of the project to generate cash flows, with typically no recourse to the sponsor's balance sheets or assets. Project financing is suitable for power plant development projects when they involve established techniques, as the party to a project will agree to bear a given risk at a non prohibitive price only if it has a clear understanding of that risk. Project finance is less appropriate for projects that involve complex or untried techniques.

Risk bearer	Type of instruments offered	Risk addressed
Export Credit Agencies & Bilateral Agencies	Political Risk Insurance Project Finance Loans Customized Financing packages	Non-commercial risks and a range of financing solutions
Multilateral & Regional Financial Institutions	Breach of contract cover A-loans, syndicated B-loans Portfolio Equity from funds Political Risk Guarantee Partial Credit Guarantee	Multiple non-commercial and commercial risks
Private Financial Institutions	Commercial Bank Loans Infrastructure Funds Quasi Equity (Preferred Shares) FX, Commodity & Interest Rate Derivatives Convertible Loans & Bonds Fixed Coupon Bonds & FRNs Securitized Receivables Credit Derivatives & CDOs Weather Derivatives	Commercial risks, including market risk, business risk, and resource risk

Table 3.6 Non-insurance risk management instruments[44]

In addition to financial architecture, financial derivatives are used to engage in transactions to hedge financial exposures to market risks, such as any remaining currency risk, interest rate risk, and commodity price risk (through futures, options, swaps, and non-recourse finance). Investment and

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[44] Source: This table is adopted from secondary data, including (UNEP, 2006)

commercial banks use energy financial markets to speculate on value of a certain commodity, or to offset their risks due to their business relationships with energy firms.

3.3.3 Insurance instruments

Various types of insurance contracts exist, through which developers can transfer risk. For some power plant development projects, especially when a developer does not have global resources to back it up, insurance instruments can be the only acceptable form of risk mitigation. However, insurances are typically an expensive tool to transfer risk so developers generally need to evaluate carefully if they're willing to pay the price for certainty. Cost of insurance depends heavily on magnitude of risks, as well as familiarity of insurance market to handle such risks. Developers of large and/or unique projects may choose to self-insure, when insurance market for such risks is non-existent, or insurances available are incorrectly priced due to insurer's unfamiliarity with the risks.

It is important for developers to select an insurance provider which will help maximize value of the insurance. Insurance companies vary in their advantage in bearing risk, depending on their experience in insuring similar risks, their skill in providing advice on measures to reduce the risk, and their ability to pool risks by holding a large, diversified portfolio of policies (Allen, Myers, & Brealey, 2006). Selection criteria of the insurance provider differ from one developer to another, but should in general include the following:

1) **Lifecycle coverage:** Developers should work with an insurer that provides coverage through each stage of development lifecycle to streamline the risk management process. Using different insurers for each stage could result in coverage gaps.
2) **Small-to-large appetite:** For power plant projects where the energy technology is still growing in maturity or for projects with potential of substantial upscale, developers should look at selecting an insurer who can cover projects of all sizes. That way, relationship with the insurer can grow as the developer's business expands, and complexity cost of selecting a new insurer can be avoided as power plant increases in size.
3) **Range of solutions:** It is important for developers to select an insurer with experience in the energy technology, understand the business in depth, and can accurately assess risks and

common losses. That way they can deliver competitive premium rates, provide sound guidance on best practices, and can speed claims along.

Insurers vary in their willingness to provide insurance. Most governments provide investment guarantees and political risk insurance designed to meet the needs of international investors.

According to OECD, in order for a risk to be "insurable"[45] the technical conditions need to be: 1) Probability and severity of losses should be quantifiable, 2) time at which insured event occurs should be unpredictable when policy is underwritten, and occurrence itself must be independent of the will of the insured, and 3) numerous persons exposed to a given hazard should be able to join together to form a risk community within which the risk is shared and diversified.

Risk transfer product	**Basic triggering mechanisms**	**Risk addressed**
Construction All Risks/ Erection All Risks	Physical loss of and/or physical damage during the construction phase of a project	All risks of physical loss or damage and third party liabilities including all contractor's work
Delay in Start Up/ Advance Loss of Profit	Physical loss of and/or physical damage during the construction phase of a project causing a delay to project handover	Loss of revenue as a result of the delay triggered by perils insured under the CAR policy
Surety Bonds	Non performance by contractor	Ensures completion of project as per agreed terms and conditions
Operating All Risks/ Physical Damage	Sudden and unforeseen physical loss or physical damage to the power plant or assets during the operational phase of a project	All risks package
Machinery Breakdown	Sudden and accidental mechanical and electrical breakdown necessitating repair or replacement	Defects in material, design, construction, erection or assembly
Business Interruption	Business interruption perils insured under the property damage policy	Loss of revenue as a result of an interruption in business caused by perils insured under the Operating All Risks policy

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[45] "Insurable risk" is one of the most basic insurance concepts. It helps define conditions under which the insurance industry will be able, over the long run, to profitably provide insurance that clients will want to buy (OECD, 2008)

Operators Extra Expense (Geothermal)	Sudden, accidental, and continuous flow from the well which cannot be controlled	All expenses associated with controlling the well, re-drilling/seepage and pollution
General/ Third-Party Liability	Liability imposed by law, and/or Express Contractual Liability, for Bodily Injury or Property Damage	Includes coverage for hull and machinery, characters liability, cargo, etc.
Political Risk Insurance	Risk arising from currency inconvertibility, political violence, confiscation, etc.	Provides protection to lenders from political risks.
Force Majeure Insurance	All risks arising from Force Majeure events.	All risks package.

Table 3.7 Overview of traditional insurance products available for power plant development projects[46]

Availability of these insurances varies depending on energy technology and market. While mature energy technologies will have an established basis of industry risk coverage, coverage for newer energy technologies continue to emerge as knowledge of their risk profile develops.

3.3.4 Reserves

As with other long-term capital investment projects, developers will typically set aside amount on their balance sheet that is reserved to meet any large anticipated expenses that may occur in the future. This type of reserve fund is set aside to ensure that the company has adequate funding to finance the project. Some of the different types of reserves include the following:

- **Operating reserve:** O&M reserve or working capital reserve is established to allow a developer to withstand cash flow fluctuations, often based on time between delivery of services and payment for those services. Operating reserve is typically 45 to 90 days of O&M expenses (AWWA, 2004).
- **Capital reserve:** Repair and replacement reserve is established to replace system assets that wear out or become obsolete. Many different criteria: a) typical year of rate-funded capital projects, b) greater than or equal to annual depreciation expense, c) 1% to 2% of total

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[46] Source: This table is developed using empirical and secondary data

original cost of utility assets, d) total system replacement cost divided by assumed useful life of the system (AWWA, 2004).

- **Bad debt reserve:** Most companies keep a bad debt reserve in the expectation that some small percentage of their creditors will not pay them in full. If the bad debt reserve is accurately estimated, then a company's net income will not be reduced when the debts are actually written off as being uncollectable.

3.4 Implementation and Review

The extent of implementation of risk management methodologies discussed in Section 3.3 varies amongst all project participants. Although project size, location, and experience may be a controlling factor, the key barrier to developer's enforcement of risk management methodologies is generally analytical, and may be influenced by one of the following characteristics:

- Inability to understand benefits of risk management efforts.
- Lack of familiarity with the techniques.
- Degree of sophistication involved in the techniques is unwarranted for project performance.
- Lack of time, information, and knowledge.
- Doubts whether these techniques are applicable to the project.
- They require availability of sound data to ensure confidence.
- Vast majority of risks are fairly subjective hence they are better dealt with based on experience from previous projects undertaken by the developer.

Developers seldom formally request risk analysis by contractors, expecting that to be included in their project management practice. However, contractors often enforce their own risk management methodologies regardless of the developer's requests. When not self-enforced, that may often be due to one of the following characteristics providing analytical barriers:

- When the piece of the project awarded to the contractor/subcontractor is not large enough to warrant the use of these techniques or research into them;
- Risk analysis in commercial terms is not always viable on projects;
- They believe project risk management is about people not scientific models;
- Lack of expertise in the techniques.

Developers, who pursue a structured approach to effective management of risks, often use international standards to support their risk management system. Examples of such standards are *"A code of practice for risk management of tunnel works"*, which is developed by the International Tunneling Insurance

Group (ITIG, 2006), and *"ISO 31000 Risk Management Principles and Guidelines in 2009"*, a selection of standards relating to risk management codified by the International Organization for Standardization (ISO, 2009). Aim of the developer is to get a coordinated approach on risk management that will apply to the project as a whole. Risk management system for a particular power plant development project also needs to be fully intergraded with existing processes of the overall corporation, such as:

- Corporation's strategic objectives (see previous example of how investment strategy is coupled with overall corporate strategy in Diagram 2.6).
- Any pre-existing risk management practices and culture at the corporation.
- Corporate policy on communication.

The risk management system also needs to be adjusted to available resources, weighing the overall costs and benefits of adding resources for added risk management efforts.

3.4.1 Incentives and barriers to implementation

Some power plant development projects can be faced with barriers that hinder them from accurately assessing risk, such as lack of historical data, and unprecedented projects for comparison. Table 3.8 gives an overview of some of those barriers, as well as the risk management methodologies that are impacted.

Risk management methodology	**Barrier**	**Applicable to**	**Description**
Transferring risks through financial architecture	Cognitive barriers	Renewable energy projects using new technology	Low level of awareness, understanding and attention afforded to financing and risk management instruments of the technology in renewable energy projects
Transferring risks through financial architecture	Market barriers	Renewable energy project using new technology	Lack of financial, legal and institutional frameworks to support uptake of renewable energy projects in different jurisdictions
Transferring risks through contracts	Political barriers	Renewable energy projects using new technology	Regulatory and policy issues and governmental leadership

Quantitative risk assessment	Analytical barriers	Renewable energy projects using new technology	Quality and availability of information necessary for prudent underwriting, developing quantitative analytical methodologies for risk management instruments and creating useful pricing models for environmental markets such as carbon emissions permits
Quantitative risk assessment	Analytical barrier	All projects	In general, projects are unique and built only once. Although some projects will have data to rely on each project is considerably different from the next, making application of quantitative assessment difficult and projects much more reliant on qualitative assessment from experts.

Table 3.8 Barriers that hinder application of risk management methodologies

In general, application of risk management instruments to renewable energy projects requires financial innovation and a willingness to test new approaches. This in itself is risky, but instead of viewing it as a barrier to applying standard risk management methodologies' practices, it can work as an opportunity in the field to explore other nonconventional methodologies and encourage innovations while gaining experience and confidence in these new markets. Table 3.9 gives an overview of some of the characteristics of power plant development projects that support use of risk management methodologies.

Risk management methodology	Supporting characteristic	Applicable to	Description
Transfer of construction risk through contracts	Construction risk is high	All projects	High risk due to size and complexity of the structure, and involvement of many contracting parties.
Qualitative risk assessment through project simulations	Complexity of network of parties involved	All projects	Large power plant development projects usually involve a temporary project team that is assembled from different companies, countries, cultures, etc.
Qualitative risk assessment	Expertise knowledge	Established energy technology projects	Projects using established energy technology benefit from the availability of highly qualified experts in their field.

Risk transfer through project financing	Large project with established technique	Non-renewable energy projects, as well as hydro, and geothermal	Suitable for large projects whose techniques are well established as the party to the project will agree to bear a given risk at a non prohibitive price only if it has a clear understanding of that risk.
Qualitative risk assessment through System Dynamics Models	Future of carbon taxes	Renewable energy projects	Uncertain development of carbon taxes and possible risk impact on the project can be modeled through System Dynamics Model.
Risk control through real options	Development of stimulus program	Renewable energy projects	In the United States, renewable energy projects are being given substantial support through federal funding, loan guarantees, and tax credits to stimulate investments in renewable energy. Uncertain development of those can be controlled through real options in design.
Risk control through real options	Development of levelized cost of electricity (LCOE) and capacity factor	All projects	The uncertain development of LCOE and capacity factor can be controlled by incorporating real options in the design of the projects.

Table 3.9 Characteristics that support the application of risk management methodologies

3.4.2 Risk documentation

Developers need to continuously manage and monitor risk trends, deviations and exceptions throughout the development lifetime. Table 3.10 shows some of the risk management related documentations commonly required from various parties of the development project at different stages of the development lifetime. In addition, a developer may use some of the following tools to review and revise risk management and mitigation at various stages of the development lifetime.

- **Stoplight chart:** A tool that is used to summarize the statuses of important risks and their mitigation efforts. Stoplight charts are effective tools for reporting risk information to senior management. Each mitigation plan is assigned one of three conditions: green indicates that the plan is working as intended and that no management action is required, yellow indicates that the plan is not working as intended, although no management action is required, and red indicates that the plan is not working and that management action is required.

- **Spreadsheet risk tracking:** This method uses spreadsheets to summarize current statuses of all risks and provides a way to monitor project risks. The basic process involves a periodic update and review of risks. Spreadsheet risk tracking reports are normally included as read-ahead material for project meetings, where reports are reviewed and updated as appropriate.
- **Cost benefit analysis:** This method evaluates the costs and benefits of a particular mitigation strategy if the strategy is not having the expected results. Cost benefit analysis provides information needed by decision makers to determine whether to continue as planned or to re-plan.
- **Contingency plans for risk mitigation:** This method requires compiling data using textual information and graphics to document detailed information about specific risk mitigation plans. Mitigation status reports provide decision makers with data required to determine appropriate control actions.

These tools will commonly serve as support to the developer when it comes to reporting: 1) Critical risk to senior management, 2) mandatory and scheduled reporting of risks and risk mitigation plans to project management team, 3) mitigation status reports, where data is compiled using textual information and graphics to document detailed information about risk mitigation plans, as well as 4) formal documentation of a risk which has been closed, meaning that it has been successfully mitigated, accepted, or has become a problem.

	Deliverable	**Prepared by**	**Scope and intent**
Planning Stage	*Site Investigation, Factual Reports*	Client	To assess basic conditions and obtain an understanding of level of investigations carried out
	Risk Assessment of Project Options	Client	To demonstrate that risks associated with project options have been assessed at an early stage
Construction Procurement Stage	*Contract Documentation*	Client	To assess level of information supplied to tenders including disclosure of hazards and associated risk identified during the Planning Stage
	Ground Reference Conditions	Client or Bidders	To assess identified site and ground conditions hazards established from investigations

	Key Method Statements	Bidders	To assess construction methods, materials, and plant identified by bidders
	Risk Assessment	Bidders	To assess tenders' perceptions and attitude to risk
	Bidders' Risk Register	Bidders	To demonstrate how the tender submission adequately and appropriately caters for risks identified and to be allocated to the contractor
Design Stage	*Design Brief*	Client/ Contractor	To confirm that scope of works has been identified appropriately
	Schedule of Third Party Infrastructure	Designer	To demonstrate that third party exposure and an assessed level of damage have been carried out
	Constructability Reviews	Designer	To demonstrate that appropriate assessments of constructability of the design have been carried out, such assessments including health and safety considerations
Construction Stage	*Project Risk Management Plan*	Contractor	To demonstrate the means and methods of regular monitoring and review of Construction Stage Risk Register by risk owners for construction stage
	Construction Stage Project Risk Register	Contractor	To confirm owners of risks, actions and measures to mitigate impact of risks during construction stage including risks identified by contractor as well as project related risks bought forward from Client's Risk Register
	Site Organization Chart	Contractor	To provide information on reporting structure and lines of communication of key personnel and persons nominated for safety critical work and self-certification
	Training Plan	Contractor	To demonstrate how contractor intends to ensure all staff are and will remain adequately and suitably trained for positions and responsibilities that they are to hold
	Method Statements	Contractor	To demonstrate and confirm working methods and plant, materials, and level of labor to be used
	Inspection and Test Plans	Contractor	To demonstrate contractor's and client's attitude to quality control and quality assurance
	Risk Assessments	Contractor	To demonstrate that hazards and associated risks involved in construction works have been fully identified and assessed for inclusion in Construction Stage Risk Register

Independent Supervision Assurance	Contractor	To demonstrate how contractor will control and maintain independent supervision of construction checking process in case of Self-Certification
Plant Selection Criteria	Contractor	To identify key plant and maintenance regime, e.g. level of spares, frequency of inspection, Maintenance staff (to be included in Method Statements)
Management Plan	Contractor	To identify and demonstrate systems the contractor intends to use to manage and control construction process with regards to the requirement of the contract and also with regard to identifying that the contractor is working to current accepted best practice
Audit Plan	Contractor	To demonstrate contractor's approach to internal and external auditing of the construction process
Value Engineering Proposals	Contractor	To identify deviations from original design, changes in methods to be used, changes to design parameters and implications including risks, perceived benefits accompanied by appropriate risk assessments

Table 3.10 Risk management related documentation throughout development lifecycle

Chapter 4: Power Plant Development Analysis

Investment decision and development process for a new power plant project is a complex system, composed of numerous sub-systems. Each system is characterized by a hierarchy of interacting and networked components with multiple functions, operations, efficiencies and costs. Selecting a model to represent each sub-system, requires trade-offs between multiple objectives and operational perspectives. According to Haimes, no single model can ever attempt to capture the essence of such systems, their multiple dimensions and perspectives (Haimes, 2008). Using a portfolio of models to build an investment strategy can help ensure that developers take full advantage of their best opportunities without taking unnecessary risks. The "smartness" of these models comes from technology and people, not just technology alone. "Essentially, all models are wrong"[47], and as Sterman points out, decision makers who use models to support their decisions need to be humble about the boundaries to their knowledge (Sterman, 2002). So while relying on models for guidance, at the end of the day decision making is in the hands of the decision maker. In addition, there are limits to availability of developer's resources needed to model investment decision. Each developer must acknowledge their acceptability threshold, or their point of "satisficing"[48], i.e. when they have sufficient information to make an educated decision, and further modeling will only add marginal value, which is not considered sufficient to justify spending additional resources to get there.

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[47] Quoted from George E. P. Box in *Empirical Model-Building and Response Surfaces* (Box & Draper, 1987)

[48] Satisficing is a portmanteau which combines the words satisfy and suffice. It was introduced by Herbert A. Simon in the 1950s (Simon, 1956).

4.1 Models for Strategy Formulation

As discussed in Chapter 2, new power plant investment decisions in centralized markets differ from those in liberalized markets. Model choice depends on exact application and organizational user of the model. For investments in centralized markets developers need to consider factors which are exogenous to the electric system, including fuel prices, demand growth, technology evolution, and macroeconomics. The most used models for such analysis are optimization (cost minimization), and multi-criteria decision models. In liberalized markets however investment analysis gets more complicated because of additional uncertainty which is endogenous to the system, such as electricity prices, regulatory changes, and competitors' decisions. For such analysis developers need models which are capable of analyzing the impact on development from uncertain factors. The main techniques used are typically scenario analysis, risk analysis, real options, agent-based simulation, system dynamics, and analytical hierarchy process. Table 4.1 summarizes a few of these models, and gives an example of their typical application based on literature review.

Methods	**Planning level***	**Example of typical application**	**Author(s)**
Agent modeling	O	Bidding strategy	(Oo, Drew, & Lo, 2008)
System dynamics	S/T	Investment strategy, competitor analysis	(Sánchez, Barquín, Centeno, & López-Peña, 2007)
Competitive analysis	S/T	Industry analysis, competitor analysis	(Rudnick, Varela, & Hogan, 1997)
Financial risk modeling	T/O	Contracting	(Lessard, 1996)
Financial modeling	T/O	Pricing, profitability	(Brealey & Myers, 1988)
Game theory	O/S	Bidding	(Fudenberg & Tirole)
Real options	S	Investment decisions	(Fan & Zhu, 2009)
Scenarios	S	Strategy evaluation investment decisions	(Schwartz, 1991)

* O = Operational, T = Tactical, S = Strategic

Table 4.1 Tools for strategic modeling for new power plant investment decision analysis[49]

The large number of available models and non-model-based approaches can be clearly seen through literature review. While project management and risk management have become topics of much interest, decision analysis, and various models for strategic decision modeling are being constantly improved. While some approaches receive noticeably more attraction than others, no single model or single approach to decision analysis has emerged as comprehensive enough to be an overruling model of choice. Graph 4.1 shows how this trend has evolved over the past fifty years.

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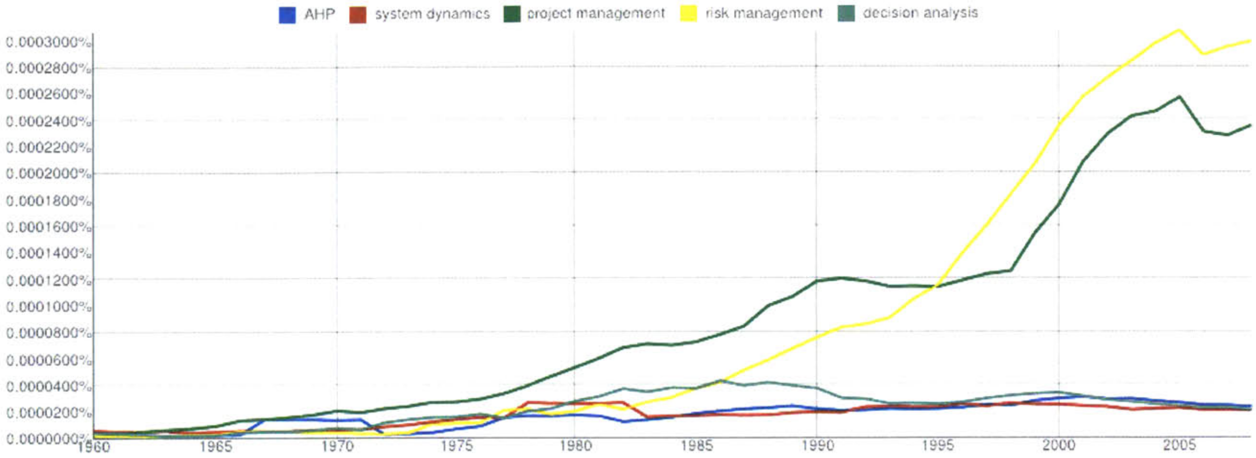
[49] Source: This table is adjusted from different sources, including (Kartam & Kartam, 2001)



Graph 4.1 Trend of phrases used in a corpus of books over the past fifty years[50]

The set of models can be classified into two groups, the first for models that are focused on uncertainty analysis (such as scenario analysis, risk analysis, and real options), and the second for models that deal with strategic analysis of competitors and system (such as agent based simulation and game theory). These two approaches are complementary and a complete analysis should be addressed with models from both sets.

For the reasons stated here above, the analysis provided in following chapter is based on a collection of models to give insight into the power plant development process, and decisions and risks which impact performance of cost, time schedule, and output of those projects, as well as overall project returns. Each model brings a different form of analysis, and together they make a coherent structure needed to form a risk informed investment decision for a new power plant development project.

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[50] Source: This graph is based on a database provided by Google Books Ngram Viewer (Google, 2012). The database was used to search for the phrases "AHP", "system dynamics", "project management", "risk management", and "decision analysis" over the past fifty years. The graph displays how those phrases have occurred in a corpus of books over the selected years. Note that this graph shows general use of these phrases across all books, not only those intended for the energy or construction industry.

4.2 Database of Projects and Developers

There are several variables of interest when analyzing performance of a power plant development project, as there is often a combination of several project characteristics which can impact the project's success or failure. For analysis of those variables, an extensive interconnected database was developed containing information on over 300 power plant development projects, and over 400 developers. The projects all have that in common that they were either commissioned on or after 2008, or are still under development. The reasons for that timeframe are various, including:

- **Scope**: The scope of this research is broad, and this enables a more narrow and concentrated analysis.
- **Industry changes**: Nature of energy industry continues to evolve, as new technologies emerge, development techniques improve, financing and insurance structures change, etc. Narrowing the timeframe enables comparison of projects that were/are being developed under similar conditions.
- **Turning point**: The year of 2008 marks a certain turning point for power plant development projects due to the global financial crisis and increased environmental impact awareness, which enhanced focus on financing risks and environmental risks.

This database was built using 1) limited project databases (see Appendix 3), 2) public announcements of the projects in the form of press releases, and news releases, and 3) in-person follow up via phone calls, emails, and meetings. Half of the projects are alternative energy projects, half of the projects are still ongoing, and their geographic location is spread across different continents. The projects are all ground mounted utility scale power plants that directly feed into the transmission grid. They are also all Greenfield projects, not refurbishments of existing plants, efficiency projects, or development phases that are part of a larger program development. The following gives an overview of the information which was collected for each power plant development project:

1. Key project information:
    - **Energy technology:** Energy technologies considered for the database were: Biomass, gas, coal, geothermal, large hydro, nuclear, oil, small hydro (defined as being 10 MW or less in size or run-off-river design), solar (Photovoltaic), and wind (onshore).
    - **Generation capacity (MW):** All projects are utility scale projects for grid connection. No constraints were on generation capacity size of the power plants.
    - **Continent:** No geographic locational constraints were on projects considered for the database.
    - **Location:** Only Greenfield projects[51] were considered for the database. Key location data was included, such as country information, nearest city, river if applicable, etc.
2. Project structure:
    - **Development Contract Type:** The type of development contracts used for the project, whether EPC, Turnkey EPC, or other non-traditional contract types.
    - **Owner/Developer:** Information on the ownership structure, and developer entity type (whether POU, IOU, or IPP).
    - **Operator:** If confirmed and/or already in operation, information on operator was included.
    - **Constructor:** Key constructors involved for civil works (and sub-contractors when that information was available).
    - **El&Mech supplier:** Supplier of electrical and mechanical equipments.
    - **Fuel supplier:** When applicable, information on fuel resource supplier (gas, oil, coal) and contract characteristics.
    - **Energy buyer:** Energy off-taker information, and terms of PPA when applicable.
3. Development process:
    - **Development status:** Only projects which had been approved and had entered into project execution phase were considered.
    - **Development timeline:** Key progress and milestones along the development timeline.

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[51] Greenfield projects are new power plants which are built from scratch on an undeveloped land in a city or rural area (called Greenfield lands) (see more on site characteristics in Section 2.1.1.3).

4. Project details:
    - **Technical details:** Other technical details, such as number of generation units.
    - **Land ownership:** Available land ownership information (public vs private).
5. Financing:
    - **Financing structure:** Available information on the financing structure and terms (Build-Operate-Transfer, Project Financing or other financing structure).
    - **Sponsors:** Available information on the sponsor, such as the D/E ratio of the project, etc.
    - **Capital Cost:** Originally estimated total capital cost, and actual capital cost for completed projects. The database registered the time that amount had been issued, and the currency of project cost.

Depending on data availability, completed development projects were examined based on how they performed on cost and time (percentage change from original estimate to actual final outcome), and which challenges or risk events contributed to that. In addition, particular innovative approaches or risk management methodologies were tracked.

The Project Database was linked to a Developer Database which registered information on each of the developers involved in developing the power plants in the Project Database. The information collected on the developers was:

- **Ownership structure:** The ownership structure of the developer was registered (such as if it is a public or private company, a joint venture, holding company, or subsidiary), information on parent company (when applicable), utility type (POU, IPP, IOU), and headquarter.
- **Power plant portfolio:** The database categorized the developers according to the types of energy technologies that exist in their project portfolio. When available, further information on that portfolio was included, such as generation capacity size
- **Reputation:** Any information available on the reputation of the developer, based on coverage in news releases or other sources (typically only when developers have a bad reputation such as from poor project execution, involvement in fraud activities, or bribes).

- **Ratings from credit agencies:** Only few of the developers existed in public ratings of credit agencies. The database was compared to ratings from MSCI (MSCI, 2012) and S&P (S&P, 2012).
- **General company information:** Any useful general information on the company, such as the size of that developer within their key energy market, and any previous name they used to go by.

In addition to these databases a major contribution to this dissertation work was from various experts in the energy industry. The Developer Database also served as a register for these records, including the contact information, and contact history for the individual contributors.

As Table 4.2 shows, industry experts contributed to the dissertation work at three stages: 1) For upfront identification of key decisions and risks for power plant development projects of different energy technologies, 2) to contribute to development of System Dynamics model design and generation of weights and interconnections through pairwise comparison of the different risks in the ANP model, and 3) to rationalize and validate the outputs of the models.

Contribution stage	**Type of industry experts (total number of interviewees)**
1) Identification of key decisions and risks	Contractors (2), Developers (11), Energy Consultants (2), Investors (3), Professors (7), Researchers (3)
2) Development of model design and parameters	Developers (9), Professors (3)
3) Rationalize and validate model outputs	Developers (3), Energy Consultants (2), Professors (3)

Table 4.2 Contribution of industry experts to data collection

The contribution of interviews and databases to our dissertation work is referenced throughout this dissertation. Main contribution of the first stage of interviews can be found in Chapter 2 and 3, whereas contribution of remaining interviews were to the work that is presented in Chapter 4.

4.3 Data Mining

Techniques for extraction of useful information from large datasets are collectively referred to as Data Mining. Given the wide range of data provided in the Project Database, it was of interest to use Data Mining methods to identify power plant development trends[52]. Data Mining methods chosen to meet each particular goal of our analyses are listed in Table 4.3.

Analysis	**Question**	**Data Mining methodology**
Project Selection	What type of power plants do different utility types develop, and how does that vary given geographic location?	Classification Tree
Performance	Is performance different given a) geographic location, and b) energy source (measured in ability to meet estimated time, cost, and quality)?	Clustering Analysis Logistic Regression

Table 4.3 Data Mining methodologies used to answer questions on power plant development trends

To reduce dimensionality, a subset of the Project Database was created using project information on location and performance on time and cost. Records with missing values were omitted in order not to understate dataset variability. Unordered categorical text variables ("nominal variables") were converted to numerical values. Table 4.4 defines variables used in the subset.

Variable	**Definition**	**Variable Type**
Energy source	Power plant type (wind, solar, coal, etc.)	Nominal variable
Continent	Continent of the project site location	Nominal variable
Ownership	Project owner type (IPP, POU, IOU)	Nominal variable
Size	Plant generation size in MW	Continuous numerical
Actual Cost	Final capital cost, in million USD[53]	Continuous numerical
% Cost Overrun	Percentage change from original cost estimate	Continuous numerical

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[52] The Data Mining was supported with XLMiner Data Mining Add-in For Excel.

[53] Foreign currency rate is converted using end of 2011 value.

Cost per kW	Capital Cost per kW	Continuous numerical
SOC	Start of construction	Continuous numerical
Actual COD	Actual Commercial Operating Date	Continuous numerical
% Time Overrun	Percentage change from original time schedule	Continuous numerical
Construction Time	Total construction time, in months	Continuous numerical

Table 4.4 Definition of selected variables from Project Database

Our approach to Data Mining analysis is outlined in the following sections. We highlight in italic font data base variables being discussed.

4.3.1 Data validation

Since the Project Database was created from scratch based on published data on power plant development projects and expert input, it is judged to be valid, sensible, reasonable, and secure data to use for the purpose of this analysis. Before conducting the analysis, the data was however tested for content validity (how well it compares to the real world) and construct validity (how well it measures up to its claims), including input consistency checks, and cross-system consistency checks. With the help of industry experts, each data point in the database was reviewed and judged as being either essential, useful, or irrelevant for measuring the power plant development trends.

4.3.1.1 Content validity

For content validity the values for *Cost per kW* and *Construction Time* were compared to a known average for these parameters, and plotted as a Box Plot diagram[54]. The Box Plot in Graph 4.2 shows the spread of the *Cost per kW* for the projects used for this analysis. Layered on top of that Box Plot are the investment cost values based on estimates published by the International Energy Agency (IEA, 2010). The graph shows that power plant development projects based on more mature energy technologies deviate less from the published average of cost per kW, while newer energy technologies are

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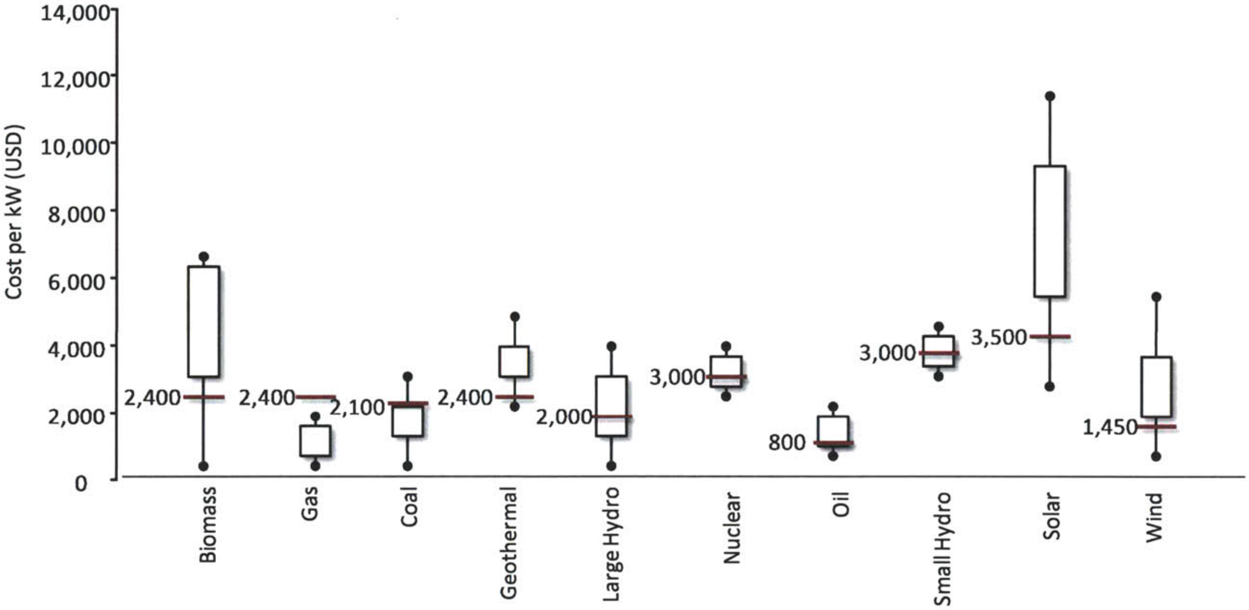
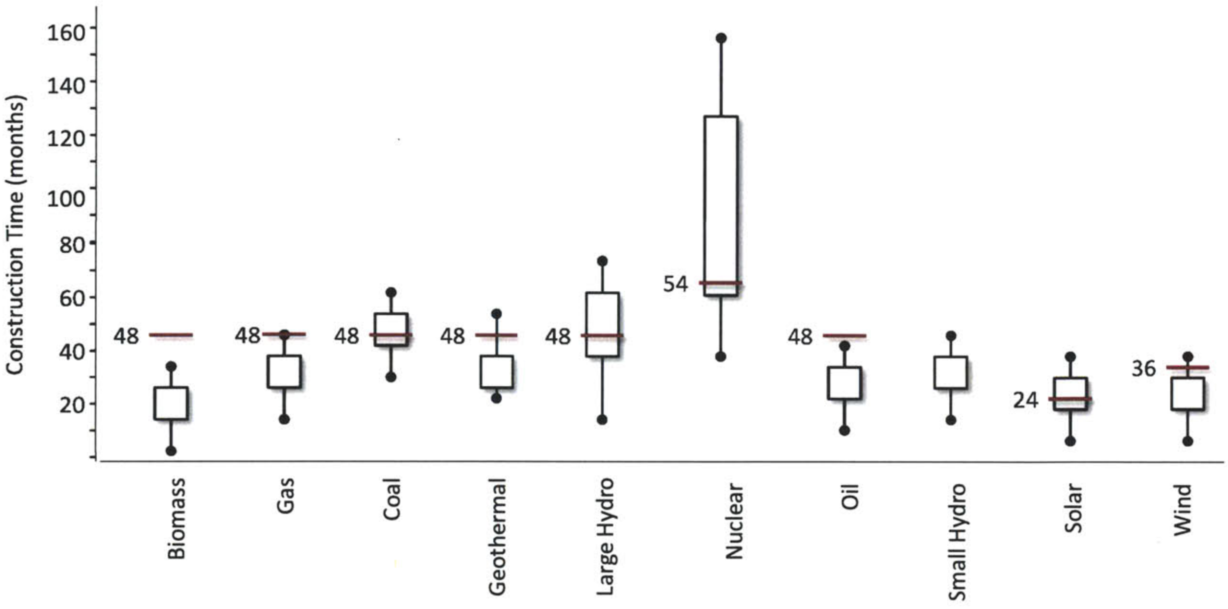
[54] The Box Plot is a useful diagram to graphically depict the data through their five number summaries: the smallest observation, lower quartile, median, upper quartile, and largest observation, as well as outliers if any. The spacing between the different parts of the box indicates the degree of spread (the bottom and top of the box being the 25th and 75th percentile), whereas the whiskers show the range to the minimum and maximum of all the data (excluding outliers).

performing worse than the average. This can be a linked to the costs technology risk those power plants face as a result of stage of their technology maturity (see discussion on risk factors specific to renewables in Section 3.1.2).



Graph 4.2 Box Plot of investment cost spread using *Cost per kW* for the different energy sources

The Box Plot in graph Graph 4.3 shows the spread of the *Construction Time* for the projects used for this analysis. Layered on top of that Box Plot are average construction time values based on estimates published by the National Renewable Energy Laboratory (NREL, 2010). As the graph shows, nuclear power plants have the greatest deviation from published average construction time. This is explained further in Section 4.3.3.2 through project type cluster analysis.



Graph 4.3 Box Plot of development duration spread based on *Construction Time*

Based on these graphs, the data was considered to be sufficiently comprehensive and accurate to allow us to work with it. These graphs do not show outliers[55], but do show clearly the wide range of projects included in the database. Outliers here are most often examples of extreme risk events, resulting in extensive time delay and cost increase.

4.3.2 Classification Tree

Classification Trees[56] are used here to find a classification rule or partition of power plant development projects into subsets of choice by each power plant selected by the developer and by differences among geographic locations. As the scatterplot in Graph 4.4 shows, regression analysis of the different variables shows that the clearest indicator for the rule was the size of the power plant.

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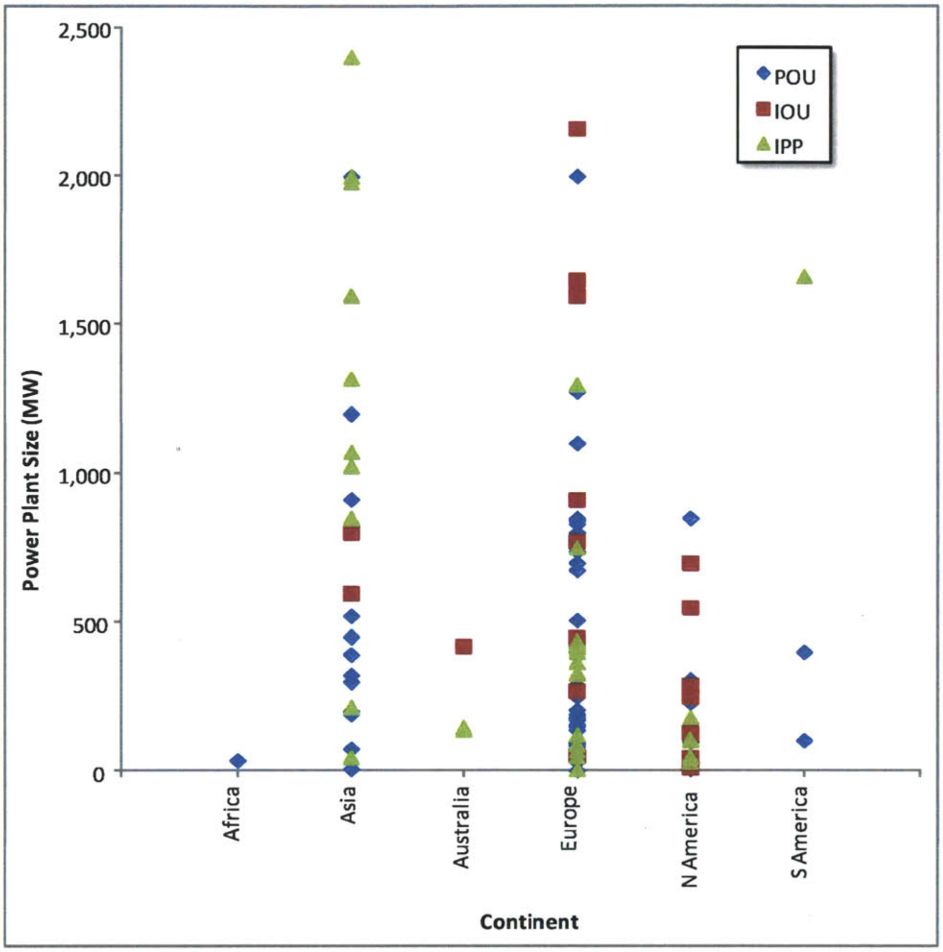
[55] Outliers for a given variable here are taken to be values over 3 standard deviations above or below the mean value of that variable.

[56] Classification Tree methodology was developed by Breiman et al.



Graph 4.4 Scatter Plot of power plant ownership distribution across continents

Building on Graph 4.4, a Classification Tree shows how power plant size in each geographic location is an indicator of the utility owner type. The tree in Figure 4.1 has been translated to show the outcome of the classification rules. Each square terminal node shows utility type outcome for that branch, and each circle node represents a decision node, and shows the predictor followed by its splitting rule.

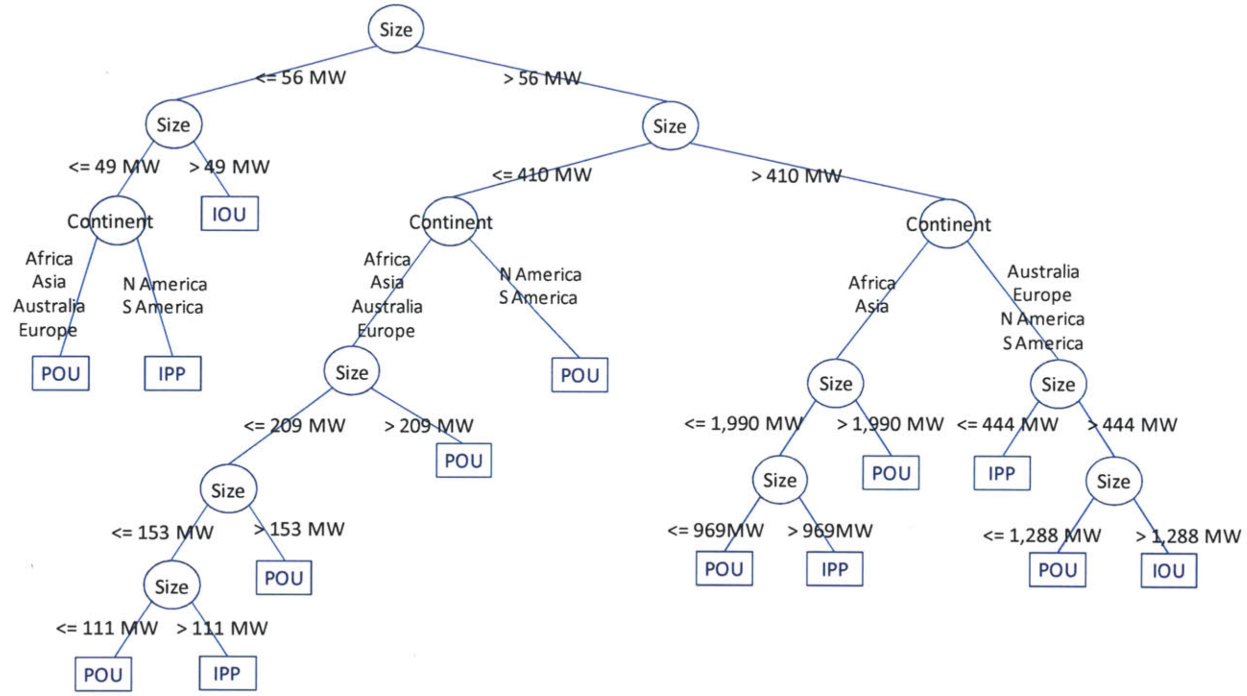


Figure 4.1 Classification Tree showing how ownership of power plants across different continents depends on the plant's size

The Classification Tree successively splits location by size so that we see how power plant ownership depends on size, and how this dependence differs across continents. For example, in Asia, utilities of type IPP tend to own power plants of size falling in the following MW range:

(111,153] and (969,1990]

Obviously that is complete over-fitting of the data, and as we saw from the scatterplot in Graph 4.4 there is a considerable overlapping of project sizes amongst utility types. The Classification Tree does however give insight into the difference in power plant portfolios for the utility types as a function of geographic location. In general, power plant classification as shown in Figure 4.1 boils down to Table 4.5[57].

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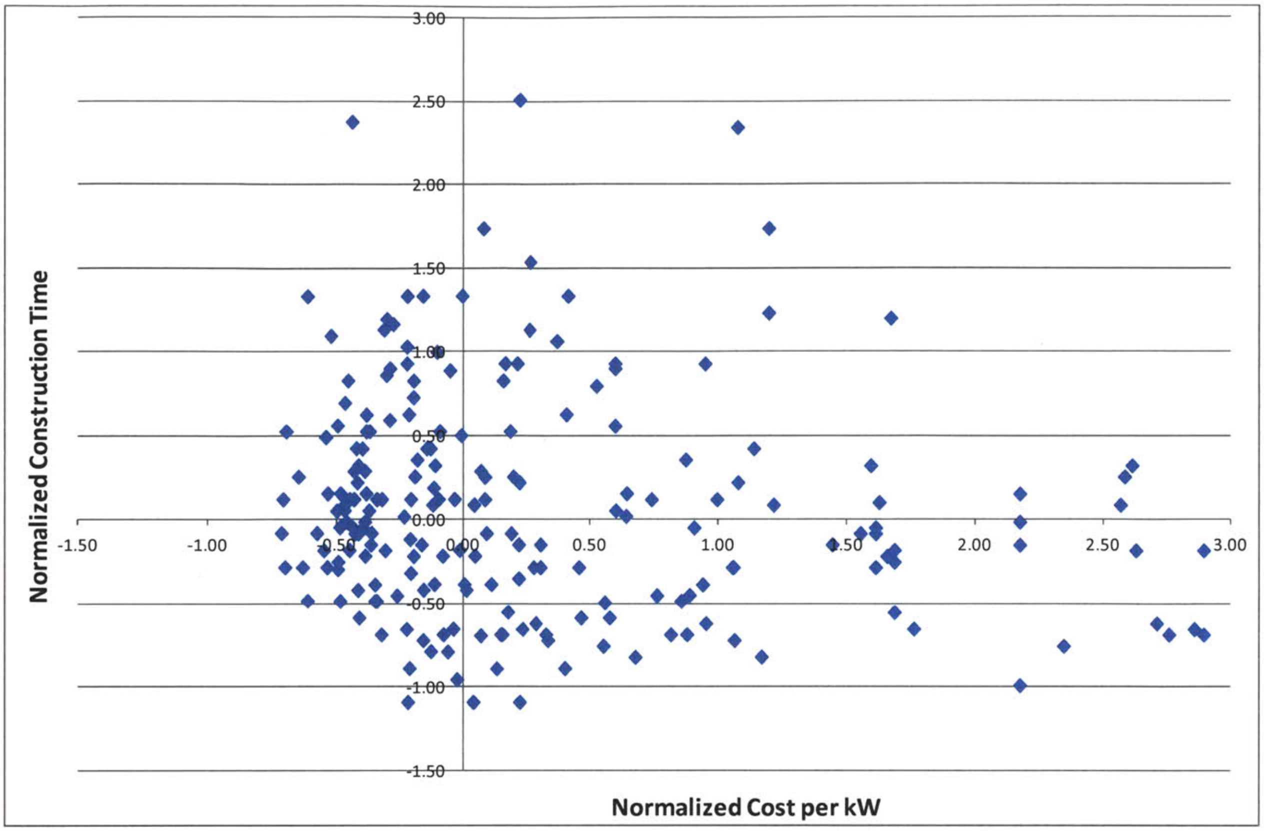
[57] This table has been simplified to a 5x2 matrix, leaving out some geographical locations and the IOU developer type. This is due to lack of data points which didn't result in valuable insight for those variables.

	Owned by the following utilities if power plant size falls within this range	
Continent	POU	IPP
Asia	Less than 1,000 MW	Over 1,000 MW
Europe	All sizes	Between 100 and 400 MW
N America	Between 50 and 400 MW	Smaller than 50 MW

Table 4.5 Results derived from Classification Tree on ownership of power plants across different continents

4.3.3 Cluster analysis

Cluster Analysis has been applied in many areas such as marketing (for market segmentation and market structure analysis), and finance analysis (for creating balanced portfolios and industry analysis) (Shmueli, Patel, & Bruce, 2007). It is used to form groups, or clusters, of similar records based on several measurements made on these records. The characteristics of each cluster are then analyzed in ways that are useful to describe the behavior of those data records. Normalized *Construction Time* and Normalized *Cost per kW* are used to generate project development clusters. In turn, performance trend as a function of cluster groups is studied.



Graph 4.5 Scatter Plot of Normalized *Cost per kW* and Normalized *Construction Time*

4.3.3.1 Geographic location clusters

An interesting insight was derived by looking at development projects clusters based on *Capital Cost per kW* and *Construction Time* sorted by *Continent*. The purpose is not to capture the outliers of extreme risk events; rather it is to see whether or not projects in certain geographic areas tend to perform on scheduled time and cost. The scatterplot of the normalized variables[58] on Graph 4.6 is zoomed in on the data points on a fixed scale to show the clustering around geographic locations.

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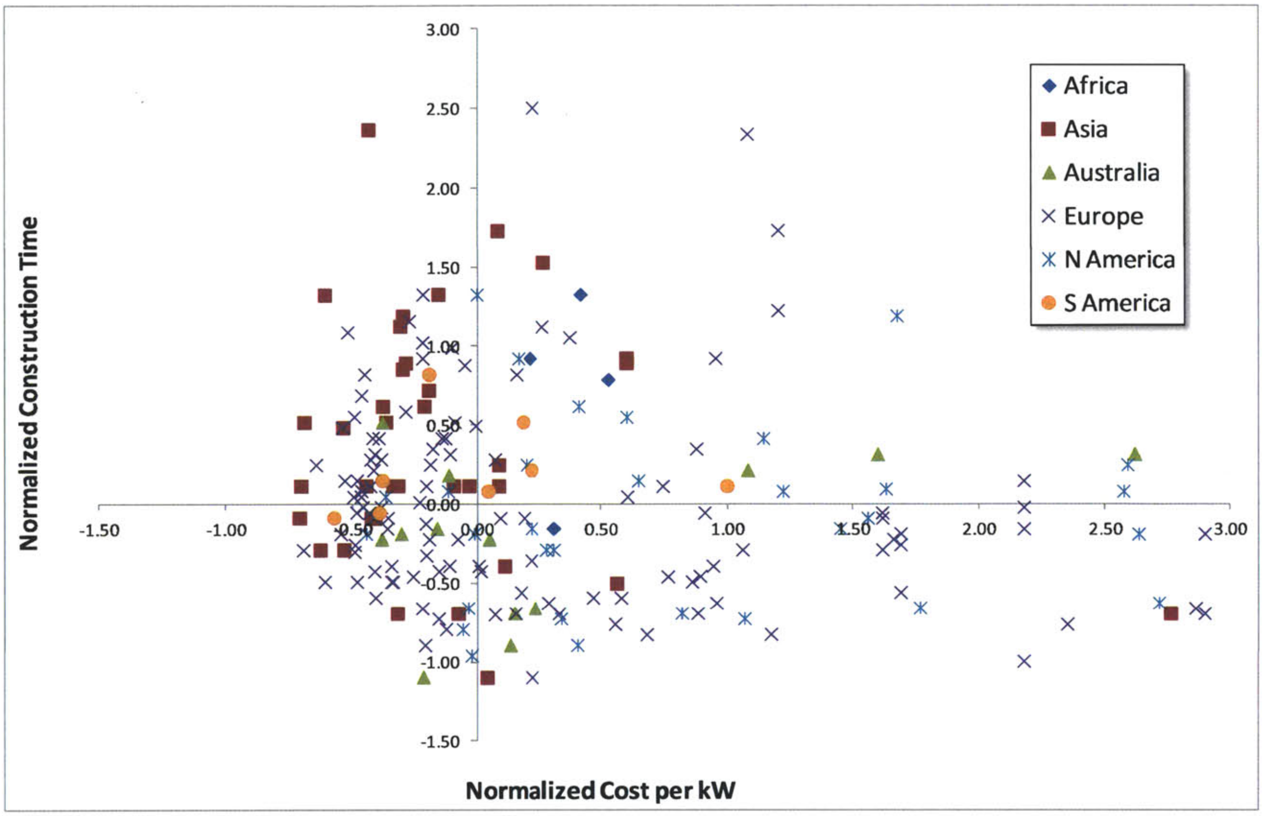
[58] Variables were normalized by subtracting the mean and dividing by the standard deviation of each variable.



Graph 4.6 Scatterplot of Normalized *Cost per kW* and Normalized *Construction Time* sorted by continent

The number of desired clusters, k_i, was set equal to the number of continents (with i = 6) to see if these particular six clusters have characteristics that appear to be representative of each of these six continents (a k-means algorithm). The distance measure used is the sum of squared Euclidean distances, and the algorithm was run for ten iterations. The resulting output shows interesting geographic clusters (a one page view of the output can be found in Appendix 4). As Table 4.4 shows, and which was evident from the scatterplot in Graph 4.6, there are overlaps among geographic clusters. However, with only one exception, each continent proved to be dominant. For example, North America has the highest continent concentration in cluster 2, or 32%, which although other continents (namely Europe) had a higher concentration within its cluster, these continents had a more dominant presence in other clusters.

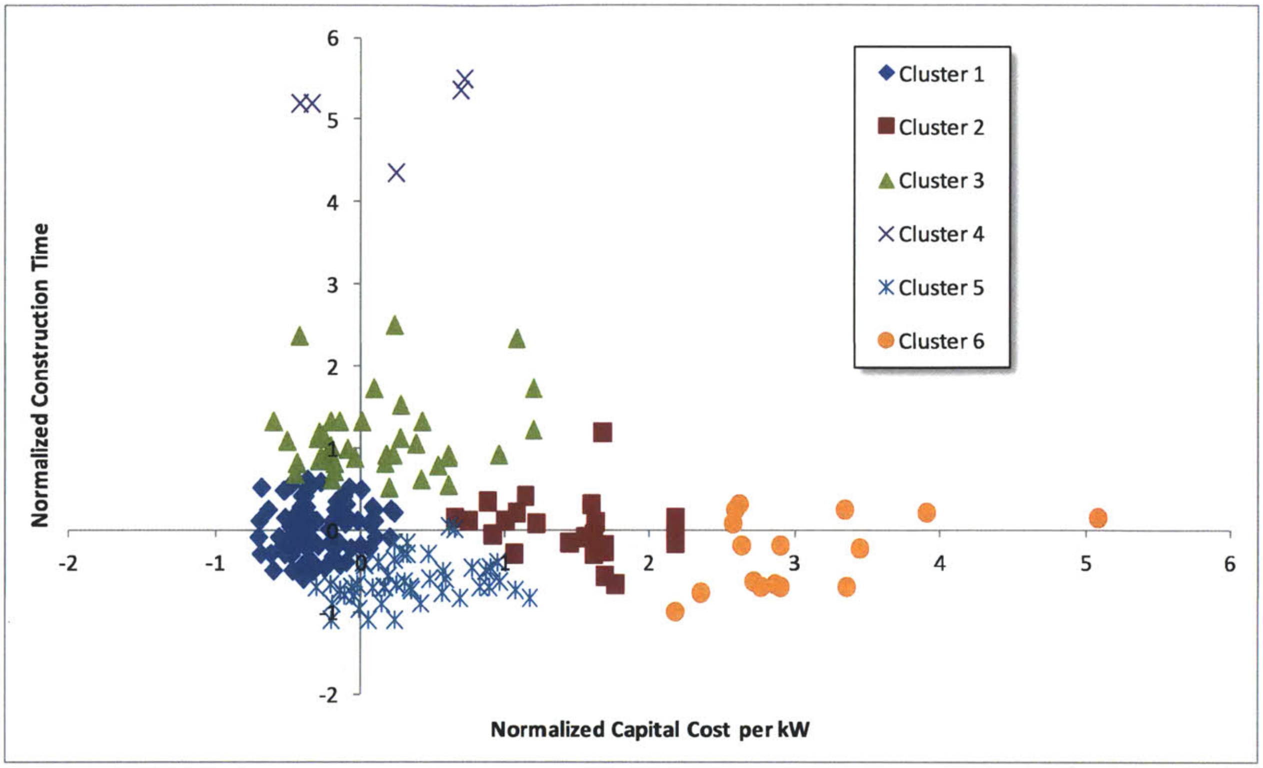
	Cluster					
	1	2	3	4	5	6
Africa	0%	0%	**8%**	0%	2%	0%
Asia	21%	0%	33%	**80%**	11%	19%
Australia	7%	8%	0%	0%	**9%**	6%
Europe	**61%**	56%	44%	0%	56%	44%
N America	6%	**32%**	10%	20%	22%	31%
S America	**6%**	4%	5%	0%	0%	0%
Total nr. of data points in cluster	87	25	39	5	45	16

Table 4.6 Cluster Analysis: Geographic clusters

Graph 4.7 summarizes the key points, and insights for the characteristics of each cluster can be described as Table 4.7 shows.

		Cluster characteristics	
Continent	Dominant in cluster	Performance on time	Performance on cost
Africa	3	Worse than average	On average
Asia	4	Much worse than average	On average
Australia	5	Better than average	Slightly worse than average
Europe	1	On average	Better than average
N America	2	On average	Worse than average
S America	1	On average	Better than average

Table 4.7 Geographic cluster characteristics

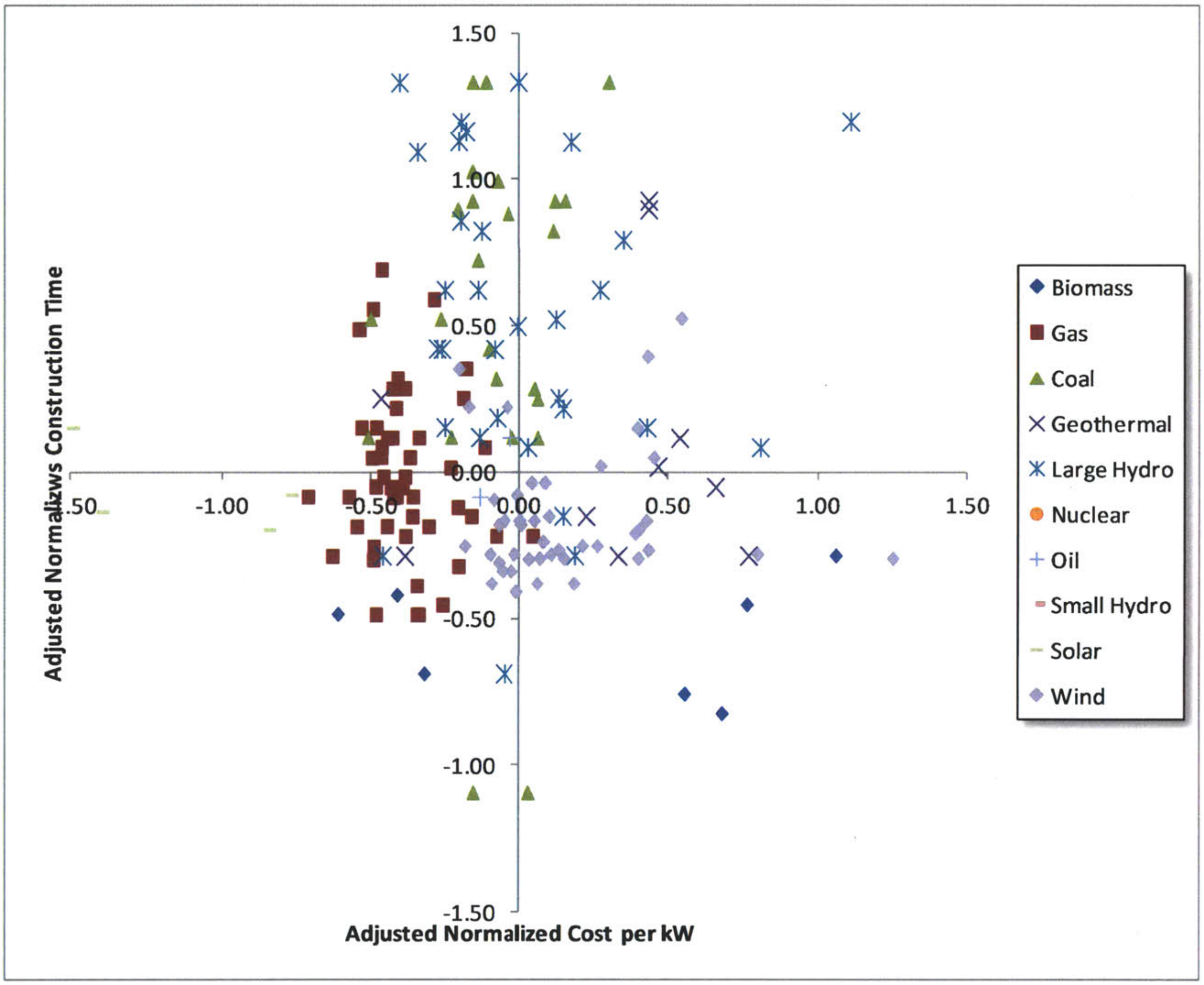


Graph 4.7 Scatter Plot of geographic location clusters

It is important to note that project types are not evenly distributed across continents. However, comparing these results to the impact of normalized values for average *Cost per kW* and average *Construction Time*, on the distribution of project types across different continents it can be assumed that the impact is negligible (see Appendix 5).

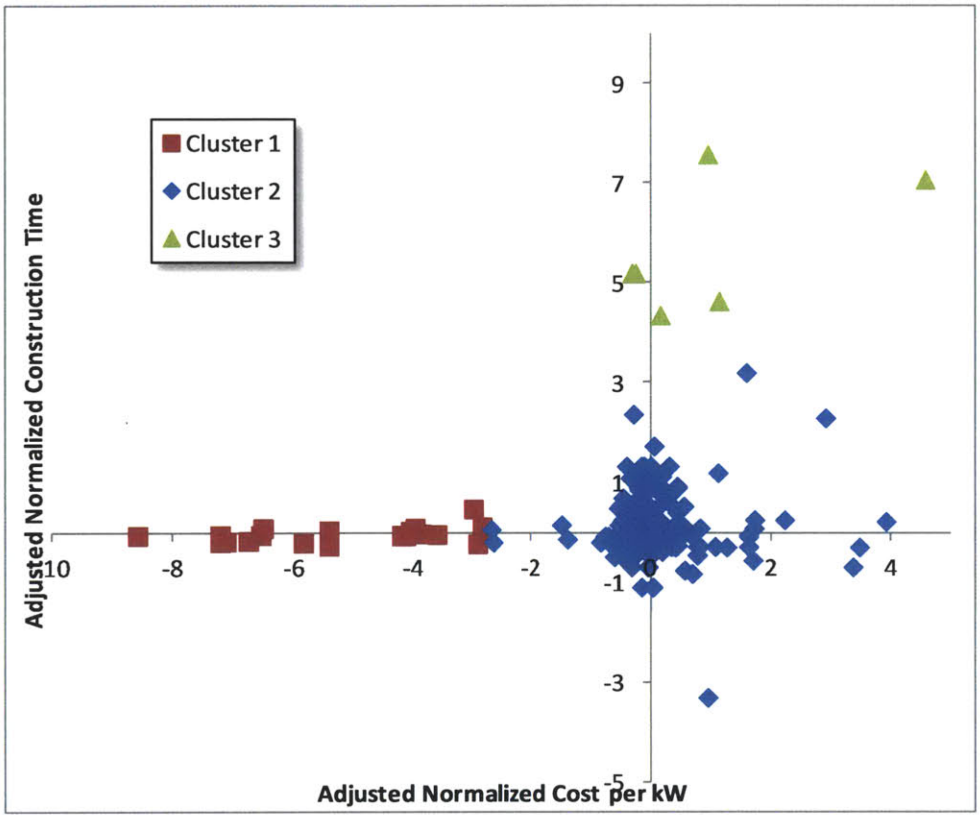
4.3.3.2 Project type clusters

As the Box Plots on Graph 4.2 and Graph 4.3 showed, the data values for *Cost per kW* and *Construction Time* were somewhat skewed from the average comparison values. As that can indicate cost increase, and time delay from the base value for such projects it was of interest to see which projects could be classified as being bad performers on those parameters. Values for Normalized *Cost per kW* and Normalized *Construction Time* were adjusted for the normalized values of the average, as can be seen in Graph 4.8.



Graph 4.8 Scatter Plot of adjusted and normalized *Cost per kW* and *Construction Time* sorted by energy source

A k-means algorithm, with k equal to 3, captures three different performance clusters (assuming that the algorithm returns an average cluster and two extreme clusters). After running the k-means algorithm, with the squared Euclidean distances over ten iterations output shows a clear average performance cluster, and two extreme clusters, one performing badly on time (i.e. having a construction duration longer than average), the other performing badly on cost (i.e. having higher cost than the average). Graph 4.9 shows a scatterplot of those three performance clusters.



Graph 4.9 Scatter Plot of the three performance clusters

Analysis of these three clusters identified solar projects as the worst performers on the cost parameter, and nuclear projects as the worst performers on the time scale.

Cluster	Characteristics	Dominated by energy source
Cluster 1	Worst performer on cost	Solar projects
Cluster 3	Worst performer on time	Nuclear projects

Table 4.8 Characteristics of project type clusters

These clusters can be directly explained through key characteristics of the energy technologies. Nuclear power plant projects are faced with high project delivery risk as they have a long lead time and pose high financial risk (see discussion on risks specific to nuclear power plant projects in Section 0). Solar power project however, are mainly exposed to cost related risk factors, such as technology risk, risk of theft, etc. which explains why they tend to perform worse on cost (see discussion on risks specific to solar power projects in Section 3.1.3.6).

4.3.4 Logistic regression

As Cluster Analysis shows, project performance trend clearly depends on project location, and energy technology. This suggests that it is interesting to see how well key project characteristics predict project performance. To this end logistic regression is deployed as a classification and prediction tool. This is a common approach for both classification (classifying or assigning a new observation whose class is unknown to an element of a predetermined set of classes based on the values of its predictors), or for profiling (used in data where the class is known to find similarities between observations within each class in terms of the predictor variables) (Shmueli, Patel, & Bruce, 2007).

Four predictors were used (see Table 4.9) to determine whether or not the project was a) more than 50% over cost schedule, and b) more than 50% over estimated development completion date[59]. Of the 258 projects used for this analysis, 8% went more than 50% over estimated development completion date, and 3% went more than 50% over estimated development cost. Based on this data the dependent variables were based on percentage overrun for each analysis.

Variable	Definition	Number of dummy variables
Energy source	Power plant type (wind, solar, coal, etc.)	9 (Gas as a reference plant)
Continent	Continent of the project site location	5 (Europe as a reference continent)
Ownership	Project owner type (IPP, POU, IOU)	2 (POU as reference utility type)
Size	Plant generation size in MW	3 (reference size up to 100 MW)

Table 4.9 Variables used as predictors for time and cost overrun

To perform logistic regression, each of the categorical predictors of interest was converted to dummy variables, with each being a binary dependent variable having two possible classes (1 if the project falls into that category, 0 if not). For categorization of the power plant size, four categories were created based on whether the size of the plant was 1) under 100 MW, 2) between 100 and 500 MW, 3) from 500 to 1000 MW, or 4) over 1000 MW. In addition, the dependent variables for each analysis were coded as

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[59] Each project is assigned a binary dependent variable (a,b). Variable (a) is assigned 1 if it is more than 50% over cost schedule, otherwise it is 0. Separately, variable (b) is assigned 1 if it is more than 50% over estimated development completion date, otherwise 0. That way each project can take four possible outcomes: (1,1),(0,1),(1,0),(0,0).

binary variables with 1 when the percentage change from original estimate for the project was more than 50% over for a) cost estimate, and b) time schedule, and 0 otherwise.

Logistic regression parameter estimates for cost overruns are in Appendix 6, and for time overruns in Appendix 7. Taking into account statistical significance energy technology type is not associated with cost. The type of energy technology is however clearly associated with the schedule not being on time. Holding all other factors constant, key insights are shown in Table 4.10.

Variable	**Odds of cost overruns**	**Odds of time delays**
Energy source	Not associated with cost overruns	Renewables plant have higher odds
Continent	Significantly higher in Africa and Asia	Higher odds in Africa and Asia
Ownership	Significantly lower for IPPs	Higher for IPPs
Size	Higher when larger than 1000 MW	Higher for all other sizes

Table 4.10 Interpretation of logistic regression model for odds of cost overruns and time delays

4.4 System Dynamics Model

Risks that impact power plant development are both internal and external to the project, and are often tightly coupled. External risk factors, such as regulatory, institutional, and political risks, are typically not controlled by the developer, but are generally controlled by a collection of affected parties, governments, and regulators. System Dynamics models can be used to assess and control the impact of external development process risks, highlighting iteration and feedback which conventional project network models prohibit. Followed are some of the key characteristics of the System Dynamics model which made it the tool of choice for analyzing impact of risks on the power plant development process:

- **Insight into past behavior:** Rather than a forecast of the future, System Dynamics models provide insights into system behavior over time as the system adapts to externalities. This helps us understand why observed temporal patterns of costs and delays occur, and aids development of action plans that account for delayed feedback in a complex system.
- **Feedback and iteration loops:** Through explicit recognition of feedbacks and delays, System Dynamics model can capture tightly coupled activities which are not well described by conventional project network models. It clearly shows cause-and-effect relationships, and how ripple effect can cause variables to increase (or decrease) simultaneously. The model also deals with nonlinear and time delayed impacts, useful for causal impact and feedback diagnosis.
- **Helps to clarify:** The System Dynamics model is a useful tool when interviewing different project stakeholders, as it can be used to clarify and test their assumptions.
- **Both quantitative and qualitative assessment:** The System Dynamics model helps model impact of risk factors that are normally given qualitative assessment and therefore not easily represented in quantitative models.

The beginning of work in System Dynamics can be traced to the late 1950s, but application of System Dynamics to project management began in earnest with Cooper's work in the 1970s (Cooper & Lee, 2009). History of System Dynamics applied to energy industry began around the same time, with research on evaluation and depletion of energy resources. Ford's work on the U.S. energy industry in the

1980s and 1990s remains a milestone of how to approach energy policy evaluation, as well as energy investment and uncertainty (Ford, 1997). Sterman's follow up work on the broad aspects of energy systems is also notable (Sterman, 1983).

Today, System Dynamics is applied extensively to model various aspects of the energy industry including resource planning and pricing deployed by large and small power companies as well as government agencies at local, state and federal level. The work has been performed by utility analysts, government planners, consultants and academics. Table 4.11 gives an overview of some of the recent application of System Dynamics for modeling for strategic decisions for the energy market, including electricity sales, and generation expansion considerations.

Model characteristics	Model stage*	Author(s)
New capacity investment behavior in a wholesale electricity market	D	(Kim, Ahn, & Yoon, 2007)
Gas price model	C	(Tan, Anderson, & Parker, 2007)
Casual loop of plants under construction	C	(Qian, 2007)
Casual loop of the power market	D	(Olsina, Garces, & Haubrich, 2006)
Financial challenge to power plant development, and key feedback loops in the utility system	C	(Ford, 1997)
Generation expansion planning	D	(Sánchez, Barquín, Centeno, & López-Peña, 2007)
Trading in electricity and gas spot markets	D	(Bunn, Dyner, & Larsen, 1997)

* Model development stage: (D) Published as fully developed, (C) Published as a model concept.

Table 4.11 System Dynamics models applied to energy market

4.4.1 Model development background

Our system dynamics model of power plant development process incorporates decision making sub-models, sub-models for calculating key financial parameters, risk impacts and mitigations, and power plant generation process and electricity sales. Each sub-model is built using a combination of literature review and expert input, in these steps.

- **Step 1:** Get acquainted with the power plant development process, highlight benefits that the System Dynamics model brings to the table, and conduct an extensive literature review of model contributions to energy industry and built environment.
- **Step 2:** Map all stakeholders and key decisions which impact a power plant development project, and highlight those industry experts whose input would be needed for modeling.
- **Step 3:** Confirm that this is a dynamic inter-temporal problem, collect data that enables construction of graphs of variables that change with time (see Sections 4.2. and 4.3).
- **Step 4:** Based on empirical data analysis, basic stock-and-flow diagram for a power plant development process was constructed with the aim of balancing complexity and keeping the number of feedback loops small.

Some known utility system feedback loops are deliberately excluded as they are not considered necessary for our purpose.

- **Follow up investment loop:** A fundamental assumption is that one-time investment is made; the impact of follow up investments in that geographic region is ignored. The model only assesses that energy market before decision is made to go ahead with development. Some feedback loops that such modeling would need to include are: a) potential overheating of the energy portfolio of that geographic location through use of that energy source, b) delayed resource effect on that geographic location reducing the remaining useful sites, and c) the impact that improving the infrastructure in this location has on lowering potential cost for further investment in that area.
- **Delayed demand control loop:** The impact that this power plant development has on total installed capacity and in turn on, the rate base, with delay in realized electricity price and consumption (Ford, 1997).

- **The death spiral:** The reinforcing feedback loop that an increase in electricity consumption has on electricity price, and with delay how that continues to increase electricity consumption (Ford, 1997).

The model variables can be described using a Bull's Eye Diagram (see Figure 4.2), a useful way of representing a model that includes many complex variables, to show the relative balance between required inputs and the variables already built into the model. The diagram includes three groups of variables:

- **Endogenous variables:** Generated using interaction of variables within the model.
- **Exogenous variables:** A constant valued variable outside of model interactions.
- **Excluded variables:** Variables which are deliberately excluded from this model. Had they been included, they could have added additional insights. These variables may be good candidates to include if this model were to be expanded as part of a future analysis.

The goal of the diagram is to demonstrate the scope and focus of the model, and hence it only includes few of the variables in the model, excluding the ones that will not add value to the understanding of the scope of the model.

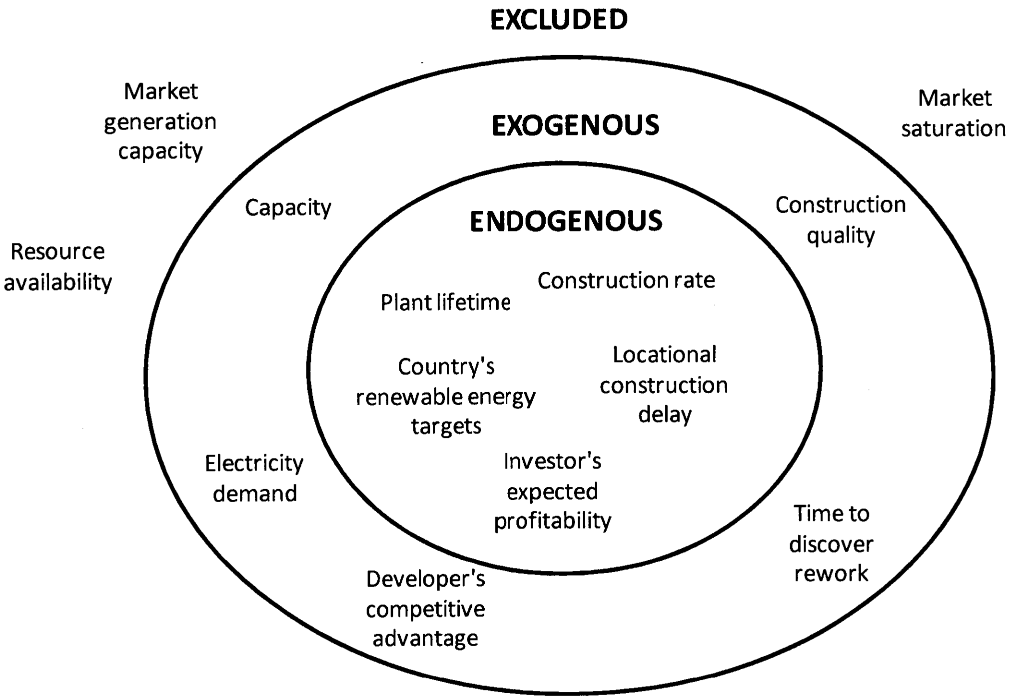

Figure 4.2 Bull's Eye diagram of the System Dynamics model

In reality, almost nothing is exogenous when taking into account the full feedback view (Sterman, 2002). Therefore ideally, it's preferred to have fewer exogenous variables. However, as this model is built to be able to work for power plant development projects of any kind the exogenous variables are many as the Bull's Eye Diagram shows.

4.4.2 Modeling power plant development process

The power plant development process is modeled as a stock-and-flow diagram, whose flow represents generation capacity under development. Diagram 4.1 gives an overview of the basic model. Note that this is a simplified overview for illustrative purposes, leaving out impact that each risk stock will have on flow of expected generation capacity through different phases of development (these stocks are connected to each valve, as discussed further in Section 4.4.3).

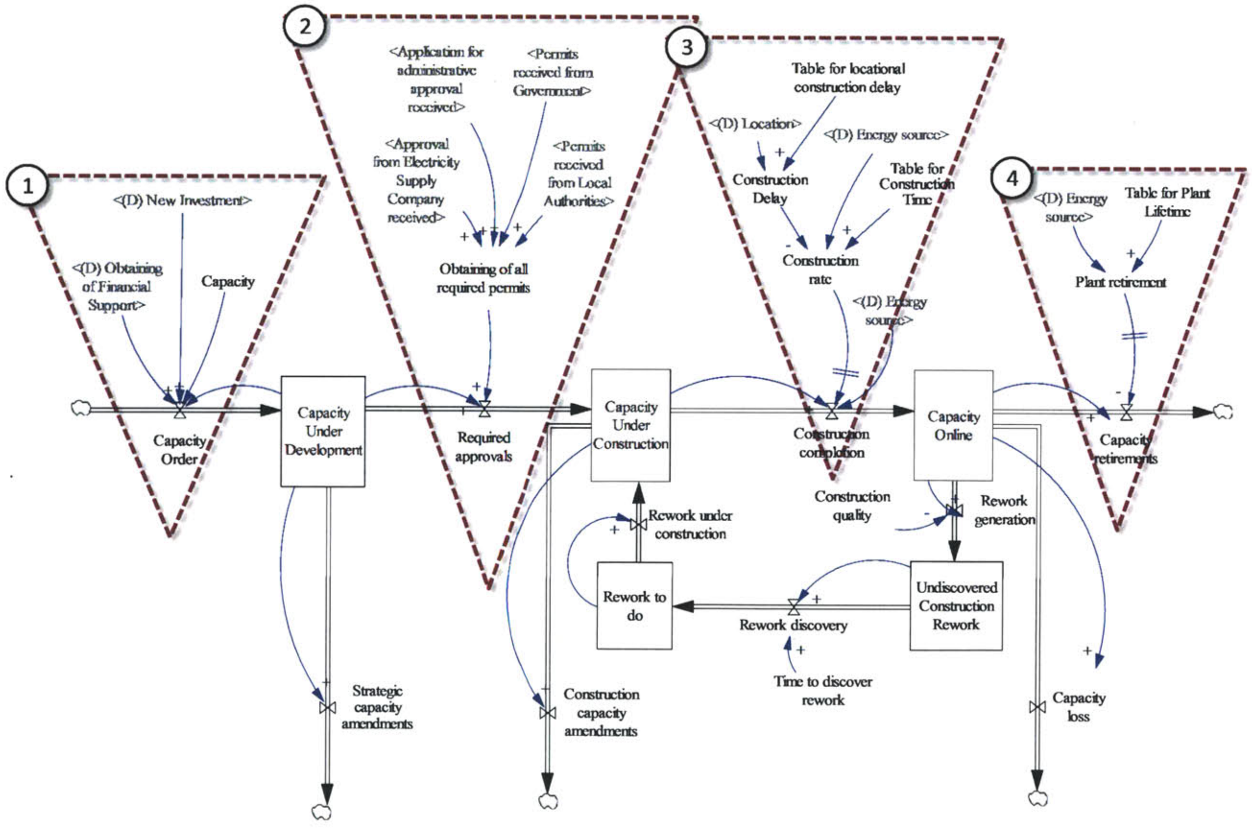

Diagram 4.1 High level stock-and-flow diagram for the power plant development process[60]

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[60] Variables within brackets < > represent shadow variables, which bring information from a sub-model. Variables which are labeled *(D)* represent decision variables.

Four main areas of flow in and out of stocks are highlighted Diagram 4.1. The following explains those in more detail.

- **Capacity order:** Expected generation capacity which goes under development is a function of the dimensionless decision variables *New Investment,* and *Obtaining of Financial Support,* as well as the exogenous variable *Capacity* in units of MW.[61] Once financial support has been obtained, and a decision to invest in a new power plant development project has been made, the stock for *Capacity under Development* receives a one-time immediate inflow of the expected capacity, as determined by the exogenous variable. Once under development, various risk factors may result in strategic generation capacity amendments (such as changes to funding or resource availability), which may either increase, partially reduce, or completely cancel project.
- **Required approvals:** Generation capacity does not flow to the stock for *Capacity under Construction* until required approvals have been received. The required approval valve is controlled by dimensionless variables representing administrative consensus, approvals from Electricity Supply Company, as well as permits from government and local authorities. Depending on which approval has been received, some initial construction may begin on site (such as when approval from local authorities allow some site preparation work on infrastructure, for example laying roads), which opens partly the valve for a one-time flow of the appropriate percentage of overall generation capacity under development. Once under construction, various risk factors may result in generation capacity amendments (such as unexpected site conditions or changes in the regulatory environment), which can result in either increase, partial reduction, or a complete cancellation of the project scope.
- **Construction Completion:** The rate at which construction is completed depends on the dimensionless decision variables *Location*, and *Energy Source*. *Energy Source* also controls amount of generation capacity which becomes operational (for example when a geothermal power plant is ready to allow partial operation for each available turbine as resource capacity builds up, or when a wind farm can start operating each wind turbine as it has been installed). Construction completion also depends on construction work quality which can be impacted by various different risk factors (such as when workers are not sufficiently skilled

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[61] The flow at this point is not impacted by the choice of energy technology or geographic location, both of which however through their sub-models tie into the variable *New Investment.*

to work with a new energy technology, or selected location requires developer to hire local workers who prove to be poor performers). Poor quality may result in need for rework, which may not get discovered until the developer inspects the work. The time it takes to execute that rework will result in a delay on expected operation, unless measures are taken to increase the construction rate (such as by adding labor, or other resources). Unless the quality is properly observed, discovering rework too late may be expensive[62], and can have a long term impact on productivity, further lowering quality of work. Skill level of workers, site conditions, and overall experience and learning curve of the project are factors likely to impact quality of work. Once operational, various risk events may result in power plant suffering some capacity loss, such as when equipments get damaged or retire. Depending on the reason, ability, and demand, that may require bringing added generation capacity online using some or all of the new development phases.

- **Capacity retirements**: Final phase is the plant decommissioning, which depends on expected lifetime for the given energy technology.

4.4.3 Modeling risk impacts and mitigations

As stated before, key feature of the System Dynamics model is its ability to display power plant development project risks, their impact on project performance, and mitigation of that impact through risk management methodologies. Risk impacts are captured in a series of sub-modes as follows:

- **Step 1:** Identify and analyze risks at each stage of the power plant development process. Group risks into six risk categories (see Section 0).
- **Step 2:** Model each of the six risk categories as a stock and flow diagram. Flow into stock is controlled by risk criteria specific to each risk category. The more risks present, the higher the flow into risk stock. Flow out of a stock is controlled by a collection of four risk mitigation methods:
    1) **Avoidance:** Risk outflow avoided through project design. This includes elimination of activities which pose the identified risks.

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[62] The change impact is not linear. Delay and disruption ratio of total cost increase to direct cost increase can be around 3 to 5x (Lyneis, 2009).

2) **Controlling:** Risk control methods that decrease the presence of risk in the project and so increase risk outflow from that stock. This type of risk reduction may span a wide range of methodologies, such as use of alternative contract strategies, use of training programs, different methods of construction, prototyping, project redesign, more detailed and further in-depth site investigation, or technical due diligence.

3) **Acceptance:** The developer accepts certain project risks. These may include risks which the developer believes are best handled by themselves for one of the following reasons: a) the developer has more information about risks and their impacts than others, b) the developer is better suited to influence outcome of risks, or c) risks have high correlation across projects which enables the developer to diversify risks within their project portfolio. The developer may have a strategic advantage in the location based on a successful prior experience, enabling better estimation and planning for that risk.

4) **Transfer:** Flow of risk into a stock which collects risks being transferred to another project participant. Depending on risk type, its occurrence may still impact power plant development performance, but cost associated with that impact is assumed by the risk bearer. Risk transfer methodologies can include various contracts, insurance mechanisms, and risk transfer through financial architecture instruments.

- **Step 3:** Show interconnections among risk criteria. For full analysis Analytical Network Process (ANP) model output are used (construction of that model and background of methodology is discussed in details in Section 4.5). The interfactorial dominance matrix provides a complete picture of interconnections among risks. To properly represent these interconnections, feedback loops were designed to incorporate expert beliefs about these interconnections.

- **Step 4:** To show how much each risk criteria contributes to a rise in a risk category stock level, risk weights developed by the ANP model are used to parameterize those risks. As a consequence, overall project risk cannot exceed 100% stock saturation if all risk factors are present in the project, and risk management does not contribute to an outflow of risks from stocks (see also discussion on using this for constructing the project risk profile in Section 4.6).

- **Step 5:** Connect risk category stocks to power plant development process. The higher the stock level, the more impact it has on the flows among development phase stocks, thereby impacting overall project performance by delaying or hindering project completion.

- **Step 6:** Connect individual risk events which impact cost factors to appropriate parameters of the operation cash flow model.

Diagram 4.2 is an example of a sub-model constructed in this way. This model is for the project risk stock (for descriptive simplicity model shows only feedback loops which in the weighted ANP model supermatrix have an impact score of 5 or above on the Saaty scale of 1 to 9).

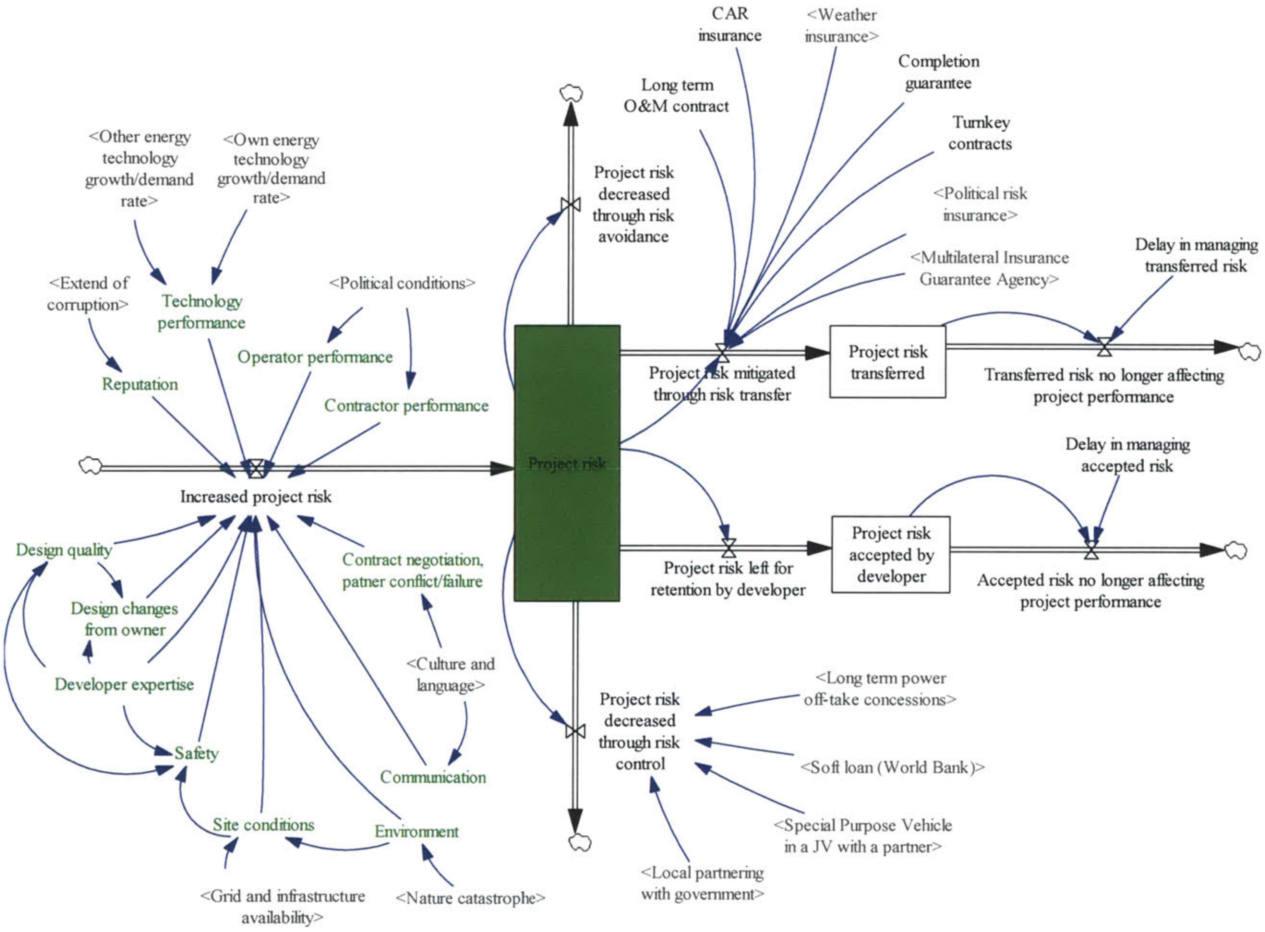

Diagram 4.2 SD model for risks and mitigation methods that make up stock-and-flow for project risks

There are many assumptions behind this representation of how risk factors impact power plant development project performance. In order to use this model effectively it is important to be aware of how key assumptions affect functionality. First, this is a highly simplified representation of the real world problem. Nevertheless, this System Dynamics model introduces a new way of dealing with risks as interconnected clusters, instead of individual risk events. Key assumptions include the following:

1) **Impact of risk events on power plant development performance:**

Severity of risk events is designed in the model to impact both development time and operational cash flow. For impact on the development time, total severity of the risk impact present at each development phase is translated into time impact (measured in months), which either increases or decreases the originally estimated duration of the different development phases. For impact on operation cash flow, depending on the risk event its severity impacts affecting cost and revenue factors, as a percentage increase or decrease to its value. This includes financial risk events, such as volatile fuel prices, commodity prices, exchange rates, or interest rates. The model does not capture instances when magnitude of cost impact as a result of a delay depends on where on the development timeline the risk event occurs. This may be the case at planning phase when few commitments for project delivery have been made, so that delay only results in a small cost per unit time (just postponing the NPV). If the delay however occurs late in construction, the cost may be extremely high (postponing the PV).

2) **Handling of risk interconnections, and risk management methodologies:**

The model has pre-assigned one risk methodology to deal with each of the possible risk occurrences in the power plant development project. This is somewhat simplified as developers may chose different risk methodologies for the risk events, from one project to another. Also, the same risk interconnections are used across all projects. This assumption generally holds, although conditions may vary depending on geographic location, developer type, ownership, and financial structure of the project.

3) **One time occurrence of risk events:**

The model does not show what happens within a development phase. At the beginning of a development phase, the project either is or is not vulnerable to a set of risk events. No risk factor can be disaggregated within a development phase. It can occur no more than once, for example when site condition issues arise during construction, or if there are repeated issues with contractors' performance. The model assumes that the probability of multiple risk occurrences within a development phase get translated into higher impact value through the ANP model results. For example, if a project is assumed to be at high risk of spiraling costs resulting from number of issues with site conditions, or collection of poorly performing contractors, the impact of the associated risk factors will be translated through a higher risk severity estimate through the ANP model.

4) **Handling of concurrent performance delay events:**

For some risk events, if they occur in a project simultaneously with another risk event, their performance impact as measured in time delay will not add to the delay the other risk already accounted for. For example, when poor site conditions may require design changes.

5) **Tradeoff of short term project performance impact and long term impact on developer:**

The model only considers a single development project. It does not prioritize management of risk events whose impact is not visible in short term performance of the project but does impact the developer's performance in future projects. For example, poor social acceptance and local community antagonism, as well as other stakeholder group behaviors which may harm the developer's reputation; i.e. bribes and/or having bad health and safety records.

4.4.4 Modeling electricity generation and operating cash flow

To capture impacts of decision rules for risk response on power plant performance and overall project returns, electricity generation, distribution and sales must be incorporated. To this end the System Dynamics model for the power plant development process is coupled with a stock-and-flow model representing electricity generation distribution, and sales, as in Diagram 4.3 (full documentation appears in Appendix 8).

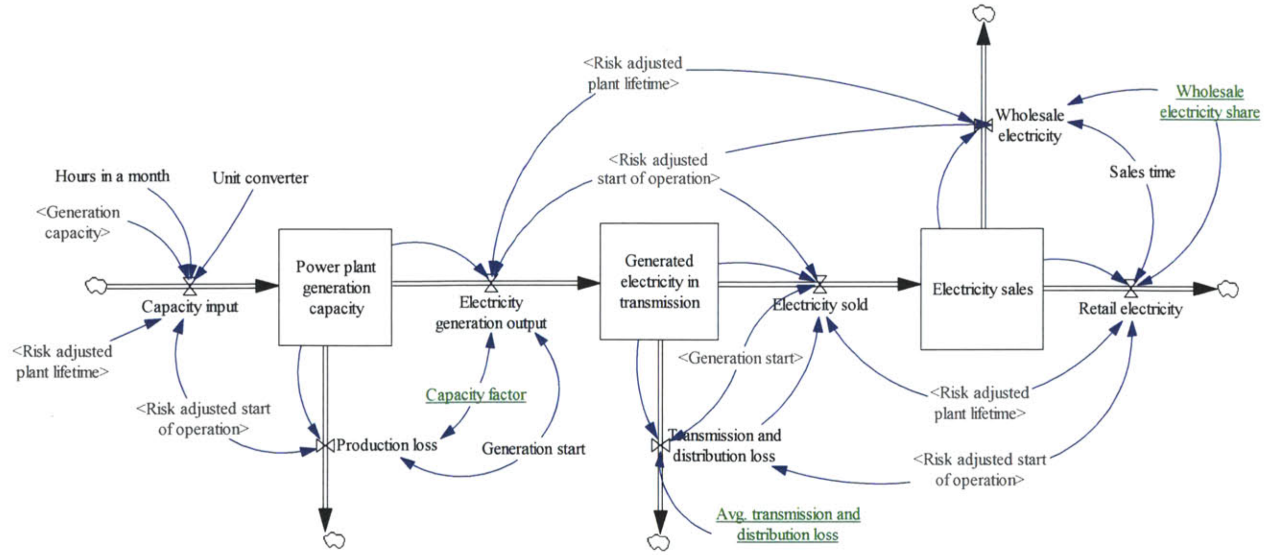

Diagram 4.3 SD model of the power plant's electricity generation, distribution, and sales

The main purpose of this stock-and-flow process is to model electricity sold both wholesale and retail, after taking into consideration production losses to generation capacity, as well as transmission and distribution losses. Three additional project specific input assumptions are needed to run this model (for identification those variables are underlined in the model diagram):

- Wholesale electricity sales as percentage of power plant generation output (%).
- Average transmission and distribution loss (%).
- Generation capacity factor for this energy technology (%).

This model's output fed into the cash flow model to translate risk impacts into changes in cost performance. Diagram 4.4 shows structure of the cash flow model (full documentation appears in Appendix 9).

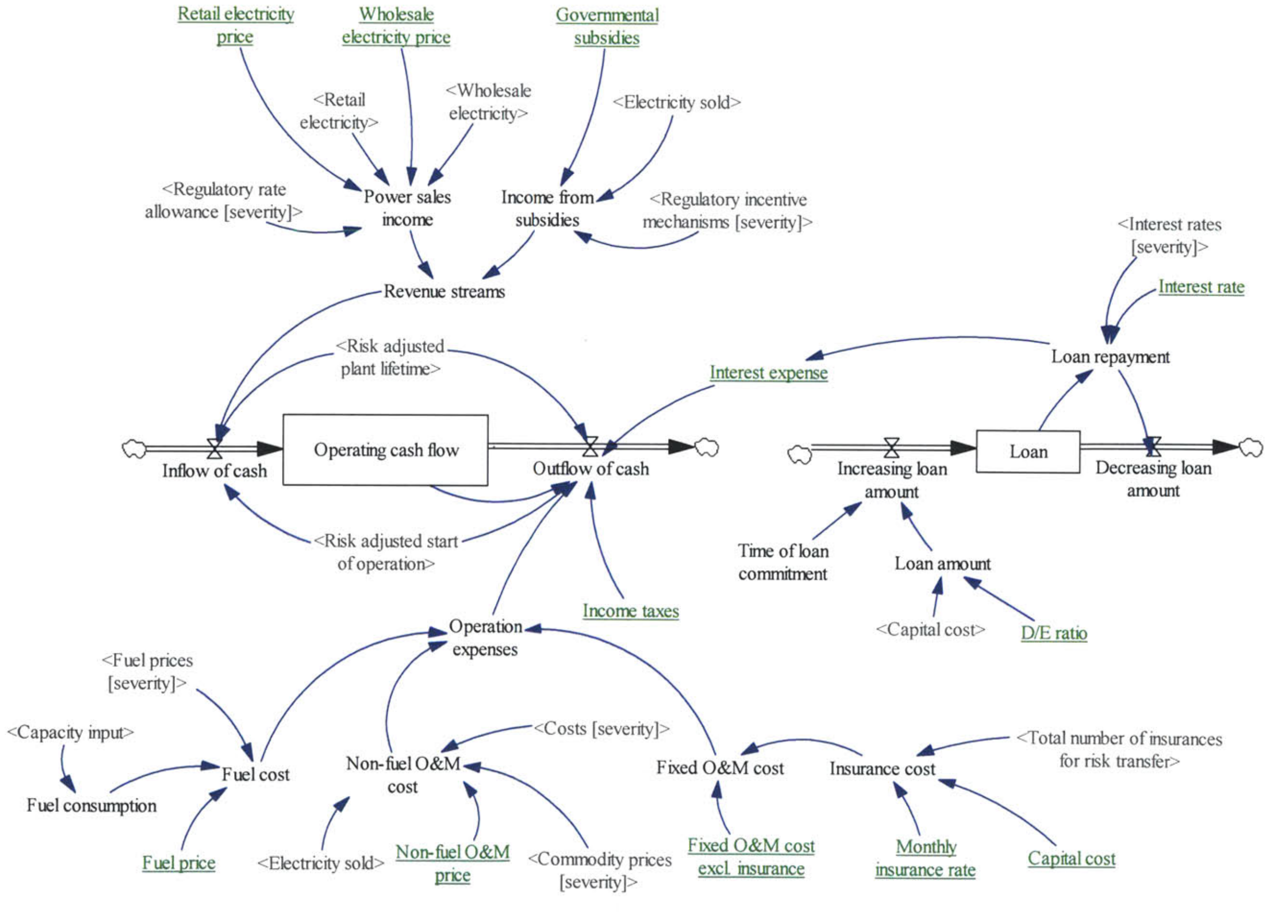

Diagram 4.4 SD model of the power plant's operating cash flow throughout its lifetime

Operating cash flow is based on electricity generation and sales, adjusted for risk impacts on electricity delivery and operation. In addition, several input assumptions need to be made about the project's financial structure, operation expenses, and sales contracts[63]. The following variables are exogenous and given (for identification those variables are underlined in the model diagram):

- Retail electricity price (USD/MWh)
- Wholesale electricity price (USD/MWh)
- Monthly insurance rate (%)
- Total capital cost at beginning of first operational year (USD)
- Non-fuel variable O&M cost (USD/MWh)
- Fixed O&M cost (USD)
- Insurance rate as % of power plant cost (%)[64]
- Income taxed as % of operating income minus interest expense[65] (%)
- Debt and equity ratio (%)
- Interest rate on debt (%)
- Debt term (years)
- Government subsidies (USD/MWh)

4.4.5 Example of SD modeling for risk management and decision making

The following example is designed to demonstrate how the System Dynamics model can be used as an aid to decision making under uncertainty. It is a simplified representation of a development of a 100 MW power plant. Diagram 4.5 shows the stock and flow model that represents the power plant development process (full documentation appears in Appendix 10).

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[63] These input assumptions do not consider any price escalations throughout the project lifetime. The only price changes that happen are through percentage increase/decrease as a result of risk impacts.

[64] Insurance is modeled separate from the fixed cost in order to be able to separate cost impact related to risk transfer through insurance mechanisms.

[65] Not considering the power plant's depreciation.

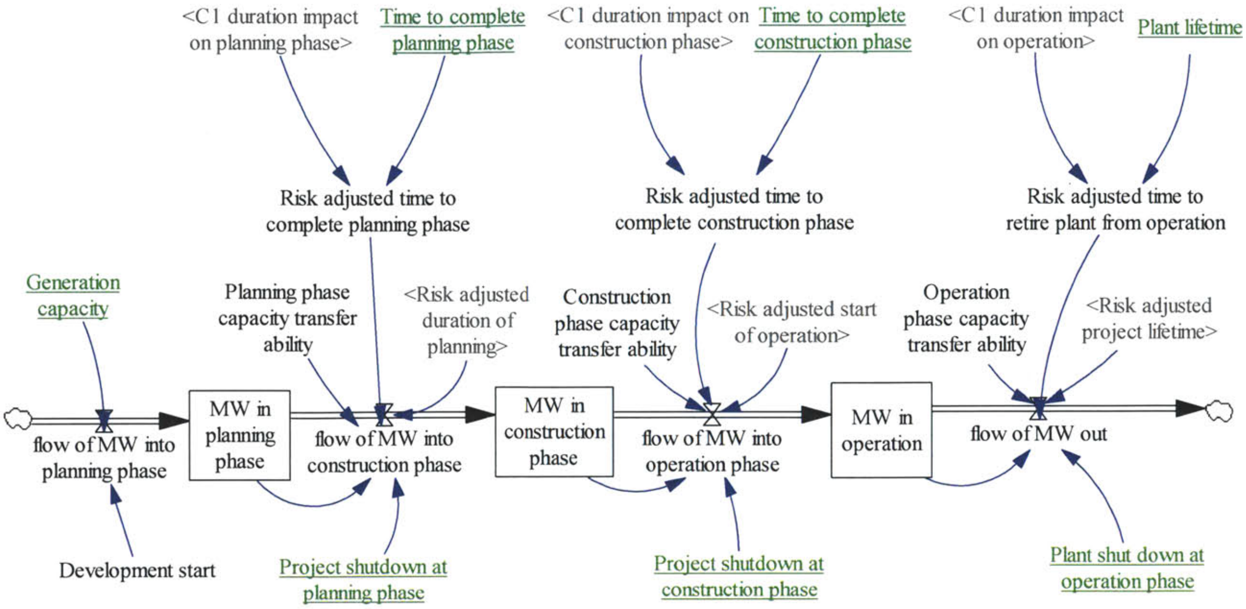

Diagram 4.5 SD stock-and-flow model of example power plant development process

The following exogenous parameters need to be assigned project specific values (for identification these parameters are underlined in the model diagrams):

- **Capacity**: Estimated generation capacity of the power plant in MW. In this example we assume that the power plant is designed to have 100 MW generation capacity[66].
- **Time duration:** Estimated duration of each development phase (planning, construction, and operation) in months. In this example we assume that the expected duration of the development phases is originally estimated to be: 12 months for the planning phase, 24 months for the construction phase, and 36 for the operation phase.
- **Risk weight:** The ANP model is used to determine impact weight values for each risk factor (see Table 4.12 for those values).
- **Risk tolerance:** The developer's tolerance for risk during each of development stages is rendered explicit. For example, if the first stage expected development time adjusted for risks are expected to exceed what the developer considers accepted delay, the project will be shut down. In this example we assume that the developer tolerates up to twice the expected

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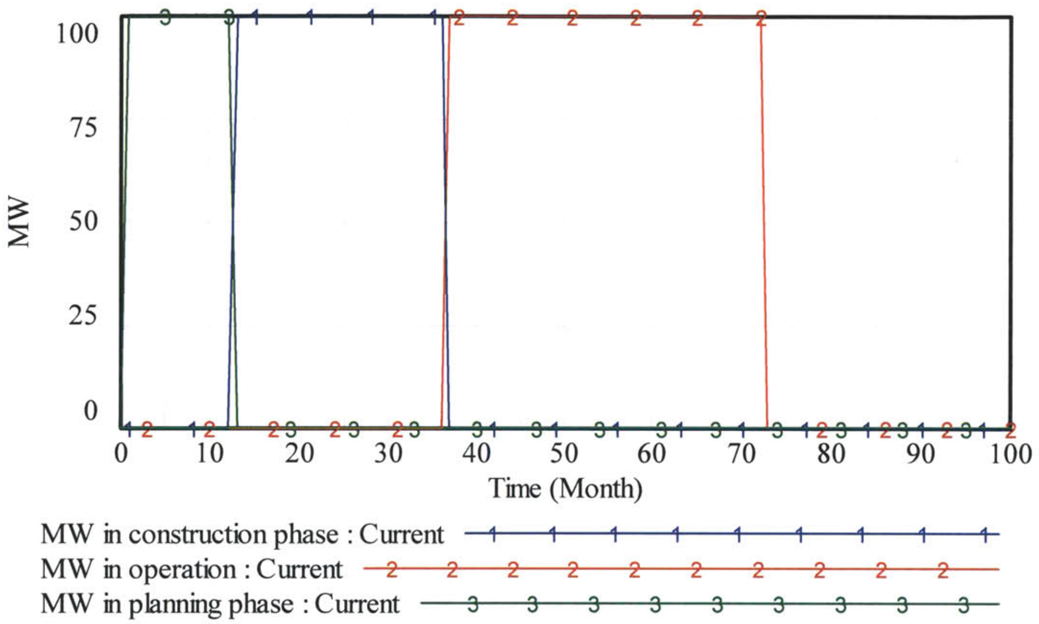
[66] Note that this simplified example does not show how the model can capture how risks can impact scope of the project through decrease (or increase) in the generation capacity.

duration for the planning and construction phases, i.e. for the planning phase the project will be shut down if the risk adjusted duration exceeds 24 months, and for the construction phase if it exceeds 48 months. For the operation phase we assume the developer will retire the project early if risk adjusted operational lifetime of the plant is expected to be lower than 24 months.

When the model is run without any performance risk impact, the total project lifetime from project start to the plant retirement is 72 months, as shown in Graph 4.10.



Graph 4.10 Modeled duration of each project development stage

We use the following three modeling scenarios to show how our model aids decision making based on the developer's appetite for risk 1) the first scenario shows how power plant development performance is impacted by risk when no risk management methods are in place to mitigate them, 2) the second scenario shows how risk management methods can help manage the impact of realized risks on development performance, and 3) the third scenario shows how a developer can prioritize implementation of risk management methods based on risk appetite.

Scenario 1) Risk impact but no risk management

In this scenario, a very simple representation of risk events is used. There is only one risk category (referred to as C_1). It represents the collection of potential risk factors in the project, and only three risk factors (referred to as R_1C_1, R_2C_1, and R_3C_1) make up that category. The following characteristics are assigned:

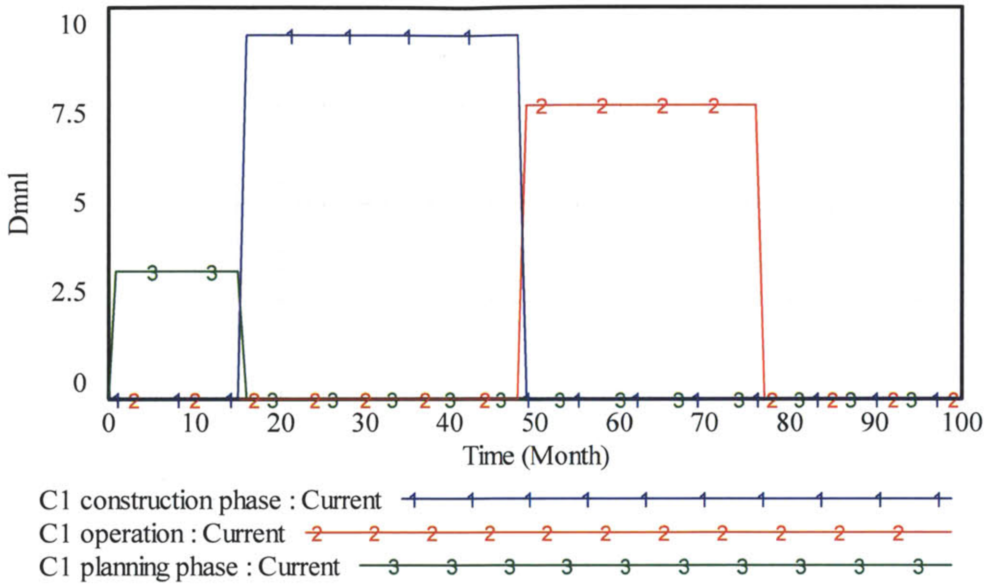
- **Phase of performance impact**: Information describing how risk factor affects each of the three development phases (planning, construction, and operation).
- **Risk weight**: ANP model weights are employed.
- **Expected risk impact**: The expected development performance impact (measured in months) which this risk event has on the project.

The product of risk weight and expected risk impact is a natural measure of risk severity. For planning and construction stages this measure is used to represent a delay. A delay can take many forms; it takes more time than expected to secure required permits during the planning stage, or as site conditions might increase construction time. During the operation stage however, a power plant designed to last a certain lifetime may need to be retired earlier due to technical generation equipment failure. Table 4.12 is an overview of values assigned to risk factors for our example.

Risk factor	Phase of performance impact	Risk weight	Expected risk impact (months)	Risk severity as performance change (months)
R_1C_1	Planning, Construction	0.35	5	1.75
R_2C_1	Planning	0.15	10	1.5
R_3C_1	Construction, Operation	0.50	15	7.5

Table 4.12 Characteristics of the risk factors used in the SD model example

Graph 4.11 shows the impact of performance risk factors at each development stage: Increased risk adjusted development time by around 3 months during the planning stage, around 9 months during the construction stage, and decrease in plant operation by around 7 months.



Graph 4.11 Severity of risk impact during each development stage

Scenario 2) Risk impact with risk management

In this scenario risk management methods are used to mitigate risks during each development phase. Table 4.13 shows how the risks are defined.

Risk factor	Phase of performance impact	Example definition	Risk management	Example risk management
R_1C_1	Planning, Construction	Political conditions	Transferred	Purchase political risk insurance
R_2C_1	Planning	Social acceptance	Accepted	Management through awareness
R_3C_1	Construction, Operation	Contractor performance	Controlled	Offer a training program

Table 4.13 Risk management for risk factors used in this SD model example

Diagram 4.6 shows how management of risk C_1 in the first development stage is modeled. As Table 4.13 shows, only two of the risk factors can impact development performance of that stage, R_1C_1 and R_2C_1. Risk R_1C_1 gets transferred. This reduces performance impact on development time, but increases overall development cost (see discussion for scenario 3). The R_2C_1 risk is accepted by the developer. That does not introduce any upfront cost, but its severity is taken into account in total expected development time.

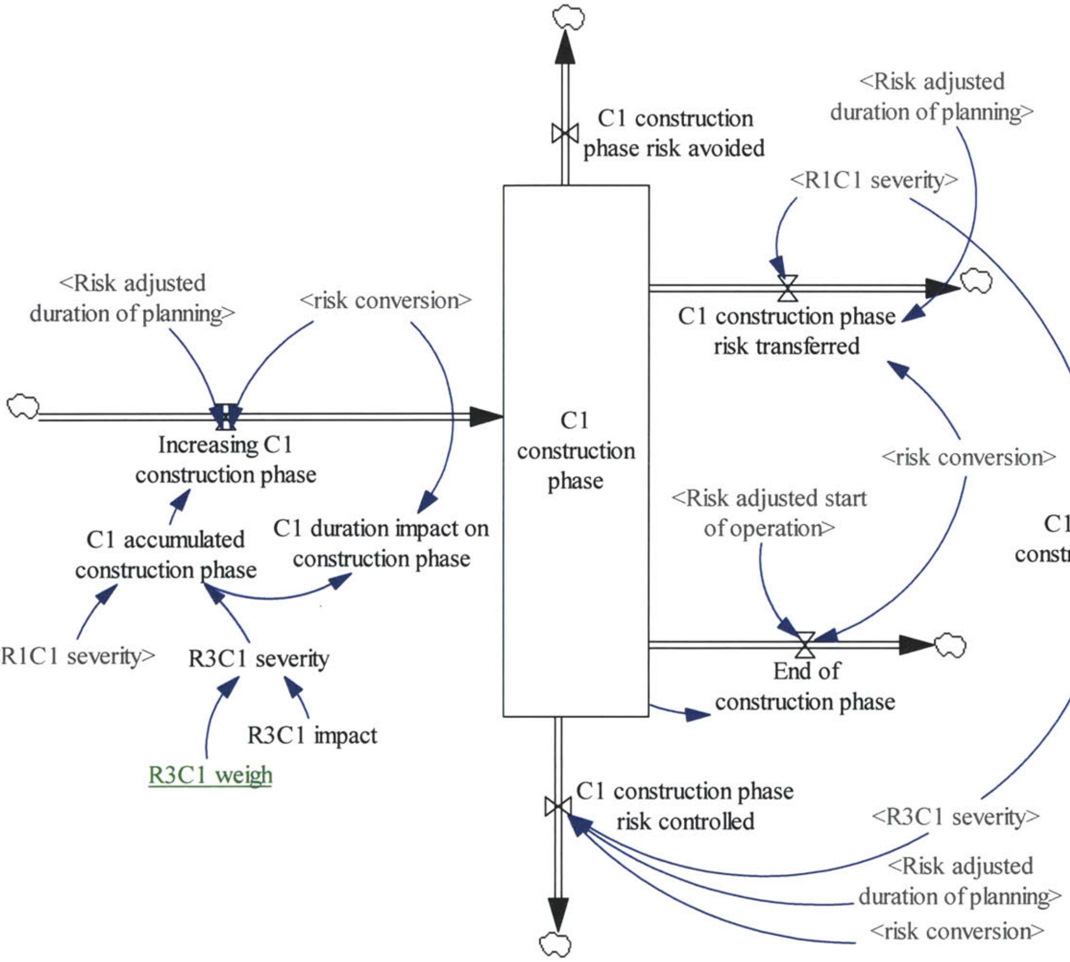


Diagram 4.6 Stock-and-flow sub-model for C1 risk and its management during planning phase

Risks R_1C_1 and R_3C_1 impact the second development stage. As in the first stage of development, risk R_1C_1 is transferred, however risk control methods are employed to mitigate risk R_3C_1, the only risk present in the third development stage, using the same risk management method as in stage two. Table 4.14 is a summary.

	Duration of each development phase (months)[67]		
Development phase	**Original estimate**	**New estimate: Scenario 1, no risk management**	**New estimate: Scenario 2, with risk management**
Planning	12	15	14
Construction	24	33	24
Operation	36	29	36

Table 4.14 Changes into power plant development performance given different scenarios

Our model also accounts for the developer's overall risk tolerance at each development stage. This risk tolerance serves as a monitor, i.e. even with no risk management methods designed into the project the developer has a certain tolerance for the potential impact of risk events on development performance. This risk tolerance can and should be designed to reflect the developer's risk appetite as discussed in the following scenario.

Scenario 3) Prioritizing risk management based on developer's risk appetite

In this scenario we show how the developer can prioritize risk management response as a function of risk appetite. Given that performance impact in this example is measured as impact on development time, one way to measure the developer's risk appetite is to determine how sensitive the project is to delay in expected Commercial Operation Date (COD), i.e. the date the power plant is fully developed and ready to start delivering generated electricity.

When a contractually agreed upon COD is not met it can have an extensive and damaging impact on the developer.

- **Development costs**: Development cost can increase as a result of increased overhead cost, cost of design changes, construction contract amendments, overtime, cost of managing pressure from media, etc.
- **Resource availability:** Extending development time needed may impact resource availability, such as manpower, and equipment. Skilled workforce and heavy equipment may be

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[67] In order to run the model, all time variables are rounded to be whole integers.

contractually obligated to move on to work on other projects. It can also impact access to infrastructure needed for development.

- **Reputation:** Late delivery can hurt the developer's reputation on many levels; it can impact future ability to secure regulatory permits, ability to be granted land access, ability to secure electricity sales contracts, other developer's willingness to form strategic partnerships, etc. Trying to fix the situation afterwards by speeding the work could increase risk of accidents, and result in poor work quality, which will also hurt the developer's reputation.
- **Late delivery fees:** Electricity delivery agreements, such as PPA, will have clauses in it detailing fees which the developer must pay for each day beyond the agreed upon electricity delivery date. In order to meet firm delivery agreements, the developer may need to pull electricity (partly or fully) from other generation sources which can have spiraling cost implications.
- **Project returns:** Lower project returns could impact stakeholders' support for future development projects, and developer's ability to secure financing on future projects.
- **Social acceptance:** Local communities may depend on electricity being delivered on time, construction development traffic to be gone, operation employment opportunity to have begun, etc. Not meeting the expected date of operation could harm not just the social acceptance by the local community but could have a spillover effect into other regions through media coverage.

Each developer will have a measure of his and her willingness to incur the multiple cost of late delivery. This measure will differ from one project to another and will not necessarily be related to site location (because of the spillover effect across the industry and overall corporation), or plant size (as smaller projects may still be strategically important for proper execution).

If in this example, we assume that the 100 MW power plant was expected to cost 100 million USD, and that the developer's assessment of the cost of electricity delivery delay will be 5% of the total capital cost for each month of delay (resulting from their assessment of cost associated with the areas impacted as listed here above), that means a total cost of 60 million USD. If we assume that the cost of transferring the risk is 1% of total capital cost per year (such as could be the cost of purchasing political risk insurance) and that the cost of controlling the risk is a 10 million USD upfront cost (such as could be the cost of providing a training program), the total cost of risk management can be assumed to be 13 million USD (ignoring time value of money in this very simplified example). This is summarized in Table 4.12.

Expected generation capacity of power plant	100 MW
Expected capital cost	100 million USD
Expected Commercial Operating Date (COD)	36 months from project start
Risk impact if no risk management	Delay of COD by 12 months
Cost associated with COD delay	5% of capital cost per each month of delay
Total cost of delay assuming no risk management	60 million USD
Total cost of risk management	13 million USD

Table 4.15 Risk management for the risk factors used in this SD model example

Based on this information, the developer can run a scenario analysis to see which risk management methods are best suited to their risk appetite, given the value comparison of their tolerance to go beyond the expected COD to the total cost of the risk management design.

4.5 ANP Based Modeling

Sequential decision making schemes that optimize via backward induction (dynamic programming) are difficult if not impossible to imbed in a System Dynamics. To attempt to overcome this disadvantage our System Dynamics model is coupled to multi-criteria decision analysis (MCDA) models: The Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) which are two MCDA techniques developed by Saaty in the 1980s (Saaty, 1996).

The idea behind them is that the human mind cannot process more than nine different things at a time. Using AHP a multi-criteria decision problem is broken down to multiple levels in such a way that they form a hierarchy with unidirectional hierarchical relationships between levels. The hierarchy's top level is structured to measure the degree to which a strategy achieves main goal of the decision problem. Lower levels are tangible and/or intangible criteria and sub-criteria that contribute to the goal. Alternatives to evaluate appear in the bottom level. AHP uses pairwise comparison to allocate weights to elements of each level, measuring their relative importance with Saaty's 1–9 scale, and finally calculates global weights for assessment at the bottom level.

However, there are limits to how well the AHP methodology can handle the complexities of many real world problems. The strict hierarchical structure is rigid. Saaty proposed the ANP model as an alternative. It represents a decision making problem as a network of criteria and alternatives grouped into clusters. This provides a more flexible and accurate modeling of complex settings, and the influence of each element in the network on other elements in that network can be represented by a super-matrix of importance weights. This two dimensional matrix adjusts relative importance weights in individual pairwise comparison matrices to build a new overall super-matrix with the eigenvectors of the adjusted relative importance weights (Aragones-Beltran, Chaparro-Gonzalez, Pastor-Ferrando, & Rodriguez-Pozo, 2010).

The following section suggests how the ANP method can be effective in building an investment strategy for selecting amongst power plant development projects based on perceived risks. As Chapter 3 showed, there are many potential risk factors in any power plant project. And, as Saaty points out, the ability of humans to assess many factors at the same time is very limited. The task is simplified by classifying risk factors into a small number of groups or sets, so that the developer can assess the relative priority or importance of each risk factor by pairwise comparison of all factors with respect to certain criteria. After assessing risks in each individual small group step by step, an overall risk assessment can be used to generate the project risk profile, which combined with the System Dynamics model can be extended beyond the investment decision point to serve as a guideline for risk management throughout the power plant development lifetime. This will be discussed in Section 4.6.

Both AHP and ANP have been applied to location, resource, and project selection problems and recently some applications have emerged in the domain of project risk assessment. The following key characteristics explain some of the reasons for adopting these methodologies for a risk based power plant development project selection.

- Risk based power plant development project selection is inherently multi-objective in nature.
- Complexity of power plant evaluation is steadily rising, as more criteria are involved in the overall assessment while evaluation data change rapidly.
- Power plant development projects include many different energy technologies for power generation, each of which has its own set of risks involved. No single decision making method is sufficient.
- To be useful, analytical methods must take into consideration not just tangible but also intangible criteria. Quantitative and qualitative risk factors must be evaluated and compared. Hard to quantify risks (such as social acceptance risk), along with risks that are not easily describable (such as future technology development) must be brought to play.
- Dependencies within and among groups of risks affect total risk.
- A detailed analysis of interdependences among clusters forces the decision maker to carefully reflect on his/her project priority approach and on the decision making problem itself, which results in a better knowledge of the problem and a more reliable final decision.

Despite obvious benefits of linking together a set of analytic decision making tools, a literature review did not uncover a single study which provides a roadmap to treatment of all power plant development project risk factors as a selection problem under uncertainty. Table 4.16 shows some recent applications of AHP and ANP based on different criteria for power plant selection in a variety of locations.

Model characteristics	**AHP/ANP**	**Authors**
Selecting amongst PV project opportunities in Spain based on a risk assessment	ANP	(Aragones-Beltran, Chaparro-Gonzalez, Pastor-Ferrando, & Rodriguez-Pozo, 2010)
Selection of a wind farm project in China based on benefits, opportunities, costs, and risks of the performance, business drivers, and socio-economic needs	AHP	(Lee, Chen, & Kang, 2009)
Power plant selection based on technological, economic, and sustainability criteria	AHP	(Chatzimouratidis & Pilavachi, 2009)
Evaluation of renewable energy alternatives based on a collection of criteria	ANP	(Kahraman, Kaya, & Cebi, 2009)
Selection of best fuel mix for energy generation in Turkey based on benefits, costs, opportunities, and risks	ANP	(Kone & Buke, 2007)
Location selection for wind observation station based on several evaluation criteria	AHP	(Aras, Erdogmus, & Koc, 2004)

Table 4.16 Recent applications of AHP and ANP for selection of power plant development projects

4.5.1 Background to the model development

As Diagram 4.7 shows, the MCDA process for the ANP approach to a power plant development selection problem can be viewed as three phases of analysis, synthesis, and evaluation.

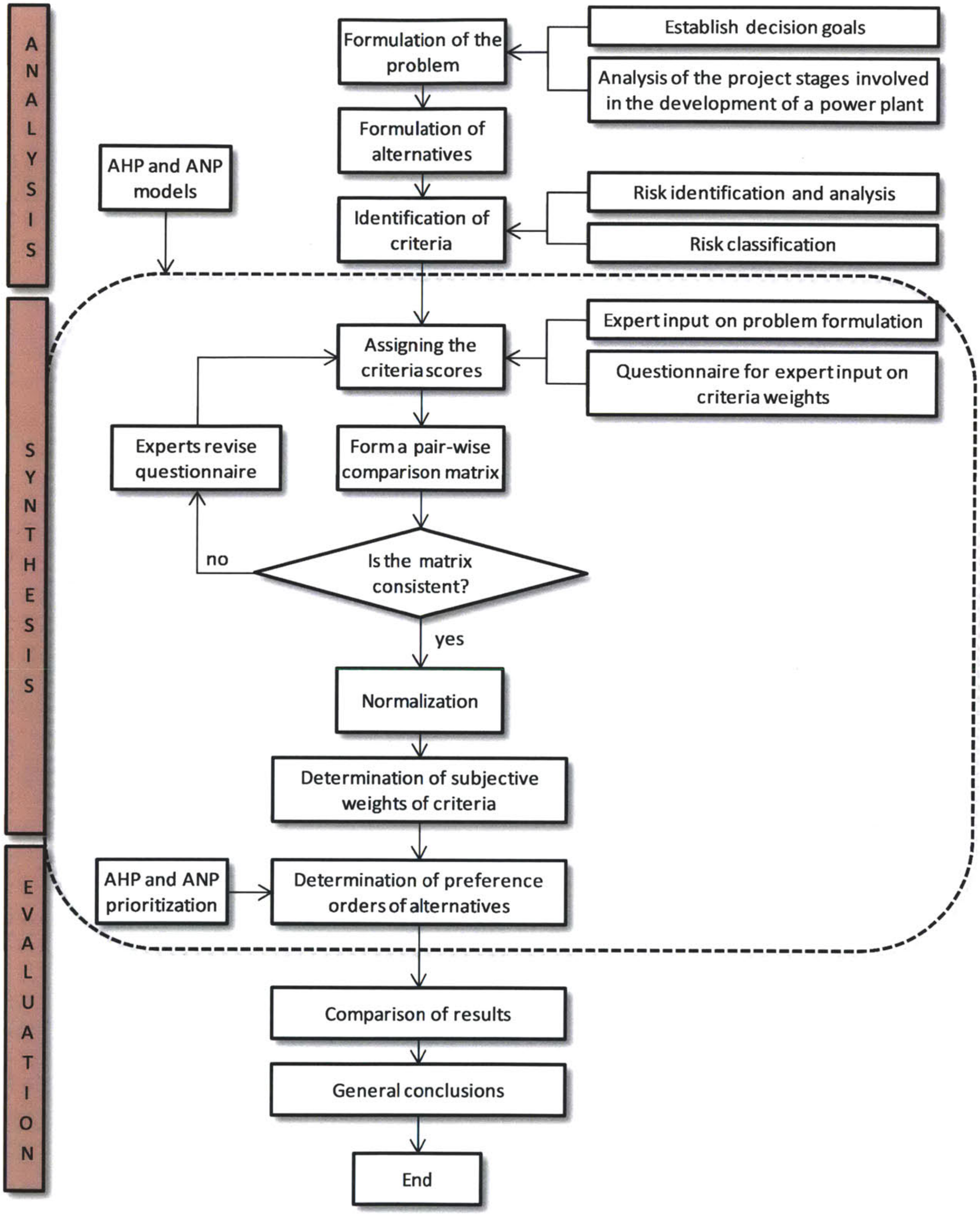

Diagram 4.7 MCDA process for the AHP and ANP approach to power plant development selection

Here is a more detailed description of each step.

- **Step 1:** The decision problem is formulated, and the principal objectives of the analysis are identified. Namely, the developer wishes to select the "best" power plant development project to invest in (from a preselected set of alternative projects) based on minimization of developer's perceived potential risk impacts on the project, and their competitive advantage to influence that risk. This step requires a full analysis of existing strategies and approaches amongst developers for new power plant investment decisions, as well as analysis of the project stages involved in the development of a power plant (see detailed discussion in Chapter 2).
- **Step 2:** In the next step, a risk identification and analysis was carried out for each stage of development. Through risk classification, risks are grouped into risk categories (see Section 0), and the model's control hierarchy is designed. The hierarchy contains six risk categories, each of which contains a subset of risk criteria. Each risk criteria is explained in detail, to ensure that they are easily understood by experts.
- **Step 3**: A developers' representative qualified as an industry expert is selected for each energy technology under evaluation. Each developer is experienced in power plant development, and was capable of providing an in-depth analysis of risk criteria. They were asked to critique the problem formulation, and then to help develop criteria scores based on ANP modeling that provided a relative importance measure of each risk criterion in terms of its influence on the other risk criteria.
- **Step 4:** Analyze influences among groups of risks and project alternatives. Create an influence network represented by a zero-one inter-factorial dominance matrix, whose element a_{ij} is 1 if the industry expert judges that risk criteria in row i influences risk criteria in column j in some fashion.
- **Step 5:** Represent risk criteria interdependence graphically using the Super Decisions software[68]. Super Decisions helps identify key relations among the clusters. This graphical representation helps determine how risk interdependencies are modeled in the System Dynamics model (see previous discussion in Section 4.4.3).
- **Step 6**: To get experts' evaluation on the criteria scores a questionnaire with Saaty's nine-point scale was prepared. This questionnaire asked the experts to conduct a pairwise comparison of

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[68] This software was obtained on www.superdecisions.com.

each of the risk criteria following the question: *"Given two lower level risk criteria, which one is more likely to present a higher risk to the project, thereby impacting the power plant development process performance, and to what extent according to Saaty's 1-9 scale"*. As this model was being constructed for demonstration of applicability, based on hypothetical project opportunities under evaluation, each developer contributed to this assessment based on their field of expertise, in terms of energy technology and geographical region. Their analysis was based on the assumption that the projects under consideration had been determined economically, technically, and environmentally feasible, and that final selection on the "best" project to invest in was the only decision remaining.

- **Step 7:** Expert input was used to form a pairwise comparison matrix, to calculate strategic criteria priorities. If an inconsistency was found in the matrix, experts were asked to revise their questionnaire answer, and the calculation was done again.
- **Step 8:** After normalizing criteria scores, criteria weights are calculated. The higher the weight, the more likely the industry expert perceives that particular risk criteria might impact power plant development project under evaluation.
- **Step 9:** Finally, we use risk weights to build development project the risk profiles (see Section 4.6 for further discussion on modeling of the risk profiles).

4.5.2 Example of ANP modeling

As discussed in Section 4.5.1, ANP modeling was done for each energy technology to be able to make a comparison of weight of risk criteria across different power plant development projects. The following section gives an example of the modeling approach. This example is based on criteria evaluation given by a representative of an IPP developer, with expertise in development of geothermal power plants[69].

A key thing to be able to compare weights of risk criteria across different types of power plant development projects was to ensure that each industry expert evaluated the energy technology based on identical lists of risk criteria, which therefore needed to be as complete and comprehensive of all potential risk criteria as could be identified. Section 3.1 shows how these risks were identified, and analyzed for each stage of the power plant development process. Through risk classification, risk criteria

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[69] Identity of the IPP developer is left out for proprietary reasons.

(or elements) were grouped into risk categories (or clusters), which were used to construct control hierarchy for the model. The hierarchy tree is presented in Figure 4.3. The goal, which is choice of the "best" power plant development project for the developer to invest in according to risk criteria of following levels, is given at the top level. At the bottom of the hierarchy are project opportunities under consideration, and intermediate levels show risk criteria grouped by risk category[70].

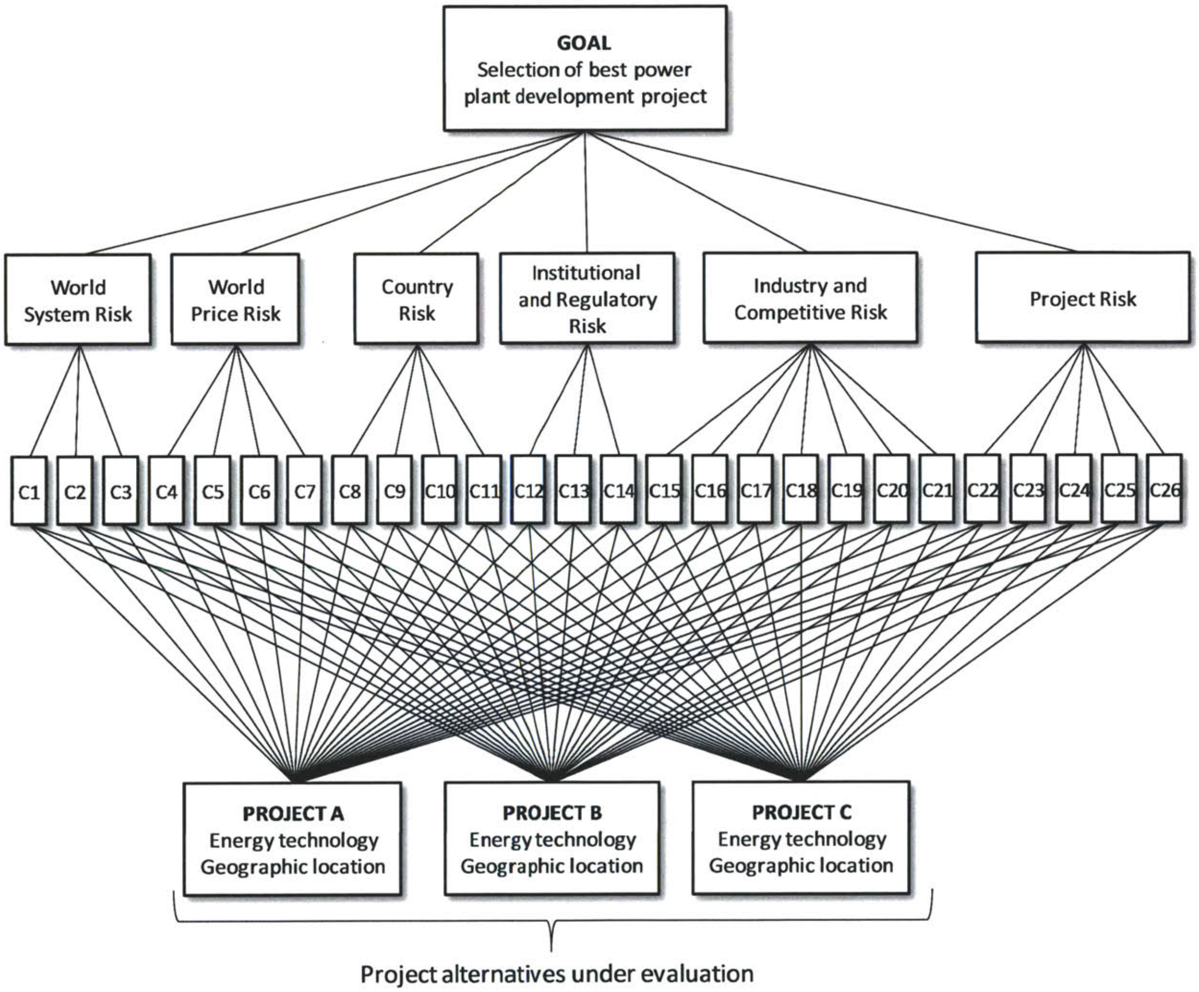

Figure 4.3 Hierarchy for the selection of the best power plant development project based on the perceived risk involved

For the determination of the influences a zero–one interfactorial dominance matrix was used whose elements a_{ij} take the value 1 or 0 depending on whether there is or there is not some influence of element i on element j. Rows and columns of the matrix are formed by all elements of the network.

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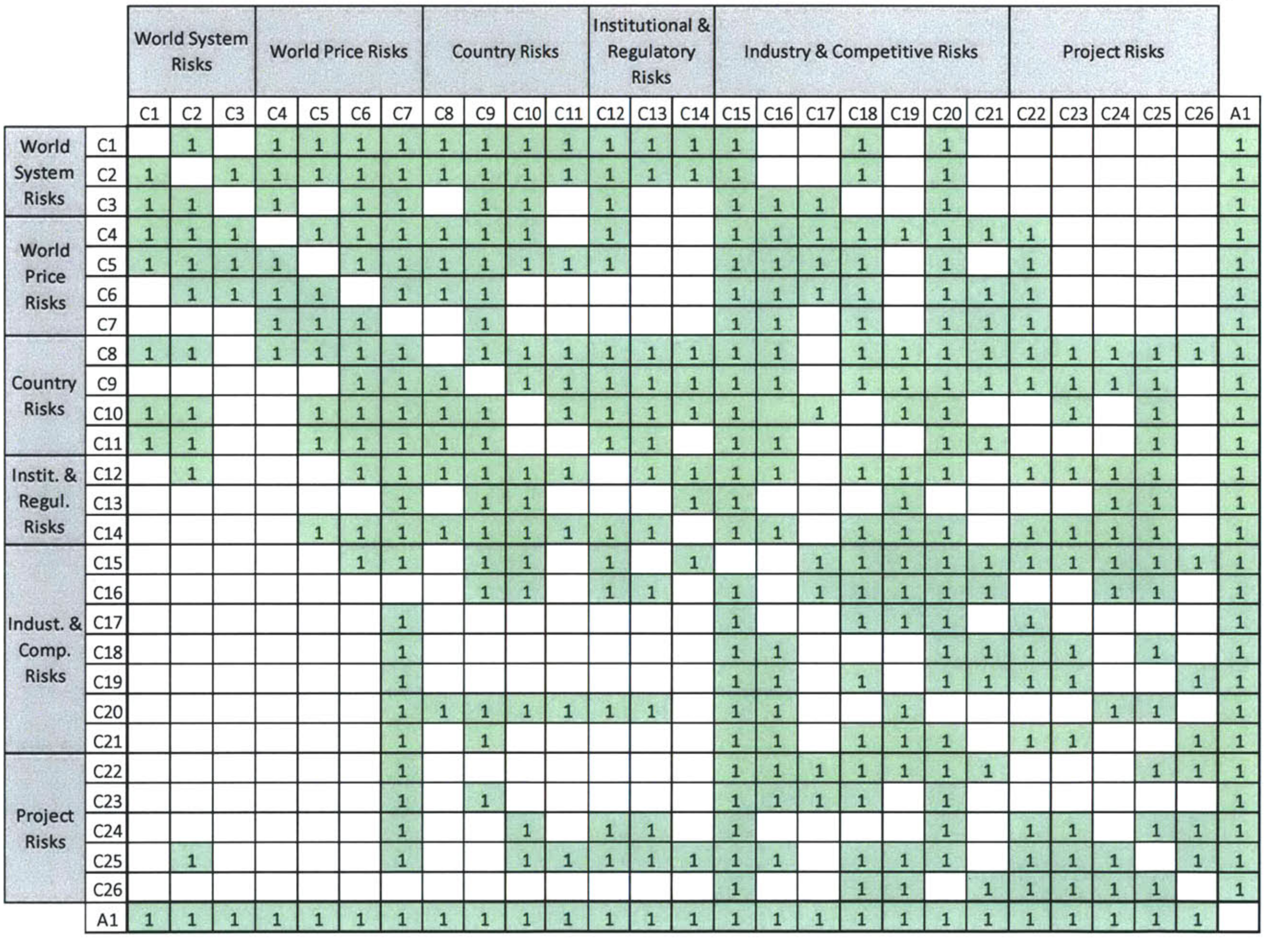
[70] According to Saaty, each cluster cannot contain more than nine elements. The complete list of risks identified which can be found in Table 3.2, is therefore slightly simplified here for correct execution of the modeling technique.

In order to construct a network of influences between different risk criteria, the industry expert was asked to determine influence that each risk criteria exerted on another risks. As there were 26 risk criteria elements, this meant n(n-1) or 650 questions which the developer needed to go through asking: *"Does risk criteria in row i have any influence on column j"*. This input was used to build a zero-one interfactorial dominance matrix, which can be seen in Figure 4.4.



		World System Risks			World Price Risks				Country Risks				Institutional & Regulatory Risks			Industry & Competitive Risks							Project Risks					
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	A1
World System Risks	C1		1		1	1	1	1	1	1	1	1	1	1	1	1			1		1							1
	C2	1		1	1	1	1	1	1	1	1	1	1	1	1	1			1		1							1
	C3	1	1		1		1	1		1	1		1			1	1	1			1							1
World Price Risks	C4	1	1	1		1	1	1	1	1	1		1			1	1	1	1	1	1	1	1					1
	C5	1	1	1	1		1	1	1	1	1	1	1			1	1	1	1		1		1					1
	C6		1	1	1	1		1	1	1						1	1	1	1		1	1	1					1
	C7				1	1	1			1						1	1		1		1	1	1					1
Country Risks	C8	1	1		1	1	1	1		1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1
	C9						1	1	1		1	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1
	C10	1	1			1	1	1	1	1		1	1	1	1	1		1		1	1			1		1		1
	C11	1	1			1	1	1	1	1			1	1		1	1				1	1				1		1
Instit. & Regul. Risks	C12		1				1	1	1	1	1	1		1	1	1	1		1	1	1		1	1	1	1		1
	C13							1		1	1				1	1				1					1	1		1
	C14					1	1	1	1	1	1	1	1	1		1	1		1	1	1		1	1	1	1		1
Indust. & Comp. Risks	C15						1	1		1	1		1		1			1	1	1	1	1	1	1	1	1	1	1
	C16									1	1		1	1		1		1	1	1	1	1			1	1		1
	C17							1								1			1	1	1		1					1
	C18							1								1	1				1	1	1	1		1		1
	C19							1								1	1		1		1	1	1	1			1	1
	C20							1	1	1	1	1	1	1		1	1			1					1	1		1
	C21							1		1						1	1		1	1	1		1	1			1	1
Project Risks	C22							1								1	1	1	1	1	1	1				1	1	1
	C23							1		1						1	1	1	1		1							1
	C24							1			1		1	1		1					1		1	1		1	1	1
	C25		1					1			1	1	1	1	1	1	1		1	1	1		1	1	1		1	1
	C26															1			1	1		1	1	1	1	1		1
	A1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

Figure 4.4 Interfactorial dominance matrix for the ANP model

This interdependence of different risk criteria was represented graphically using the Super Decisions software[71] that showed relationship among the clusters that can be seen in Figure 4.5. At such high level the relationship among the clusters do not derive any particular insight, but when viewed one level below, the interdependence gave an interesting insight that acontributed to modeling of risk interdependence of the System Dynamics model (see previous discussion in Section 4.4.3).

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[71] This software was obtained on www.superdecisions.com.

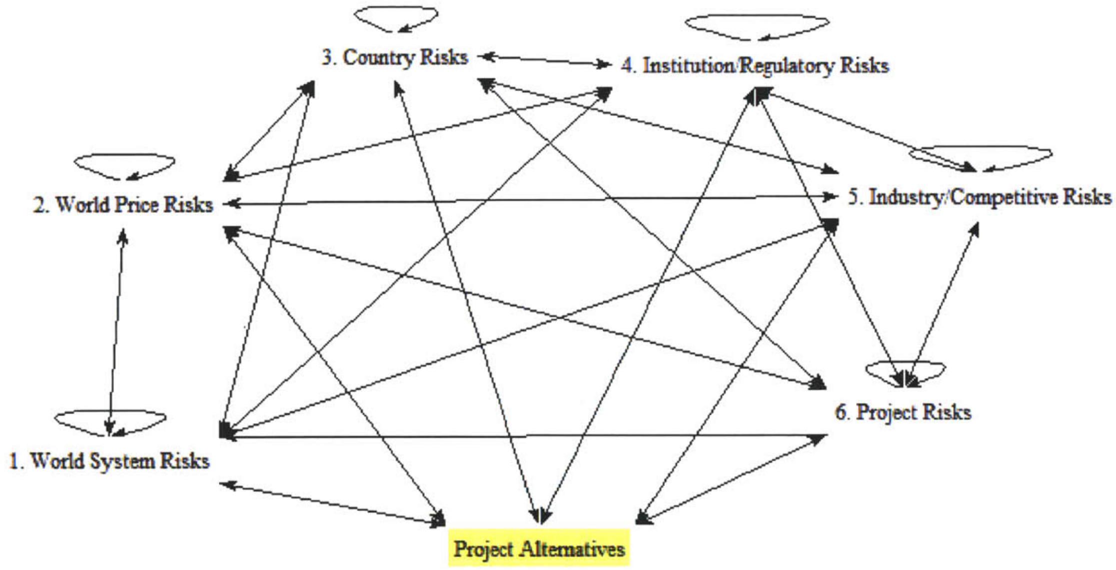
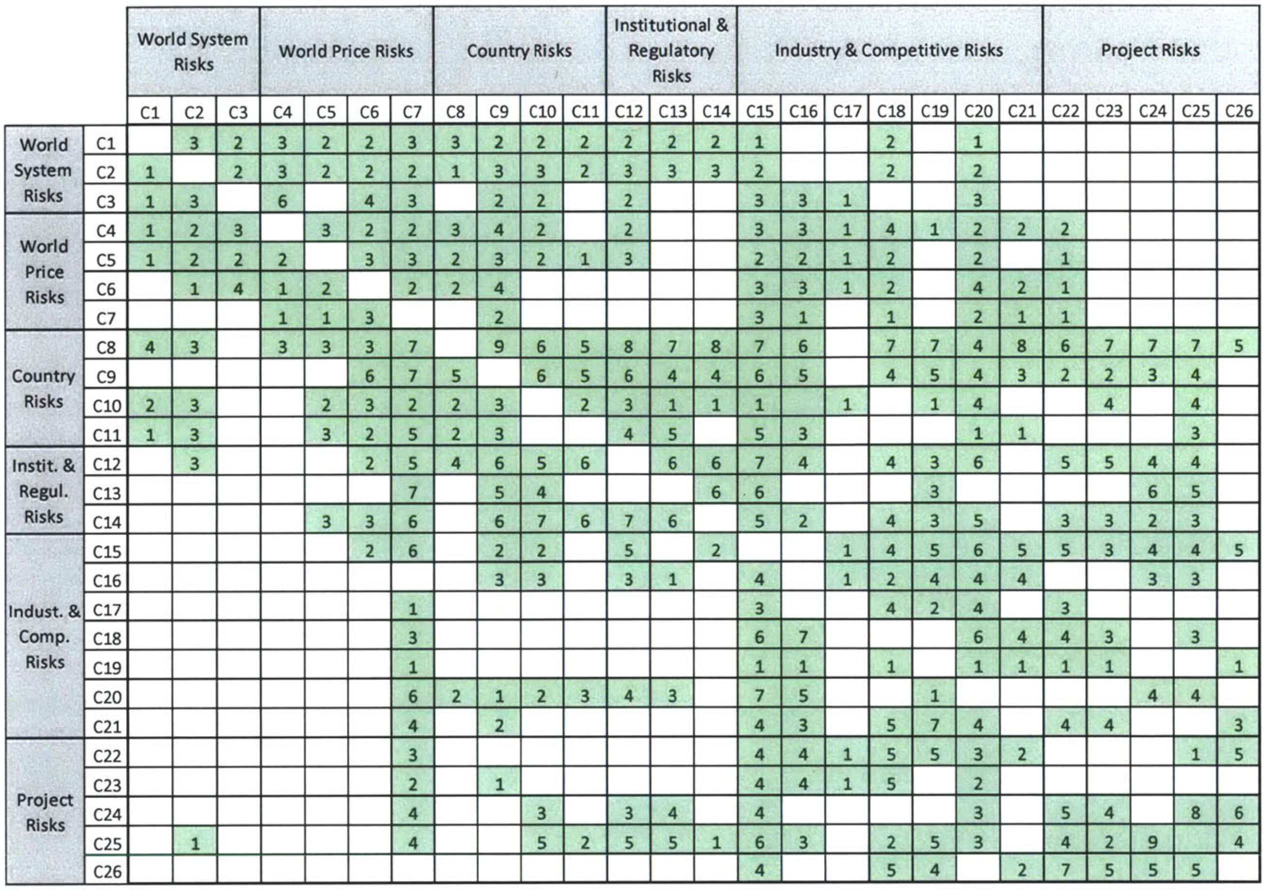


Figure 4.5 Influence relationship in the ANP model

In order to determine weight of the risk criteria, the industry expert was asked to prioritize the risk influence. This was done using a pairwise comparison based on Saaty's 1-9 scale. Using the interfactorial dominance matrix, each risk criteria which exerts influence on another risk criteria, was evaluated to what extent this influence was. The score (given as a_{ij} for risk influence of criteria in row i to criteria in column j) in the pairwise comparison matrix thereby represents relative importance of risk criteria in row i over risk criteria in row j. Given these two risk criteria, the score a_{ij} shows how more likely it is for criteria in row i than criteria in column j to present a risk to the overall project which would impact power plant development process performance. Resulting unweighted supermatrix can be seen in Figure 4.6.



		World System Risks			World Price Risks				Country Risks				Institutional & Regulatory Risks			Industry & Competitive Risks							Project Risks				
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26
World System Risks	C1		3	2	3	2	2	3	3	2	2	2	2	2	2	1			2		1						
	C2	1		2	3	2	2	2	1	3	3	2	3	3	3	2			2		2						
	C3	1	3		6		4	3		2	2		2			3	3	1			3						
World Price Risks	C4	1	2	3		3	2	2	3	4	2		2			3	3	1	4	1	2	2	2				
	C5	1	2	2	2		3	3	2	3	2	1	3			2	2	1	2		2		1				
	C6		1	4	1	2		2	2	4						3	3	1	2		4	2	1				
	C7				1	1	3			2						3	1		1		2	1	1				
Country Risks	C8	4	3		3	3	3	7		9	6	5	8	7	8	7	6		7	7	4	8	6	7	7	7	5
	C9						6	7	5		6	5	6	4	4	6	5		4	5	4	3	2	2	3	4	
	C10	2	3			2	3	2	2	3		2	3	1	1	1		1		1	4			4		4	
	C11	1	3			3	2	5	2	3			4	5		5	3				1	1				3	
Instit. & Regul. Risks	C12		3				2	5	4	6	5	6		6	6	7	4		4	3	6		5	5	4	4	
	C13							7		5	4				6	6				3					6	5	
	C14					3	3	6		6	7	6	7	6		5	2		4	3	5		3	3	2	3	
Indust. & Comp. Risks	C15						2	6		2	2		5		2			1	4	5	6	5	5	3	4	4	5
	C16									3	3		3	1		4		1	2	4	4	4			3	3	
	C17							1								3			4	2	4		3				
	C18							3								6	7				6	4	4	3		3	
	C19							1								1	1		1		1	1	1	1			1
	C20							6	2	1	2	3	4	3		7	5			1					4	4	
	C21							4		2						4	3		5	7	4		4	4			3
Project Risks	C22							3								4	4	1	5	5	3	2				1	5
	C23							2		1						4	4	1	5		2						
	C24							4			3		3	4		4					3		5	4		8	6
	C25		1					4			5	2	5	5	1	6	3		2	5	3		4	2	9		4
	C26															4			5	4		2	7	5	5	5	

Figure 4.6 Unweighted supermatrix of the ANP model

After normalizing the criteria scores of the matrix, each criteria weight was obtained. As Table 4.17 shows, top risks that this industry expert believed to be of concern for developing a geothermal power plant were mainly country risk factors, followed by risks related to industry and regulatory environment. This is likely to be expected for development of any renewable power plant project under evaluation, as political and economic stability play a vital role in support for and success of the development project.

Category	REF	Risks	AHP score	Category score
World System Risks	C1	Political conditions	3%	9%
	C2	Trade regimes	3%	
	C3	Global demand	3%	
World Price Risks	C4	Commodity prices	4%	11%
	C5	Exchange rates	3%	
	C6	Interest rates	3%	
	C7	Risk premium	1%	
Country Risks	C8	Political stability, terrorism, civil unrest	12%	26%
	C9	Financial, economic stability, inflation	7%	
	C10	Expropriation, taxation	3%	
	C11	Repatriation policies	4%	
Instit. & Regul. Risks	C12	Regulatory stability or intervention	7%	17%
	C13	Contract enforcement	4%	
	C14	Legal stability	6%	
Indust. & Comp. Risks	C15	Industry evolution	5%	21%
	C16	Demand, growth rates	3%	
	C17	Supply conditions	1%	
	C18	Costs	3%	
	C19	Distribution	1%	
	C20	Prices	4%	
	C21	Infrastructure	3%	
Project Risks	C22	Construction	3%	17%
	C23	Operations	2%	
	C24	Partner/ally	4%	
	C25	Contract negotiation, partner conflict	5%	
	C26	Project management	3%	
		Total score	100%	100%

Table 4.17 Risk weights obtained from the AHP matrix

As this exercise was being conducted for a hypothetical project selection, the weights were not used to decide upon a selection amongst project. However, by developing a separate model for each of the energy technologies risk weights developed were used to make a risk profile comparison which is discussed in Section 4.6.

4.6 *Modeling of a Risk Profile*

A graphical representation of a project's risk profile can be useful in understanding the overall risk status of the project, historical trends of severity of risks, and estimates of future development. The following section suggests a novel way to construct and make use of such risk profile, using risk weights generated through the ANP model, and industry experts' estimate on the phase of occurrence and potential impact of that risk on the power plant development project. This section will show how such risk profile can be a useful tool to 1) support new investment decisions, as well as 2) monitor and manage risks throughout the development lifetime.

1) **Prior to investment decision:** Being able to develop expected risk profile for a power plant development project prior to the investment decision has two important applications:
    a. Risk profiles of different power plant development project opportunities can be compared, enabling the developer to make an educated investment decision based on expected risks and their impact, compared to the developer's risk appetite, and available risk mitigation responses. Developers may want to compare the risk profiles based on their own risk appetite, or ability to manage risks. Depending on the power plant project details, the developer may prefer a certain risk distribution (with lower or higher upfront risk during the planning phase of the project), or a risk distribution tilted towards their risk management strengths.
    b. Upon deciding on a power plant development project, the risk profile can be used for the developer's contingency plan, and allocation towards risk mitigation approaches throughout the development lifecycle.
2) **Throughout development lifetime:** By updating the risk profile at scheduled intervals throughout the development lifetime, it can be used as a project management tool, which can be useful in the following way:
    a. Updated risk profile can serve as an input to a report to inform project stakeholders of ongoing risk management of the project.

b. Coupled with the System Dynamics model, the developer can use the risk profile to demonstrate impact that risk management efforts may have on overall performance of the project. As the project continues through development, the developer may choose to use this information to alter the contingency plan for the project.

As previous chapters have discussed, each project's risk profile will vary from one to another. Attempts to create a generic risk profile for the typical power plant development project, given energy technology and geographic location, will always be wrong, as what would be determined as "typical risks" are in their nature uncertain and estimates of their impacts are bound to vary greatly from one industry expert to another. Factors which can impact risk estimates are numerous, including the following:

- Developer's experience and capability to conduct risk estimation, or bias towards a project selection[72].
- Developer's competitive advantage or available resources to manage risks may impact his/her judgment on potential impact of those risks.
- Timing of when the estimate is conducted may impact perceived magnitude of risks under evaluation.

The following sections will discuss in more details how the risk profile can be constructed, and used to support new investment decisions, and monitor and manage risks throughout the development of a power plant project.

4.6.1 Constructing a risk profile

In practice, there exist many different ways to graphically represent a risk profile. Commonly used methodology is to estimate impact, and probability of risk occurrence, to calculate expected severity of that risk. The trend of this risk can be estimated across fixed intervals for a given period, enabling a graphical representation of stacked risk severity. Such an approach was used for this research, based on the following data:

- **Risk identification:** Complete list of risks, as identified in Chapter 3, and their estimated phase of occurrence.

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[72] See also discussion on bias in project analysis in Section 2.2.2.4

- **Risk probabilities:** Weights which were generated by the ANP model were used to represent likelihood of risk occurrence.
- **Risk impact:** Impact of each risk factor was assessed using a scale of 1-5, defined as expected consequence of risk on the power plant development performance, as Table 4.18 shows.

Product of the probability and risk impact is used to get risk severity of each of the risk factors. Diagram 4.8 was created as a general representation of how stacking severity of risks across the development timeline, can be used to construct risk profile for a power plant development project.

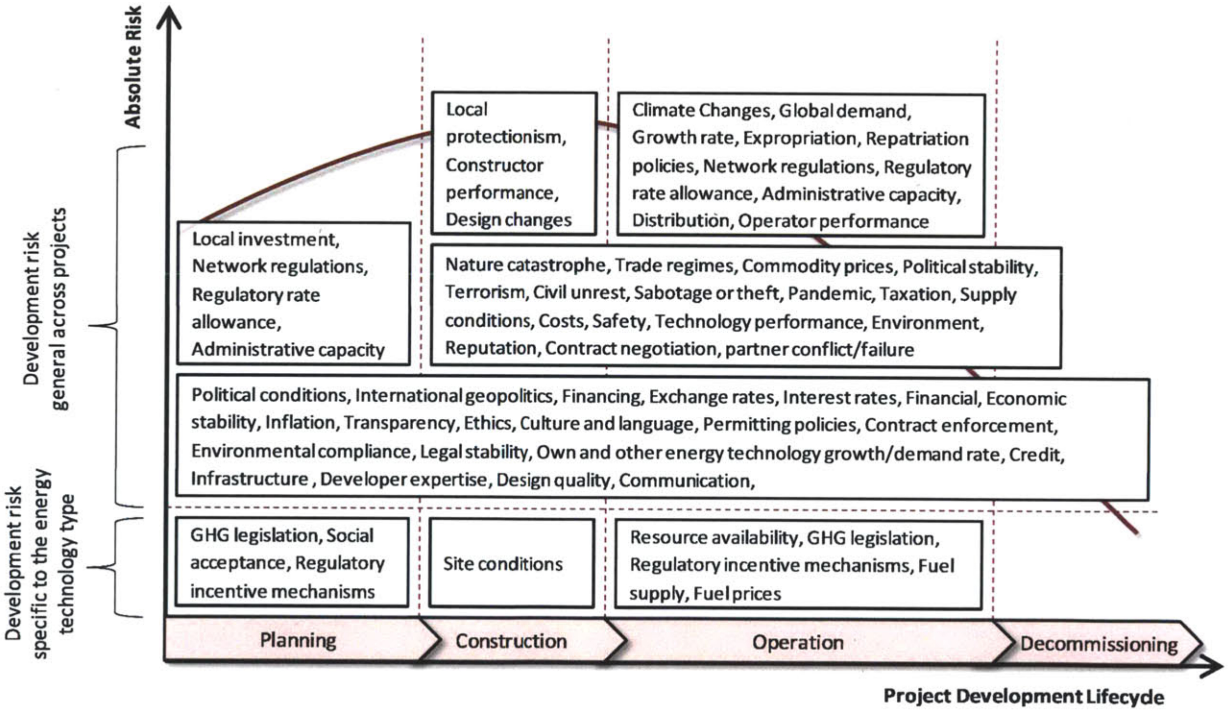

Diagram 4.8 Constructing a risk profile based on distribution of risk throughout the development lifecycle[73]

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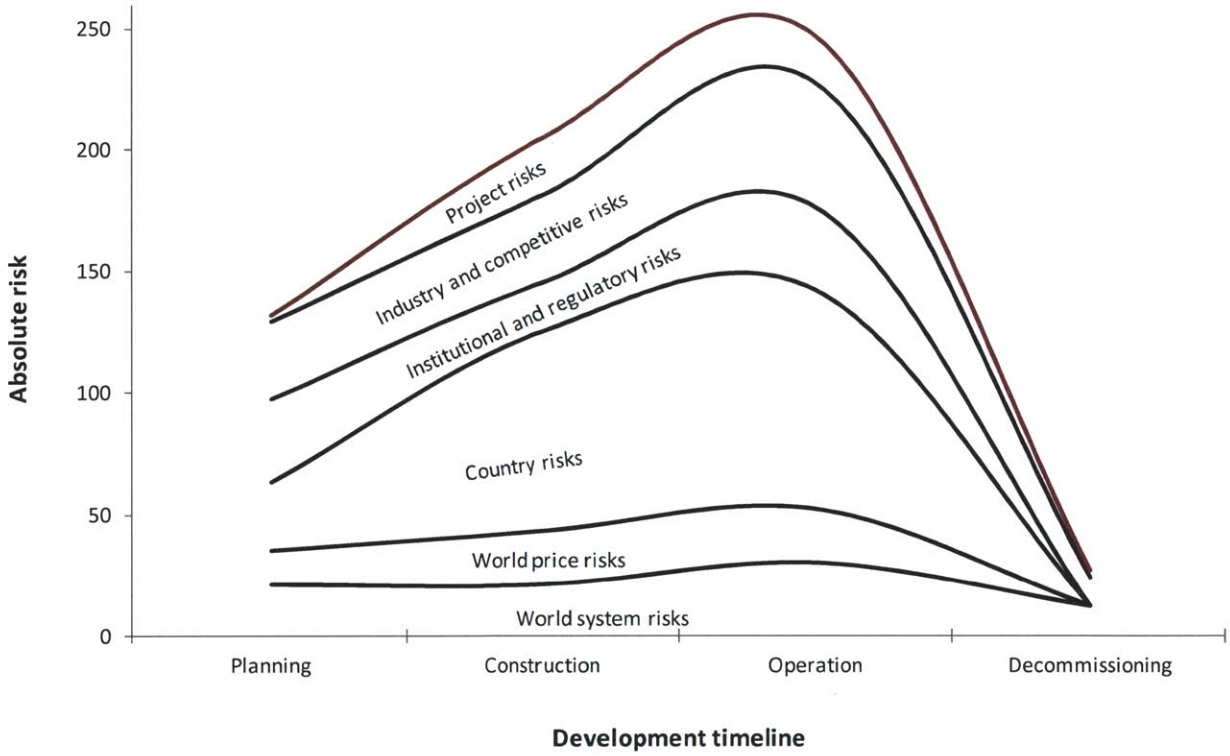
[73] This graph can also be found in Chapter 3, following a discussion on risk identification.

Impact score	**Consequence to power plant development performance**
1	Very low: This risk will not have an immediate impact on project performance which will remain mostly unchanged, but risk awareness and monitoring remains worthwhile as it could trigger other risk occurrences.
2	Low: This risk is of some concern to the project. Its occurrence may require minimal changes to the project, or risk management of some sort.
3	Moderate: This risk will be of concern to the project. Managing its impact will be expensive but may not impact development timeline.
4	High: This risk will be of high concern to the project, and will cause a delay to the project delivery. Managing its impact on project performance will be expensive.
5	Very high: This risk will be of serious concern to the project. If it occurs it will not be possible to complete development of the power plant.

Table 4.18 Scale of impact of risk to power plant development performance

Graph 4.12 gives an example of a risk profile, which was developed using data for a geothermal power plant development project. The data behind the risk profile can be found in Appendix 11. In constructing the risk profile, it was assumed that a risk factor would have an even impact at each phase of the potential risk occurrence. For example, a geothermal power plant development project which is estimated to have a 7% probability of risk occurrence related to changes or uncertain development of RPS targets or incentive mechanisms (such as government grants or loan programs), could only expect to be impacted by that risk factor during development phases of planning and operation. Scale of impact of that risk was estimated to be low (with impact score of 2). Therefore, when constructing the risk profile, a risk severity of 14 (calculated as product of risk impact and risk probability) counted towards accumulated risk in that risk category (Institutional & Regulatory Risks) only at those two development phases.



Graph 4.12 Example of a risk profile constructed for a geothermal power plant development project

As Chapters 2 and 3 highlighted, country risk factors play a large role in selection of a power plant development project. This risk profile clearly supports that risk factors which make up the country risk category have the largest overall risk severity or an average of 33% of total accumulated expected risk severity across the development timeline. This is followed by the second largest risk category, for industry and competitive risks, which make up an average of 21% of overall risk severity.

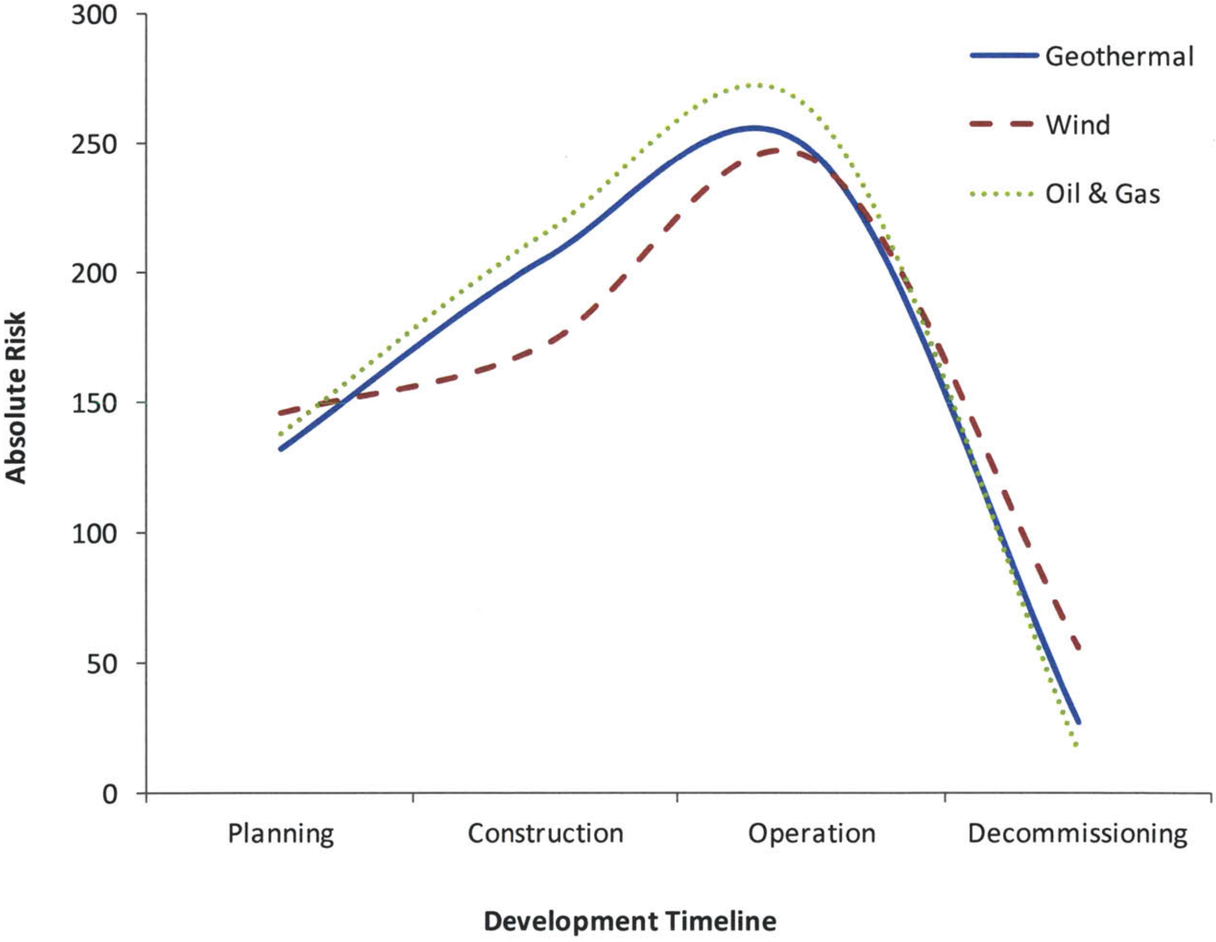
4.6.2 Risk profiles used to support new investment decisions

As stated earlier, constructing a graphical representation of the risk profile for a power plant development project, prior to investment decision has two important applications:

1) Risk profiles of different power plant development project opportunities can be compared, enabling the developer to make an educated investment decision based on expected risks and their impact, compared to the developer's risk appetite, and available risk mitigation responses.

2) Upon deciding on a power plant development project, the risk profile can be used for the developer's contingency budget plan, and allocation towards risk mitigation approaches throughout the development lifecycle.

To demonstrate use of such graphical representation, Graph 4.13 shows comparison of risk profiles constructed for power plant development projects based on three different energy technologies; geothermal, wind, and oil & gas thermal. The data behind the graph can be found in Appendix 12.



Graph 4.13 Risk profile comparison for different energy technologies [74]

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[74] The development timeline is a dimensionless representation of the four development phases.

The difference in the risk profiles is summarized in Table 4.19, which gives some of the potential explanations for how the industry expert's insight to potential risk factors differs from one energy technology to another.

	ANP scores[75]			
Risk category	**GEO**	**WIN**	**O&G**	**Potential explanation**
World System Risks	9%	10%	12%	Wind farms require typically a lower capital investment, and are less dependent on stability of trade regimes and global demand, whereas fossil fuel may introduce higher risks at a global level related to tariffs, quotas or other restrictions used to support development of renewable power plants.
World Price Risks	11%	12%	11%	Main difference in risk assessment was higher expected impact of risks associated with price of commodities needed for development of wind farms. This is likely a result of volatility in wind turbine prices, due to technology development, changing production support schemes, and predicted continuation of financial difficulties and layoffs amongst turbine manufacturers.
Country Risks	26%	12%	26%	Considerable lower assessment of country risk factors for wind farms could be explained by shorter development time, and lower need for capital and manpower for development and operation.
Institutional & Regulatory Risks	17%	17%	17%	The uncertainty surrounding potential changes in the institutional and regulatory environment were estimated to present similar magnitude of risk to each of the energy technologies. For example, development of GHG legislation and regulatory incentive mechanisms can have both positive and negative impact on development performance.
Industrial & Competitive Risks	21%	38%	27%	Although some industrial evolutions may present same magnitude of risk to each energy technology (such as supply conditions of equipment and material), other developments present risks at different levels of magnitude. For example, feasibility of wind farms depends heavily on access to transmission system and reliance on infrastructure, whereas O&G plants are heavily reliant on fuel supply prices and availability.

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[75] The ANP scores were developed as described in Section 4.5. The abbreviations stand for each of the energy technologies under consideration: GEO = geothermal, WIN = wind, O&G = oil and gas.

Project Risks	17%	11%	7%	Lower project risk for O&G plants may be explained by technology maturity, which may present less uncertainty in construction and operation performance, as well as management of all project related contracts.

Table 4.19 Experts' evaluation on potential risk impact for the power plant depending on energy technology

As earlier chapters discussed, this data was collected based on a typical power plant development project for each energy technology. Estimate of risk impact is therefore not influenced by developer's ability to manage that risk. This emphasizes the importance of constructing a unique risk profile for each project under consideration, to take into consideration developer's risk management efforts, and to monitor development of each risk factor.

Developers may have a risk preference based on their own risk appetite, or ability to manage risks. This may impact their choice of power plant development project, making a graphical representation of the risk profiles a useful decision making tool. Depending on the power plant project details, the developer may prefer a certain risk distribution (with lower or higher upfront risk during planning phase of the project), or a risk distribution tilted towards their risk management strengths. For example, a developer capable of forming strategic alliances with local partners may not be as concerned about country specific risks related to securing permits during planning phase of the project. If they are however unable to manage country specific risk through financing (such as through the World Bank), they may be concerned about projects that pose high risks related to the economic stability during construction phase of the project. Based on the example here above, such developer might prefer to develop the wind farm. Having decided on a power plant development project, the developer can look more closely into the risk profile structure of the project, to plan out their contingency budget and allocation towards risk mitigation approaches throughout the development lifecycle.

4.6.3 Risk profiles used to support risk management allocations

In addition to serving as a decision making tool for new power plant investments, and plan for contingency budget and allocation towards risk mitigation, the risk profile can be used as an important project management tool to monitor risk management efforts. By continuously updating the risk profile at scheduled intervals throughout the development lifetime, the risk profile can be useful in the following way:

1) The updated risk profile can serve as an input to a report to inform project stakeholders of the ongoing risk management of the project.

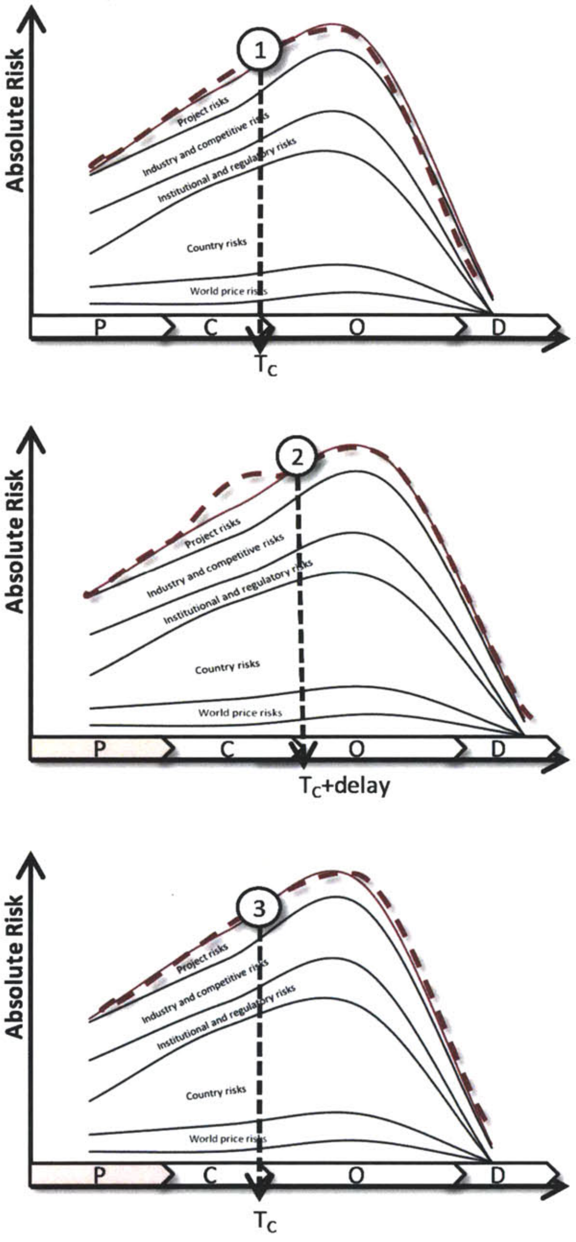
2) Coupled with the System Dynamics model, the developer can use the risk profile to demonstrate impact that risk management efforts may have on overall performance of the project. As the project continues through development, the developer may choose to use this information to alter the contingency plan for the project.

3) Having a complete history of the risk profile throughout the development lifetime can serve as an important lesson for the developer, adding to the development learning curve and benefiting future projects.

Graph 4.14 gives a simplified example of how the risk profile, coupled with the System Dynamics model can be used to update risk scenarios as they evolve throughout the development timeline. In this example, when the risk profile is updated at the end of planning phase it reveals an increase in the project risk category. This may have resulted from an initial construction activity revealing some site problems. Using an unchanged schedule with same resource allocation, additional work needed to make up for these problems is expected to delay completion of overall construction of the power plant (this can be demonstrated through the System Dynamics model).

In examples such as this one, it can be assumed that a percentage increase in construction time will be roughly equal to the percentage increase in construction cost. For some projects, delay may not be acceptable due to electricity delivery commitments and associated late fees, which will impact overall project return. The developer may therefore want to use the System Dynamics to run a few different risk management scenarios, comparing them on a cost-benefit basis, to find risk approach which best fits developer's needs.

Following each update of the risk profile, the developer may also want to monitor ongoing risk management efforts, to ensure a continuing proper allocation of the contingency budget.



①

Based on original risk profile construction duration and cost was estimated:

Construction duration = T_C months
Construction cost = C_C USD

②

Once planning phase is completed and construction begins additional project risk factors emerge. New risk profile shows that following an unchanged schedule, new cost and time schedule will be:

Construction duration = (T_C +delay) months
Construction cost = (C_C + cost of delay) USD

③

The System Dynamics model can be used to run scenarios for different risk mitigation options, in order to choose the appropriate reaction which will optimize risk response based on developer's preference of cost allocation. If developer chooses to allocate money on risk mitigation which will reduce time delay, new cost and time schedule will be:

Construction duration = T_C months
Construction cost = (C_C + cost of risk mitigation) USD

Graph 4.14 Risk profile used to assess risk mitigation scenarios

4.7 SWOT Analysis

In addition to evaluating project opportunities, developers may be faced with questions regarding their overall industry focus, in particularly as new renewable technologies emerge. A tool commonly used to analyze internal and external environment in order to understand industry attractiveness is the Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. This tool was originally developed for business management and marketing application in the 1980s, but has since been successfully applied for regional planning in the energy industry (Terrados, Almonacid, & Hontoria, 2007).

The following section will discuss how to use this tool to evaluate attractiveness of conventional energy industry compared to the renewable energy industry. It also introduces a way to turn the ANP model into a SWOT analysis.

4.7.1 Industry attractiveness analysis using SWOT

A SWOT analysis of industry attractiveness is done through a process of identifying internal and external factors which are the most important strategic considerations for future development of the industry. These factors are typically listed in a matrix, which is then used to adopt a strategy resulting in a good fit between those factors. Designing the SWOT matrix plays a large role in developing understanding of industry attractiveness. The process encourages debate and confrontation among decision makers of criteria for strategies proposal and definition. If used correctly, SWOT can provide a good basis for industry analysis. However, it does have its limitations, as in practice it's merely a process of identification and classification based on qualitative analysis, and expression of individual factors tends to be of a general nature and brief. In particularly it lacks 1) ability to prioritize individual factors, 2) ability to group factors by importance into subcategories, in an attempt to highlight the most significant group, and 3) ability to analytically assess a fit between SWOT factors and alternatives under evaluation.

Figure 4.7 and Figure 4.8 give example of how SWOT analysis can be useful in identifying industry attractiveness for power plant development projects using conventional energy technologies, and renewable energy technologies. This analysis is based on observation from literature review and data collection.

Strengths

Maturing and proven technology, engineering, and construction

Price advantages to renewable energy in most markets

Stable generation of conventional energy sources ideal for base load

Well established global manufacturing and supply network

Weaknesses

High capital costs and long build and delivery times

Long complex supply chain and technologies with many links

Public perception of safety, environmental risk

New large plants need long-term off-take contracts

Long time required for new supply chains to achieve pay-back

Contractual and risk management complexities

Cost barriers to entry for smaller companies limit competition

Large electricity demand required to justify building a plant

Finite, depleting fossil reserves limit long-term sustainability

Opportunities

Financial strength of the conventional energy sector can support costly technology improvements

As countries restrict their energy budget, renewables tend to get pushed off the table giving more room for conventional energy projects

Threats

New renewable technologies make older plants less competitive

Reliability, safety of aging equipment in older plants

Governments seek to toughen fiscal terns of long-term contracts

Advances in alternative technologies

Planning delays and administrative red tape

Deregulation in markets (threat for monopolies)

Figure 4.7 SWOT analysis for conventional energy industry

Strengths

- Abundant but remote energy resources, and mostly abundant resource life
- Technology advances, and competing technologies and suppliers, continue to reduce costs
- Strong renewable energy demand growth in existing and new markets, and new market opportunities opening with deregulation
- Supply and demand diversifying to involve many countries
- Cleaner energy than conventional energy sources
- Viable for small scale application in rural areas off the grid
- Fewer interntional barriers than for conventional energy sources
- Geographical diversity limits geopolitical influence

Weaknesses

- Vulnerable to changes in government support policies and local political risk
- Vulnerable to fiscal changes
- Potential over capacity in some markets
- Lack of network infrastructure to remote resouce locations
- Costly to bring skilled workforce onto development site
- Limited resource to project finance
- Insufficient skilled personnel to sustain rapid growth
- Limited investor confidence in some techonologies
- Some emerging technologies have patent infringement claims

Opportunities

- New and evolving technologies improve efficiency along supply chain
- Further economics of scale and larger capacity plants
- Hurdles to entry lowering for new entrants
- Improving price competitiveness and lower breakeven prices
- Improving operating, contracting, and procurement processes
- Government goals to replace conventional energy sources
- Improves portfolio to diversify and reduce market risk
- Geopolitical tensions favor renewables over conventional energy
- Government R&D funding support improved techonology efficiency

Threats

- Security, terrorism, sabotage could damage public perception
- Shortage of skilled manpower could limit growth
- Regional over-supply ; too much competition
- Strong price competition from other renewables
- NIMBY-ism could constrain site availability for new plants
- Environmental objections
- Uncertain R&D outcomes
- Competitive pressure

Figure 4.8 SWOT analysis for renewable energy projects

When using the SWOT analysis to analyze industry attractiveness, the developer should compare the factors identified to their risk appetite and competitive advantage, and translate that into their investment strategy.

	Strengths	**Weaknesses**
Opportunities	How can the developer use the strengths to take advantage of the opportunities?	How can the developer overcome the weaknesses that prevent them from taking advantage of the opportunities?
Threats	How can the developer use the strengths to reduce the likelihood and impact of the threats?	How can the developer address the weaknesses that will make the threats a reality?

Table 4.20 How to translate SWOT analysis into investment strategy

4.7.2 Combining ANP and SWOT into A'WOT analysis

As previously discussed, SWOT analysis has its limitations. One methodology which has been suggested to meet those limitations is to combine the AHP framework and the SWOT analysis into a hybrid method called A'WOT analysis (Kurttila, Pesonen, Kangas, & Kajanus, 2000). The idea behind the methodology is to use AHP for prioritization of SWOT factors by assigning them the corresponding weights.

To demonstrate the applicability of this, the following uses the ANP model that was developed in Section 4.5 to evaluate development project for a geothermal power plant.

- **Step 1:** Risk factors which had been identified for the ANP model were considered to be a sufficient representation of important internal (strengths and weaknesses), and external (opportunities and threats) factors to make up for the SWOT analysis. Each risk criteria was categorized in the SWOT matrix depending on key characteristics of the geothermal energy technology as compared to other energy technologies (each developer may categorize differently depending on which of the risk criteria identified presents an internal environment to where they possess strength or weakness, or external environment specific to the project which to them would pose opportunities or threats). For example, resource availability can be generally considered strength, whereas reliance on infrastructure and distribution can be considered a weakness due to a typically remote site location. The SWOT matrix can be seen in Figure 4.9.

- **Step 2:** Due to this general application, each category of the SWOT matrix was given equal importance (under practical application the developer may have a preference for priority of the categories which can be derived using the AHP technique). Weights which had been generated by the ANP model were applied to factors of the SWOT matrix.
- **Step 3:** Finally, risk criteria are shown on a graph for a visual demonstration of their prioritization (see Diagram 4.9).

Strengths

C3	Global demand
C13	Contract enforcement
C14	Legal stability
C15	Industry evolution
C16	Demand, growth rates
C17	Supply conditions
C18	Costs
C22	Construction
C23	Operations
C26	Project management

Weaknesses

C8	Political stability, terrorism
C9	Financial, economic stability
C12	Regulatory stability/intervention
C19	Distribution
C20	Prices
C21	Infrastructure

Opportunities

C4	Commodity prices
C24	Partner/ally
C25	Contract negotiation/conflict

Threats

C1	Political conditions
C2	Trade regimes
C5	Exchange rates
C6	Interest rates
C7	Risk premium
C10	Expropriation, taxation
C11	Repatriation policies

Figure 4.9 Categorization of ANP risk criteria for SWOT analysis

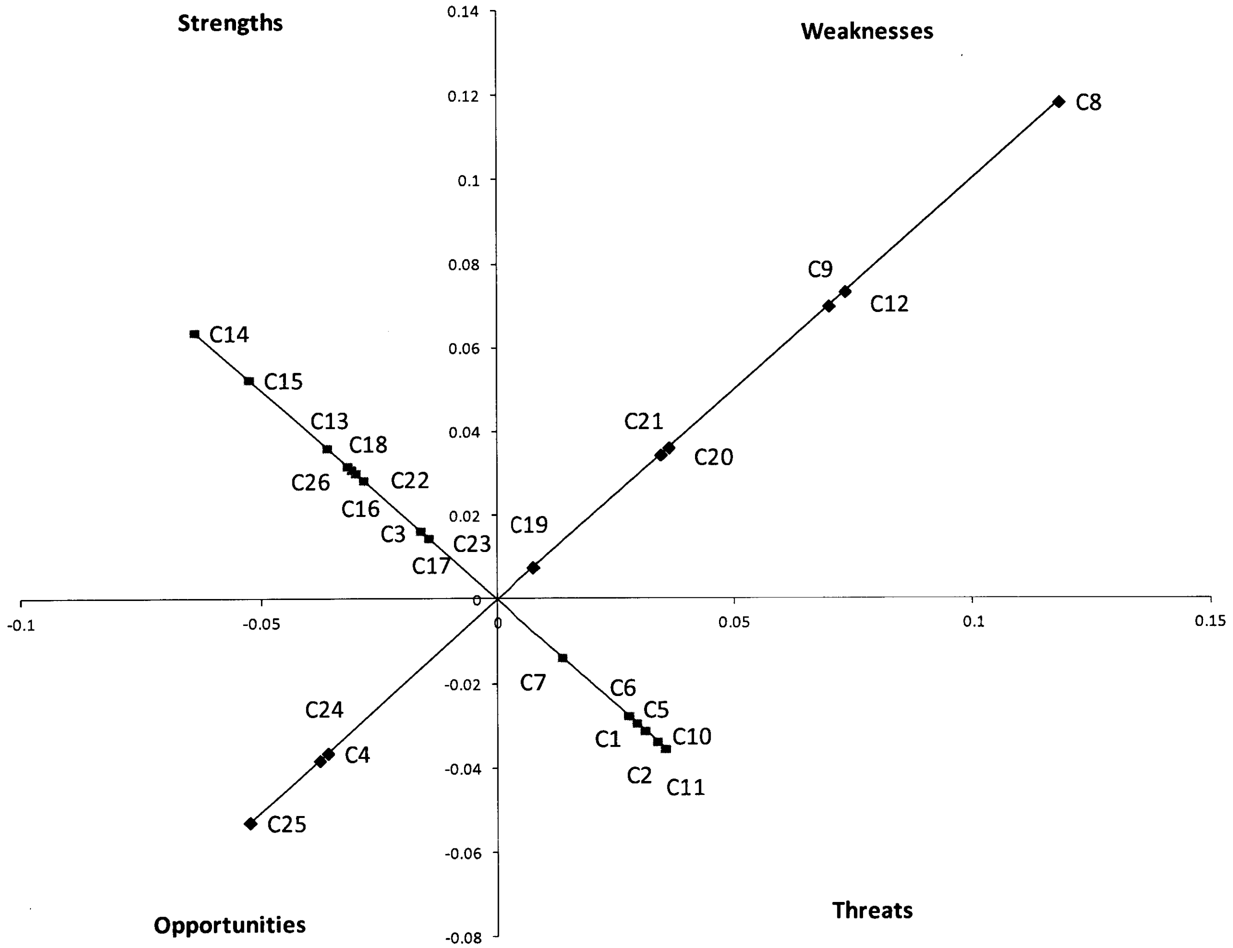


Diagram 4.9 A'WOT analysis of a geothermal power plant development project

Chapter 5: Summary and Future Research

This dissertation brought together a collection of models to help answer the questions for how a developer should go about choosing between different project opportunities based on the risk involved, and given their own risk appetite. Diagram 5.1 shows how these models came together and how they help feed information into each other.

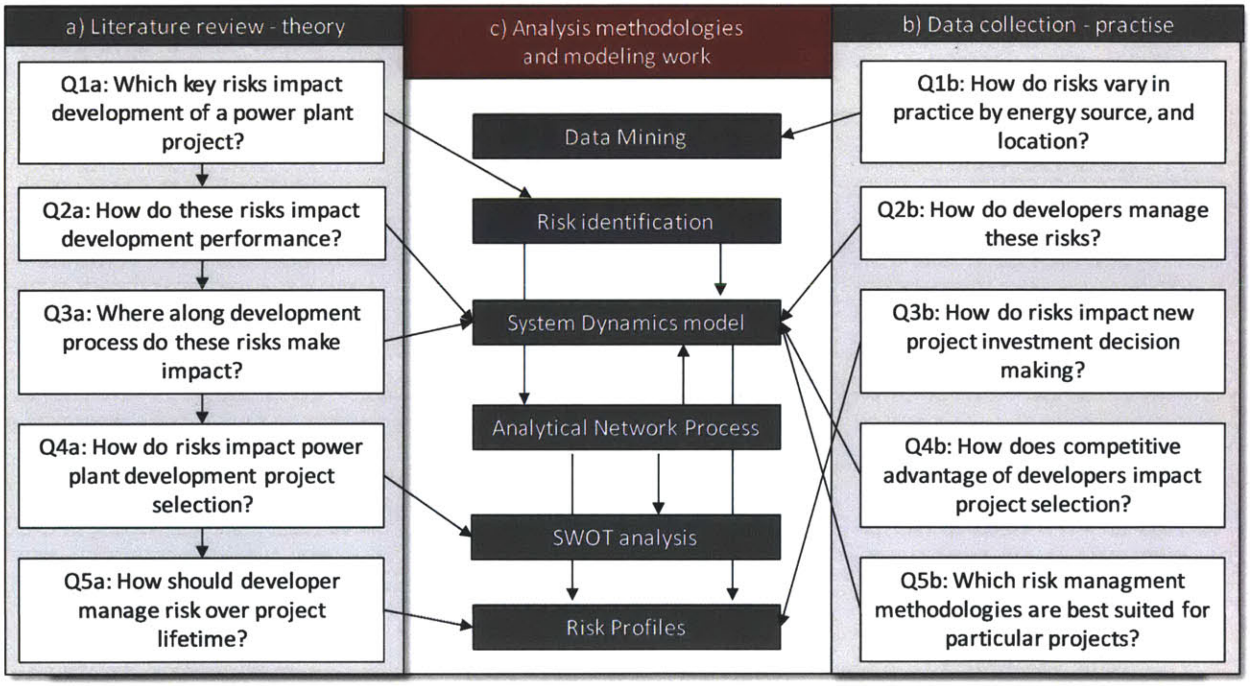


Diagram 5.1 Research approach and use of models and analysis methodologies

The following chapter will summarize the main contributions of these models, and will suggest how they can be extended for future work.

5.1 Main Contributions

The main contribution of this dissertation is new insights into how to make risk informed decisions about power plant selection and development management. Key questions modeling system can help answer are the following:

1) **Who should develop?**

   Which projects should a developer consider in their investment strategy, and how does that change given developer type, geographic location, and energy technology?

2) **Which project to develop?**

   Given risks in the project, developers' competitive advantage, and risk appetite, which power plant development projects under consideration should developers consider for their portfolio?

3) **How to manage risk in the project?**

   What risk events are likely to impact development performance? Where along the project lifetime might they occur, and what is their potential impact? How do the answers to these questions change throughout the development lifetime and how should allocation of risk management efforts adapt to these changes?

The following sections summarize dissertation findings which support decision making based on answer to these questions.

5.1.1 Who should develop?

Data from around 300 power plant development projects was analyzed using Data Mining methodologies to derive insights aimed at answering the following questions:

- What type of power plants do distinct utility types develop, and how do these types vary as a function of geographic location?
- Does performance (measured in ability to meet time, cost, and quality) differ as a function of geographic location, and energy technology?

Regression analysis shows that power plant capacity generation size (as opposed to the type of energy technology) is the clearest indicator of power plant development project a utility type owner selects and how that choice differs as a function of geographic locations. Classification Tree methodology suggests that the larger the power plant, the likelier it is to be developed by POUs.

Cluster Analysis of power plant development performance indicators suggests that solar projects are the worst cost performers, and nuclear projects the worst time scale performers. Clustering across geographic regions revealed the following characteristics of project performance.

	Cluster characteristics	
Continent	**Performance on time**	**Performance on cost**
Africa	Worse than average	On average
Asia	Much worse than average	On average
Australia	Better than average	Slightly worse than average
Europe	On average	Better than average
N America	On average	Worse than average
S America	On average	Better than average

Table 5.1 Characteristics of geographic clusters based on Cluster Analysis

These regional performance indicators coupled with a project selection by capacity size are cohere with financing capabilities and funds available to the different type of developers. The larger the project on cost, time, and risk scale, the harder it is to get initial funding. As POUs have a lower WACC than other developer types, they can go for projects with lower expected IRR.

Developer	Capital Structure	WACC
IOUs	50% debt at 6%, 50% equity at 14%	6.8%
POUs	100% debt	5.1%
IPPs	60% debt at 8%, 40% equity at 17%	9.8%

Table 5.2 Typical financing opportunities for power plant developers

Logistic regression suggests that, in general, energy technology type is not associated with the actual cost being higher than estimated cost. Energy technology type is however clearly associated with schedule not being on time.

Variable	Odds of cost overruns	Odds of time delays
Energy source	Not associated with cost overruns	Renewables plant have higher odds
Continent	Significantly higher in Africa and Asia	Higher odds in Africa and Asia
Ownership	Significantly lower for IPPs	Higher for IPPs
Size	Higher when larger than 1000 MW	Higher for all other sizes

Table 5.3 Interpretation of logistic regression model for odds of cost overrun and time delays

These insights serve as a guideline for which power plant development opportunities developers should consider, in particular as a function of 1) developer type, 2) the developers' financing capabilities, and 3) developers' risk appetite for development delays.

5.1.2 Which project to develop?

The dissertation presents a novel approach to construct a project risk profile to support risk informed project selection for new power plant development projects. The methodology is based on an extensive risk identification of all risks involved in power plant development projects, across what is defined as four phases of development: planning, construction, operation, and decommissioning. Using the Analytical Network Process model, the weights of each of the risk criteria identified is developed, which when stacked up across the development lifetime contributes to magnitude of risks which make up the risk profile. Diagram 5.2 shows how risk factors present at different phases of the development project make up the risk profile.

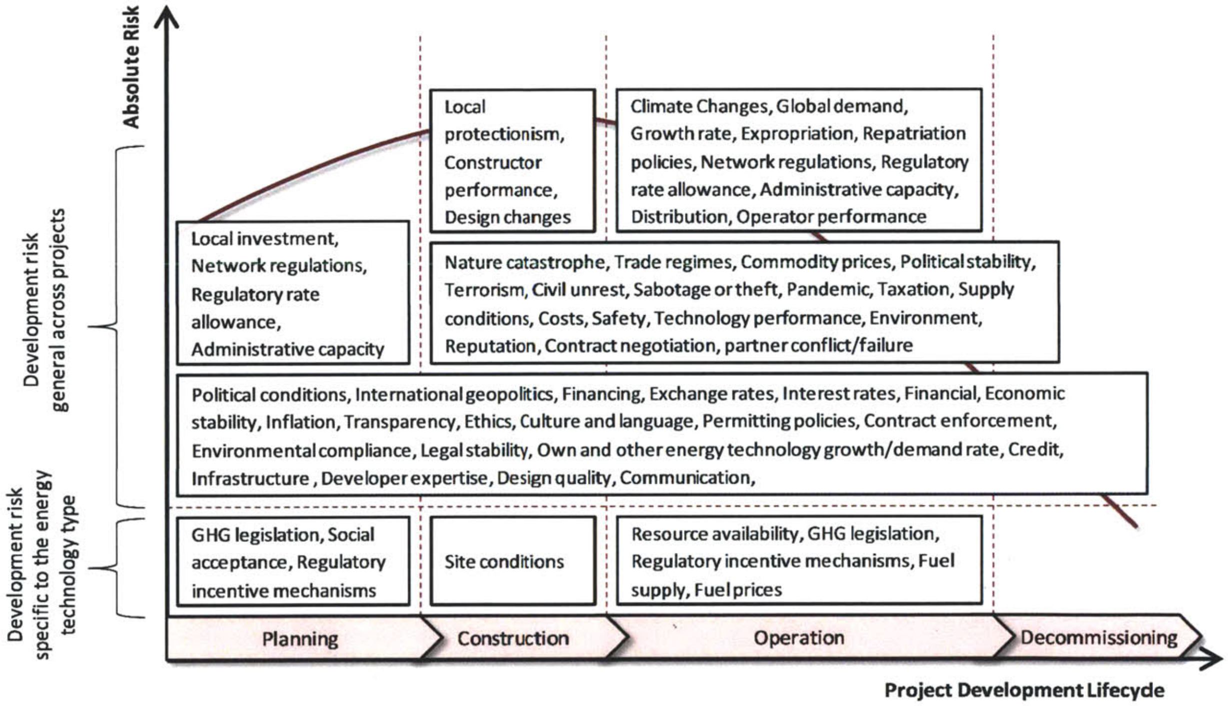
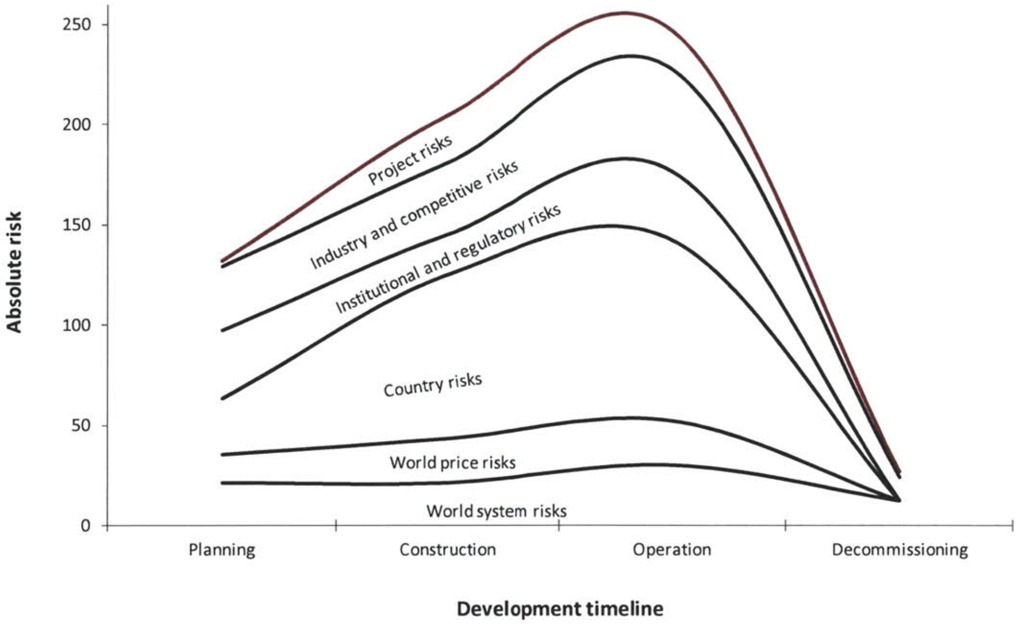
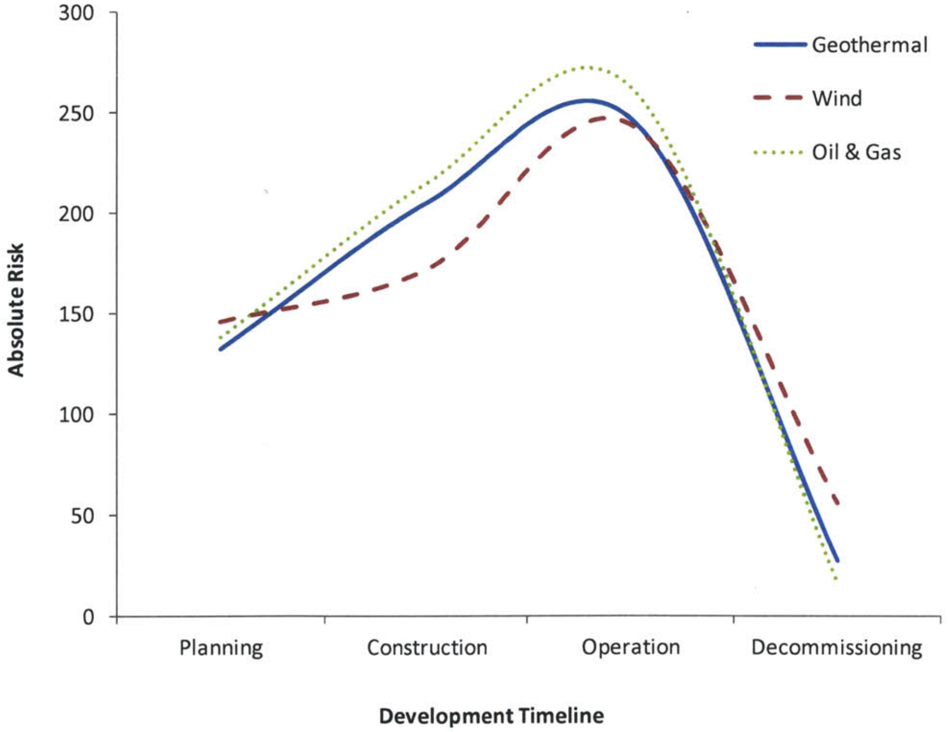


Diagram 5.2 Distribution of risks throughout the development lifecycle

The dissertation used a geothermal power plant project as an example of how to construct the risk profile, and compared that to risk profiles based on data derived from a wind development project, and an oil & gas project (see Graph 5.1 and Graph 5.2).



Graph 5.1 Example of a risk profile constructed for a geothermal power plant development project



Graph 5.2 Risk profile comparison for different energy technologies [76]

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[76] The development timeline is a dimensionless representation of the four development phases.

Developers may have a risk preference based on their own risk appetite, or ability to manage risks. This may impact their choice of power plant development project, making a graphical representation of the risk profiles a useful decision making tool. Depending on the power plant project details, the developer may prefer a certain risk distribution (with lower or higher upfront risk during the planning phase of the project), or a risk distribution tilted towards their risk management strengths. Having decided on a power plant development project, the developer can look more closely into the risk profile structure of the project, to plan out their contingency budget and allocation towards risk mitigation approaches throughout the development lifecycle.

5.1.3 How to manage risks in the project?

This dissertation presented a novel approach to modeling how risk impact on power plant development performance parameters. Models of the power plant development process, electricity generation, and cash flow were coupled with models that measured risks in the project, given energy technology, and geographic location. The level of risk in the project controlled development performance through impact on development time, scope, and cost, while risk management methodologies helped mitigate the negative impact of those risks.

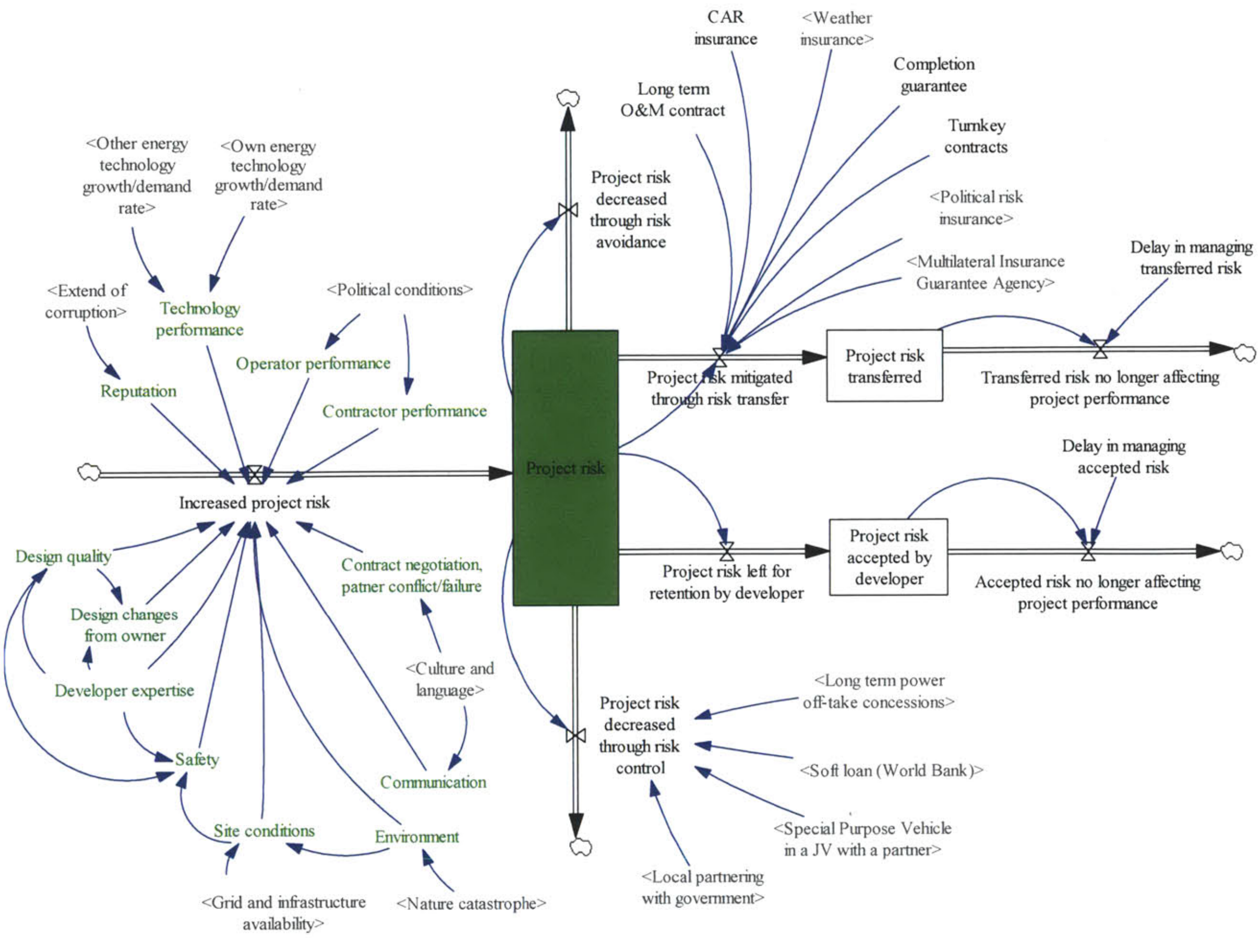
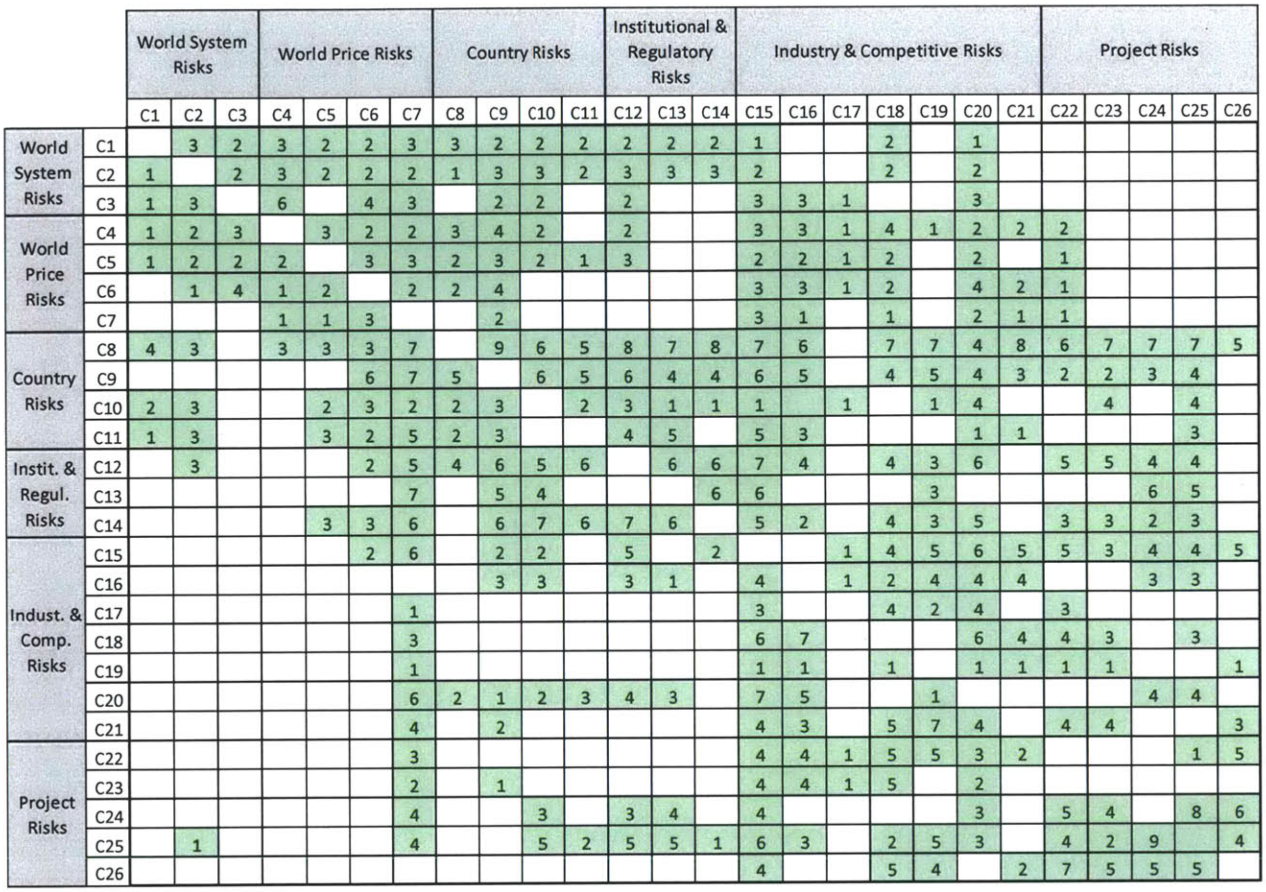


Diagram 5.3 Sub-model for risks and mitigation methods that make up the stock and flow for project risk

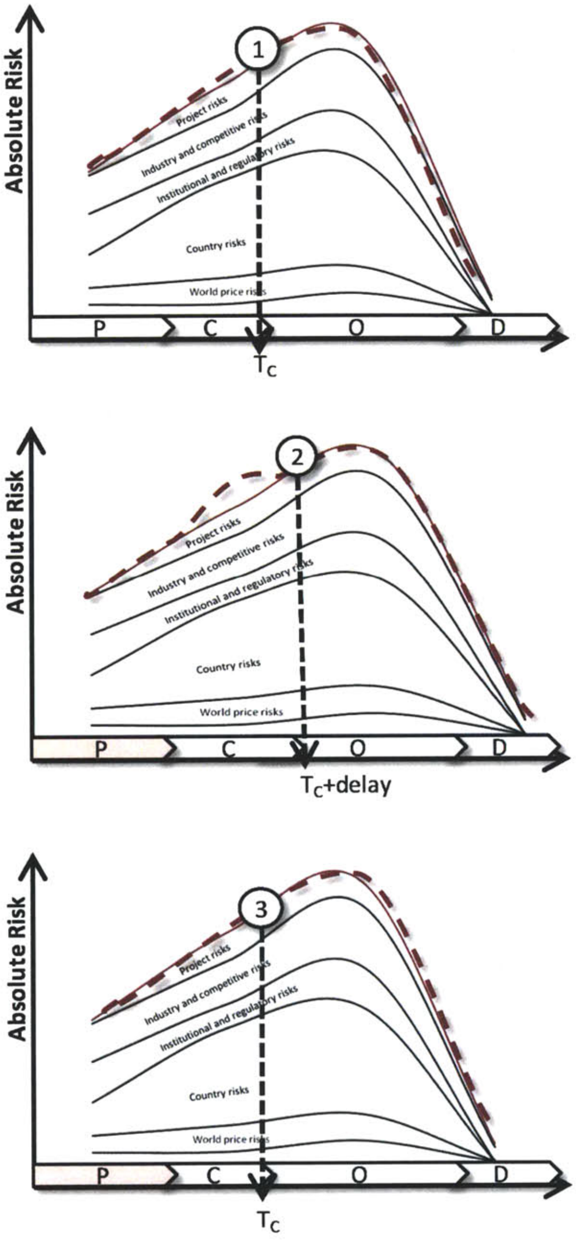
An important contributor to modeling the risk impact into the System Dynamics model was the Analytical Network Process model. It's application to the model development was twofold: 1) through pairwise comparison of different risk criteria, the interfactorial network of risks could be translated into the System Dynamics model as interactions and feedback loops, and 2) as the ANP matrix showed scale of which risk factors were likely to impact the development process, risk weights could be used to control impact through which the risk stocks had on the power plant development performance in the System Dynamics models. Figure 5.1 shows the example used in the dissertation on development of the supermatrix of the ANP model.



		World System Risks			World Price Risks				Country Risks				Institutional & Regulatory Risks			Industry & Competitive Risks							Project Risks				
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26
World System Risks	C1		3	2	3	2	2	3	3	2	2	2	2	2	2	1			2		1						
	C2	1		2	3	2	2	2	1	3	3	2	3	3	3	2			2		2						
	C3	1	3		6		4	3		2	2		2			3	3	1			3						
World Price Risks	C4	1	2	3		3	2	2	3	4	2		2			3	3	1	4	1	2	2	2				
	C5	1	2	2	2		3	3	2	3	2	1	3			2	2	1	2		2		1				
	C6		1	4	1	2		2	2	4						3	3	1	2		4	2	1				
	C7				1	1	3			2						3	1		1		2	1	1				
Country Risks	C8	4	3		3	3	3	7		9	6	5	8	7	8	7	6		7	7	4	8	6	7	7	7	5
	C9						6	7	5		6	5	6	4	4	6	5		4	5	4	3	2	2	3	4	
	C10	2	3			2	3	2	2	3		2	3	1	1	1		1		1	4			4		4	
	C11	1	3			3	2	5	2	3			4	5		5	3				1	1				3	
Instit. & Regul. Risks	C12		3				2	5	4	6	5	6		6	6	7	4		4	3	6		5	5	4	4	
	C13							7		5	4				6	6				3					6	5	
	C14					3	3	6		6	7	6	7	6		5	2		4	3	5		3	3	2	3	
Indust. & Comp. Risks	C15						2	6		2	2		5		2			1	4	5	6	5	5	3	4	4	5
	C16									3	3		3	1		4		1	2	4	4	4			3	3	
	C17							1								3			4	2	4		3				
	C18							3								6	7				6	4	4	3		3	
	C19							1								1	1		1		1	1	1	1			1
	C20							6	2	1	2	3	4	3		7	5			1					4	4	
	C21							4		2						4	3		5	7	4		4	4			3
Project Risks	C22							3								4	4	1	5	5	3	2				1	5
	C23							2		1						4	4	1	5		2						
	C24							4			3		3	4		4					3		5	4		8	6
	C25		1					4			5	2	5	5	1	6	3		2	5	3		4	2	9		4
	C26															4			5	4		2	7	5	5	5	

Figure 5.1 Unweighted supermatrix of the ANP model

Having developed these models, this dissertation proposes that they can be used to monitor effort of risk management allocation throughout the development lifetime. By running the model again as uncertain parameters evolve, risk management allocation can be shifted, enabling better control over the project reserves. Graph 5.3 gives an example of how the developer can run a scenario analysis to see which risk management methodologies are best suited to meet their risk appetite, given the value comparison of their tolerance to go beyond the expected COD to total cost of the risk management design.



1

Based on original risk profile construction duration and cost was estimated:

Construction duration = T_C months
Construction cost = C_C USD

2

Once planning phase is completed and construction begins additional project risk factors emerge. New risk profile shows that following an unchanged schedule, new cost and time schedule will be:

Construction duration = (T_C +delay) months
Construction cost = (C_C + cost of delay) USD

3

The System Dynamics model can be used to run scenarios for different risk mitigation options, in order to choose the appropriate reaction which will optimize risk response based on developer's preference of cost allocation. If developer chooses to allocate money on risk mitigation which will reduce time delay, new cost and time schedule will be:

Construction duration = T_C months
Construction cost = (C_C + cost of risk mitigation) USD

Graph 5.3 Risk profile used to assess risk mitigation scenarios

5.2 Future Work

Development and implementation of the collection of models used in this dissertation although satisfactory are subject to some limitations. From these and other considerations, perspectives for future research are presented in the following section.

5.2.1 Expanding data

The ANP model results currently apply across the whole development timeline. For a more detailed analysis of risk impacts, the ANP model could be run separately across each of the four development phases including a complete set of identified risks in the six risk categories. This would be a more accurate representation of the real world as risk impacts are typically different given the stage of development at which they occur. Currently, the models are based on a limited set of these risks, or 26 risk events out of the 55 risk events identified. This means that when generating risk weights through pairwise comparison of the ANP matrix, each industry expert needed to go through n(n-1) or 650 questions to derive the weight to the risks for that energy technology. If all 55 identified risks would be included that would mean expanding the questions to 2,970, and if that were to be done separately for each of the four development phases that would mean 11,880 questions for each industry expert.

The ANP model also simplifies impact scores to be the same across all energy technologies irrespective of location. Expanding the data to include different impact scores for each energy technology and location, could generate an interesting insight, as it would give a clearer representation of how the project risk profiles differ. Ideally, this analysis could be based on a collection of estimates for each energy technology. If done for a number of projects across different location, this could reveal the true range of these risk impacts, which could help demonstrate whether the range is more dependent on energy technology, or location from one project to another.

5.2.2 Expanding scope of models

The System Dynamics model is currently designed to offer an application of a certain risk management method to each particular risk event. The model could be expanded to include a range of choices of risk management methods which the developer could adjust to the model for mitigation of a particular risk event. The model could also be adjusted such that even though a risk management method is in place (such as when insurance has been purchased, or developer has invested in training) the risk occurrence may still have a partial impact on development performance. Currently the model is designed to remove the risk event from impacting the performance if a risk management method has been designed to mitigate that impact.

In addition, the models are particularly focused on the downside of risks by mitigating the negative impact of the risks on the development performance. They do not consider the potential upside of the risks such as when developer may benefit from uncertain development of the risk events (for example when site requires less preparation work than expected or when exchange rates develop in favor of the project's returns). These upside risks can impact future expansions of the plant, extending lifetime beyond planned, future conversion options, etc.

The operating cash flow model section of the System Dynamics model is currently limited to modeling fixed electricity prices, and assumes guaranteed electricity delivery throughout the plant's operation. This is a highly simplified model of the real world operation. That model could be expanded to represent more accurately the uncertainty surrounding the plant's operation and further risks related to the electricity dispatching, such as uncertain development of electricity off-taker or prices, development of the network grid through "smart grids", and impact on renewable and conventional power plants through changes in "pecking order" for electricity dispatch.

The operating cash flow model could also be extended to contain more detailed cost information behind variable and fixed cost, and to capture the different costs associated with different insurance programs. Currently the model assumes the same cost amount for an insurance program for each use of that risk transfer mechanism.

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APPENDIX 1: KEY POWER PLANT DEVELOPMENT ACTIVITIES

The following table lists the key power plant development activities, and the project teams involved. This table is adjusted based on various sources of literature review and expert input, including (Ling & Lau, 2002).

Phases	Activities	Team involved
Conception and feasibility studies	1. Define the need for the development 2. Evaluate plant capacity 3. Analyze technology 4. Evaluate site(s) 5. Environment impact assessment (EIA) 6. Obtain permits and regulatory approvals 7. Prioritize project objectives 8. Analyze project risks 9. Prepare conceptual scopes and estimates 10. Prepare preliminary design options 11. Define project implementation approach 12. Establish project control approach	Project Analysis Team: a) Project Manager b) Project planning design and implementation group c) Operations group d) Project affected people e) Consultants f) Contractors/Suppliers
Project planning	1. Plan and develop project requirements 2. Process requirements and prepare design brief 3. Prepare conceptual design and specification 4. Prepare bid documents and RFP 5. Establish pre-qualification evaluation criteria	Project Development Team: a) Project Development Committee b) Client's O&M Group provides inputs on specific requirements
Bidding and Contracting	1. Conduct pre-qualification exercise 2. Shortlist pre-qualified contractors for tender 3. Contractors submit bids and proposals 4. Evaluate bids 5. Negotiate contractors 6. Appoint contractors	Contract Committee: a) Project Development Committee b) Legal and other advisers
Project implementation	1. Administer contract 2. Contractors develop detailed design 3. Review design and give approvals 4. Approve sub-vendors and sub-contractors 5. Contractors proceed with construction and commissioning 6. Control quality on site 7. Commissioning 8. Training operators	Project Management Team: a) Client's Project Group b) Project Manager

APPENDIX 2: TOOLS AND METHODOLOGIES FOR RISK MANAGEMENT

The following is a list of tools and methodologies for identification, assessment, and management of risk. It is derived through literature search (see Reference list). It excludes methods that do not explicitly deal with risk management, such as multi-attribute utility theory (MAUT), and multi-criteria decision making (MCDM), which are rather used for decision analysis problems, and Earned Value Management (EVM) and other performance management tools.

Tool	Group	Description, strengths, and weaknesses of tool/methodology
Checklist	Identification	Description: A lists of questions and considerations for use during each step of the risk management process. Can be developed based on a) historical information and knowledge that has been accumulated from previous similar projects and from other sources of information, b) interviewing of experienced project participants, stakeholders and experts based on their intuition/pure gut feel, c) expert audit usually using formal scoring methods, d) through brainstorming of the project team usually with experts. Strengths: This method provides the opportunity for participants to build on each others' ideas. Weaknesses: A list based on historical information can be seen as exhaustive. A list based on brainstorming can be bias towards ideas of individual team member.
Delphi technique	Identification	Description: A way to reach a consensus of experts. A facilitator uses a questionnaire to solicit ideas about the important project risks. The responses are summarized and are then sent back to the experts for further comment. Consensus may be reached in a few rounds of this process. Strengths: The Delphi technique helps reduce bias in the data and keeps any one person from having too much influence on the outcome. Weaknesses: Time consuming and expensive.
Subjective probability	Assessment (quantitative)	Description: Uses the experience gained from similar projects undertaken in the past to decide on the likelihood of risk exposure and the outcomes. In construction projects, risk premiums (contingencies or added margins) cover unforeseen

		events. Strengths: The amount of the premium varies between projects and is mostly dependent upon attendant risk and the decision maker's risk attitude. Weaknesses: Requires quantification of probability of occurrence and probability distribution of risk factors before the procedures involved in calculations can be undertaken.
Sensitivity analysis	Assessment (quantitative)	Descriptions: A sensitivity coefficient is a derivative; the change in some outcome with respect to a change in some input. Techniques used to proved information on the risk variables which are considered to be of potentially serious impact on project cost and time estimates. Strengths: Provides answers to a whole range of "what if" questions, it is simple to use and has the ability to focus on a particular estimate. Even if the probability of a particular risk cannot be determined precisely, sensitivity analysis can be used to determine which variables have the greatest influence on the risk. Weaknesses: Does not reflect diversification. Says nothing about the likelihood of a change in a variable. Ignores relationships among variables.
Event trees (fault trees, probability trees)	Assessment (quantitative)	Description: The results of the evaluations are the probabilities of various outcomes from given faults or failures. Each event tree shows a particular event and the conditions causing that event, leading to the determination of the likelihood of these events. These methods can be adapted to project cost, schedule, and performance risk assessments. Strengths: Commonly used in reliability studies, probabilistic risk assessments (for example for nuclear power plants), and failure modes and effects analyses.
Additive models	Assessment (quantitative)	Description: Models in which the combination of risk factors is based on simple addition (is the basis for the PERT technique). Strengths: Easily understood, and it is usually obvious which activities contribute the most to the total project uncertainty and which do not.
Risk adjusted discount rate	Assessment (quantitative)	Description: Discount rate is used to adjust future cash flows to reflect the lower value of risky investments.
System Dynamics Model	Assessment (qualitative & quantitative)	Description: Describe and explain how project behavior and performance are driven by the feedback loops, delays, and nonlinear relationships in processes, resources, and management. Can be used to clarify and test project participants' assumptions as well as to design and test proposed

		project improvements and managerial policies. Are based on dynamic feedback so the models can also be used to evaluate the impacts of various failure modes or root causes, particularly in cases where the root causes can be identified but the ripple effect of their impacts is difficult to estimate with any confidence. Use of these models is not standard practice for project planning and risk management but they can significantly help owners to improve their understanding of project risks. Strengths: Projects with tightly coupled activities are not well described by conventional project network models (which prohibit iteration and feedback). Efforts to apply conventional methods to these projects can lead to incorrect conclusions, counterproductive decisions, and project failures. Weaknesses: Require skilled modelers.
Monte Carlo simulation models (stochastic simulation)	Assessment (qualitative)	Description: Using this method the probability of project outcome is obtained by carrying out a number of iterations, depending on the degree of confidence required. Monte Carlo simulation is typically used to combine the risks from multiple risk factors and is useful to determine whether the total risk of a project is too great to allow it to proceed or to determine the appropriate amount of contingency Strengths: Can be useful in the absence of real data in that they are based on subjective assessments of the probability distributions that do not require large databases of previous project information. Weaknesses: An often-cited weakness of this method is that subjective assessments of probability distributions often lack credibility, because they may be influenced by bias. This can be overcome to some degree by a carefully structured application of expert judgment.
Value at Risk (VaR)	Assessment (qualitative)	Description: Attempts to summarize the downside risk using a single number which represents the worst possible monetary loss over a target horizon with a given probability. Three basic methodologies for calculating VaR: historical simulation, delta-normal approach, and Monte Carlo simulation.
Risk classification	Assessment (qualitative)	Description: Classifying risks requires grouping risks based on their shared characteristics. The groups, which can also be called classes or sets, show the relationships among the risks. Strengths: Risk classification can be used to help identify duplicate risks as well as to help simplify a list of risks.
Analytic hierarchy process (AHP)	Assessment (qualitative)	Description: Method to assess the impact of risk factors. Deals with the relative priority or importance of each factor by pair

		wise comparison of all factors with respect to certain criteria. Strengths: Very effective in construction practice, because risk factors are numerous, particularly in large projects, and the ability of humans to assess many factors at the same time is very limited. Therefore, it is necessary to break down the numerous risk factors into small groups, so that people can easily assess these small group risk factors step by step, and then combine them to obtain the whole risk assessment.
Strengths, weaknesses, opportunities, and threats (SWOT) analysis	Assessment (qualitative)	Description: This technique ensures examination of the project from each of the SWOT perspectives, to fully examine the risk that has been identified. Strengths: The analysis can be conducted and documented quickly. Weaknesses: Only useful for focusing on the strategic issues. If not there is a risk of generating too much detail and being swamped with minor issues.
Project simulations	Assessment (qualitative)	Description: Group enactments or simulations of operations, in which managers and other project participants perform the project activities in a virtual environment before undertaking them on the project. This type of simulation may or may not be supported by computers; the emphasis is not on the computer models but rather on the interactions of the participants and the effects of these interactions on project outcomes. Engineering and construction contractors have developed project simulation methods, and owners can develop their own or specify that their contractors should perform such simulations before a project starts, in conjunction with the other pre project planning efforts. Strengths: Good for team building before a project starts up. Weaknesses: Often expensive, but they can be cost effective in the long run, compared to the typical approach of jumping into major projects with little or no preparation of the personnel and their working relationships.
Pareto Diagrams	Assessment (qualitative)	Description: Simple method for prioritizing risk elements. Show the sources of uncertainty or impact in descending order which makes explicit those activities that have the greatest effect on the project completion date or cost and that therefore require the greatest management attention. The "Pareto Principle" states that 80% of the problems come from 20% of the causes. Strengths: Can be used to identify those factors that have the greatest cumulative effect on the system. Commercial software is available to create Pareto charts.

Failure modes and effects analysis (FMEA)	Assessment (qualitative)	Description: A method used for initial screening only and ranking of risks for further investigation. Not a method for quantifying risks on a probabilistic basis. Effective in a team environment. Strengths: In the absence of more quantitative factors all root causes can be used to rank the risks.
Cause and effect analysis (Ishikawa, fishbone diagrams)	Assessment (qualitative)	Description: This method analyzes the relationships and interrelationships between a risk and it associated causes. Analyzing the causes and effects of risks and actions may provide additional insight into their dependencies and relationships to support decisions. Strengths: Encourage the consideration of all possible causes of the risk, rather than just the ones that are most obvious. Weaknesses: Limited by the brainstorming.
System or process flow charts	Assessment (qualitative)	Description: Show how various elements of system interrelate, and the mechanism of causation. Strengths: Seeing the flow sometimes triggers someone to identify a risk that may have slipped through the cracks.
Influence diagrams	Assessment (qualitative)	Description: These are graphical representations of situations showing causal influences, time ordering of events, and other relationships among variables and outcomes. Strengths: Are compact, one or two order of reduction in node representation in typical problems.
Simple stratification methods (heat map, risk matrix, risk map)	Assessment (qualitative)	Description: Use green/yellow/red or high/medium/low rating scales on a variety of risky endeavors. Sometimes a point scale is used to assess likelihood and consequence so that the two values can be multiplied together to get a risk score.
Event chain methodology	Assessment (qualitative)	Description: Risk modeling and schedule network analysis technique that is focused on identifying and managing events and event chains that affect project schedules.
Morphological Analysis	Assessment (qualitative)	Description: A problem structuring and problem solving technique designed for multi dimensional, non quantifiable problems where causal modeling and simulation do not function well or at all. Strengths: Does not drop any of the components of the system itself, but works backwards from the output towards the system internals.
Program Evaluation and Review Technique (PERT)	Assessment (qualitative)	Description: Commonly used for determining uncertainty in project completion times. PERT charts are dependency and probability schedules that can be used to analyze the impacts of

chart		changes in risk status and mitigation plans.
Real Options	Management (control)	Description: For projects with high flexibility and high uncertainty, using real options can add value by helping to manage downside risk and making it possible to profit from upside gains. Strengths: Can reduce upfront cost, increase the project's net present value (NPV), decrease exposure to downside risk, and improve ability to benefit from upside gain. Weaknesses: Can be expensive to incorporate, although the benefits are proven to outweigh the cost.
Game Theory	Management (control)	Description: Models the interactions between different parties. Strengths: Useful for planning strategies regarding risk from competitors' moves, and interaction between defenders and opponents upon attacks on the infrastructure. Weaknesses: Requires that protocols for interaction are precise (whereas in the real world they are often ambiguous). The theory often provides many equilibria and no way to choose among them.
Diversification	Management (control)	Description: This technique builds on the principle of not putting all the eggs in the same basket. Both integrated and specialty energy companies use diversification to reduce their risks. Integrated companies can invest in a variety of unrelated businesses or in the same businesses at different geographic locations. Strengths: Diversification can reduce risks that are specific to each participant. Weaknesses: Not all risks, for example a major economic downturn, can be mitigated by diversification.
Financial Architecture	Management (transfer)	Description: The financial architecture of a project (as represented by its use of debt, equity, recourse, and guarantees) has the dual role of allocating risk and making effective renegotiation possible.
Hedging	Management (transfer)	Description: Financial derivatives can be used to engage in transactions to hedge the financial exposures to market risks, such as any remaining currency risk, interest rate risk, and commodity price risk (through futures, options, swaps, and non-recourse finance).
Joint Venture	Management (transfer)	Description: By undertaking the project with another firm (joint venture/consortium) part of the risk is transferred through equity.

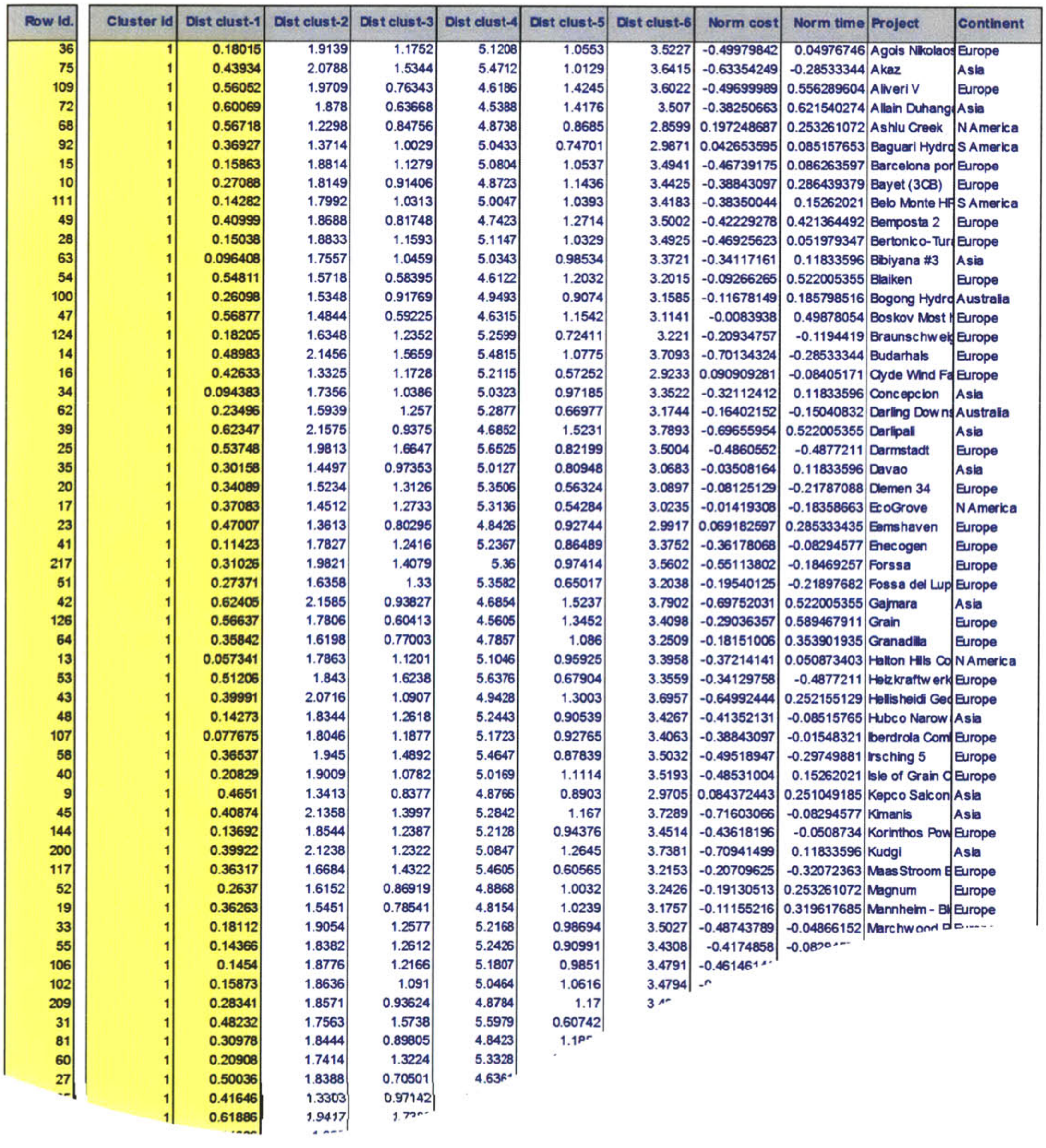
		Strengths: Useful in transferring the risk for projects in unfamiliar market, such as emerging economy projects through participation with local partners. Joint ventures do not need to be permanent, the shares of the partners may evolve over time and the joint venture may eventually be dissolved.
Project finance	Management (transfer)	Strengths: Suitable for projects which involve established techniques because a party to a project will agree to bear a given risk at a non prohibitive price only if it has a clear understanding of that risk. Weaknesses: Less appropriate for projects that involve complex or untried technologies.
Risk transfer contracts	Management (transfer)	Weakness: Reallocating risk among parties does not necessarily reduce the total risk that must be borne and therefore does not reduce the overall cost of capital.
Insurance	Management (transfer)	Description: Risks can be transferred by a variety of insurance contracts, such as completion insurance, insurance against force majeure, and purchase of insurance against political risks. Strengths: Through insurances, the players are able to operate at higher debt ratios than they otherwise could.

APPENDIX 3: DATABASES WHICH PROVIDED LIMITED PROJECT INFORMATION

DATABASE	DATA AVAILABILITY	KEY VARIABLES
EBRD Renewable Development Initiative Website: (ERDB, 2011)	Tracked latest developments in the region of the European Bank for Reconstruction and Development countries until the end of 2011 (comprises 29 countries located throughout Central and Eastern Europe (CEE) and the Former Soviet Union).	Project Name, Developer, Electricity Purchaser, Location, Technology, Development Status, Capacity
Power Engineering Website: (Power Engineering, 2012)	Good source of news on power plant development projects. Provides the most recent news, and five years of searchable editorial archives.	News updates
SEIA: Utility-Scale Solar Projects in the United States Report: (SEIA, 2012)	Contains key information about utility-scale solar projects in the United States either operating, under construction, or under development	Project Name, Developer, Electricity Purchaser, Location, Technology, Development Status, Land Type, Capacity
Platt's Power in Asia	The Power in Asia monthly project tracker briefly lists projects under development or construction in Asia-Pacific whose status changed during the past month.	Development Milestones (including signing of PPA and other project agreements, award of turnkey or EPC contracts, commencement of construction and commencement of commercial operation)
Platt's Power in Europe	The Power in Europe project tracker comprises major central plant additions and the largest renewable projects planned as reported.	Development Milestones (including signing of PPA and other project agreements, award of turnkey or EPC contracts, commencement of construction and commencement of commercial operation)
Power-Technology Website: (Power Technology, 2012)	Power Technology is a procurement and reference resource providing information on power generation equipment suppliers, up-to-date news and press releases, white papers and information on current industry projects.	Project Name, Developer, Location, Devleopment Status, Capacity, Estimated Investment Cost

APPENDIX 4: OUTPUT FOR K-MEANS CLUSTERING

Followed table displays the first few lines of the output for k-means clustering with k=6, sorted by Cluster ID.



Row Id.	Cluster id	Dist clust-1	Dist clust-2	Dist clust-3	Dist clust-4	Dist clust-5	Dist clust-6	Norm cost	Norm time	Project	Continent
36	1	0.18015	1.9139	1.1752	5.1208	1.0553	3.5227	-0.49979842	0.04976746	Agois Nikolaos	Europe
75	1	0.43934	2.0788	1.5344	5.4712	1.0129	3.6415	-0.63354249	-0.28533344	Akaz	Asia
109	1	0.56052	1.9709	0.76343	4.6186	1.4245	3.6022	-0.49699989	0.556289604	Aliveri V	Europe
72	1	0.60069	1.878	0.63668	4.5388	1.4176	3.507	-0.38250663	0.621540274	Allain Duhang	Asia
68	1	0.56718	1.2298	0.84756	4.8738	0.8685	2.8599	0.197248687	0.253261072	Ashlu Creek	N America
92	1	0.36927	1.3714	1.0029	5.0433	0.74701	2.9871	0.042653595	0.085157653	Baguari Hydro	S America
15	1	0.15863	1.8814	1.1279	5.0804	1.0537	3.4941	-0.46739175	0.086263597	Barcelona por	Europe
10	1	0.27088	1.8149	0.91406	4.8723	1.1436	3.4425	-0.38843097	0.286439379	Bayet (3CB)	Europe
111	1	0.14282	1.7992	1.0313	5.0047	1.0393	3.4183	-0.38350044	0.15262021	Belo Monte HP	S America
49	1	0.40999	1.8688	0.81748	4.7423	1.2714	3.5002	-0.42229278	0.421364492	Bemposta 2	Europe
28	1	0.15038	1.8833	1.1593	5.1147	1.0329	3.4925	-0.46925623	0.051979347	Bertonico-Tur	Europe
63	1	0.096408	1.7557	1.0459	5.0343	0.98534	3.3721	-0.34117161	0.11833596	Bibiyana #3	Asia
54	1	0.54811	1.5718	0.58395	4.6122	1.2032	3.2015	-0.09266265	0.522005355	Blaiken	Europe
100	1	0.26098	1.5348	0.91769	4.9493	0.9074	3.1585	-0.11678149	0.185798516	Bogong Hydro	Australia
47	1	0.56877	1.4844	0.59225	4.6315	1.1542	3.1141	-0.0083938	0.49878054	Boskov Most	Europe
124	1	0.18205	1.6348	1.2352	5.2599	0.72411	3.221	-0.20934757	-0.1194419	Braunschweig	Europe
14	1	0.48983	2.1456	1.5659	5.4815	1.0775	3.7093	-0.70134324	-0.28533344	Budarhals	Europe
16	1	0.42633	1.3325	1.1728	5.2115	0.57252	2.9233	0.090909281	-0.08405171	Clyde Wind Fa	Europe
34	1	0.094383	1.7356	1.0386	5.0323	0.97185	3.3522	-0.32112412	0.11833596	Concepcion	Asia
62	1	0.23496	1.5939	1.257	5.2877	0.66977	3.1744	-0.16402152	-0.15040832	Darling Downs	Australia
39	1	0.62347	2.1575	0.9375	4.6852	1.5231	3.7893	-0.69655954	0.522005355	Darlipali	Asia
25	1	0.53748	1.9813	1.6647	5.6525	0.82199	3.5004	-0.4860552	-0.4877211	Darmstadt	Europe
35	1	0.30158	1.4497	0.97353	5.0127	0.80948	3.0683	-0.03508164	0.11833596	Davao	Asia
20	1	0.34089	1.5234	1.3126	5.3506	0.56324	3.0897	-0.08125129	-0.21787088	Diemen 34	Europe
17	1	0.37083	1.4512	1.2733	5.3136	0.54284	3.0235	-0.01419308	-0.18358663	EcoGrove	N America
23	1	0.47007	1.3613	0.80295	4.8426	0.92744	2.9917	0.069182597	0.285333435	Eemshaven	Europe
41	1	0.11423	1.7827	1.2416	5.2367	0.86489	3.3752	-0.36178068	-0.08294577	Enecogen	Europe
217	1	0.31026	1.9821	1.4079	5.36	0.97414	3.5602	-0.55113802	-0.18469257	Forssa	Europe
51	1	0.27371	1.6358	1.33	5.3582	0.65017	3.2038	-0.19540125	-0.21897682	Fossa del Lup	Europe
42	1	0.62405	2.1585	0.93827	4.6854	1.5237	3.7902	-0.69752031	0.522005355	Gajmara	Asia
126	1	0.56637	1.7806	0.60413	4.5605	1.3452	3.4098	-0.29036357	0.589467911	Grain	Europe
64	1	0.35842	1.6198	0.77003	4.7857	1.086	3.2509	-0.18151006	0.353901935	Granadilla	Europe
13	1	0.057341	1.7863	1.1201	5.1046	0.95925	3.3958	-0.37214141	0.050873403	Halton Hills Co	N America
53	1	0.51206	1.843	1.6238	5.6376	0.67904	3.3559	-0.34129758	-0.4877211	Heizkraftwerk	Europe
43	1	0.39991	2.0716	1.0907	4.9428	1.3003	3.6957	-0.64992444	0.252155129	Hellisheidi Geo	Europe
48	1	0.14273	1.8344	1.2618	5.2443	0.90539	3.4267	-0.41352131	-0.08515765	Hubco Narow	Asia
107	1	0.077675	1.8046	1.1877	5.1723	0.92765	3.4063	-0.38843097	-0.01548321	Iberdrola Com	Europe
58	1	0.36537	1.945	1.4892	5.4647	0.87839	3.5032	-0.49518947	-0.29749881	Irsching 5	Europe
40	1	0.20829	1.9009	1.0782	5.0169	1.1114	3.5193	-0.48531004	0.15262021	Isle of Grain C	Europe
9	1	0.4651	1.3413	0.8377	4.8766	0.8903	2.9705	0.084372443	0.251049185	Kepco Salcon	Asia
45	1	0.40874	2.1358	1.3997	5.2842	1.167	3.7289	-0.71603066	-0.08294577	Kimanis	Asia
144	1	0.13692	1.8544	1.2387	5.2128	0.94376	3.4514	-0.43618196	-0.0508734	Korinthos Pow	Europe
200	1	0.39922	2.1238	1.2322	5.0847	1.2645	3.7381	-0.70941499	0.11833596	Kudgi	Asia
117	1	0.36317	1.6684	1.4322	5.4605	0.60565	3.2153	-0.20709625	-0.32072363	MaasStroom E	Europe
52	1	0.2637	1.6152	0.86919	4.8868	1.0032	3.2426	-0.19130513	0.253261072	Magnum	Europe
19	1	0.36263	1.5451	0.78541	4.8154	1.0239	3.1757	-0.11155216	0.319617685	Mannheim - Bl	Europe
33	1	0.18112	1.9054	1.2577	5.2168	0.98694	3.5027	-0.48743789	-0.04866152	Marchwood	
55	1	0.14366	1.8382	1.2612	5.2426	0.90991	3.4308	-0.4174858	-0.082		
106	1	0.1454	1.8776	1.2166	5.1807	0.9851	3.4791	-0.46146			
102	1	0.15873	1.8636	1.091	5.0464	1.0616	3.4794	-			
209	1	0.28341	1.8571	0.93624	4.8784	1.17	3.4				
31	1	0.48232	1.7563	1.5738	5.5979	0.60742					
81	1	0.30978	1.8444	0.89805	4.8423	1.1					
60	1	0.20908	1.7414	1.3224	5.3328						
27	1	0.50036	1.8388	0.70501	4.63						
	1	0.41646	1.3303	0.97142							
	1	0.61886	1.9417	1.7							

APPENDIX 5: NORMALIZED VALUES FOR GEOGRAPHIC CLUSTERING

Impact of normalized Cost per kW range on project portfolio

Continent	Biomass	CCGT	Coal	Geothermal	Large Hydro	Nuclear	Oil	Small Hydro	Solar	Wind	Total impact
Africa	0	0	-0.19	0	-0.13	0	0	0	0	0	-0.32
Asia	0	0	-0.10	0	-0.10	0.04	-0.16	0	0.14	-0.05	-0.23
Australia	0	0	-0.03	0	-0.04	0	0	0	0.32	-0.37	-0.12
Europe	0	0	-0.03	0	-0.03	0.02	0	0.01	0.17	-0.34	-0.20
N America	0	0	-0.01	0	-0.14	0	0	0.04	0.36	-0.37	-0.12
S America	0	0	0	0	-0.28	0.08	0	0	0	-0.13	-0.33
Oceania	0	0	0	0	0	0	0	0	0	-0.30	-0.30
										Average	-0.23

Impact of normalized Construction Time range on project portfolio

Continent	Biomass	CCGT	Coal	Geothermal	Large Hydro	Nuclear	Oil	Small Hydro	Solar	Wind	Total impact
Africa	0	0	0	0	0	0	0	0	0	0	0
Asia	0	0	0	0	0	0.04	0	0	-0.26	-0.05	-0.28
Australia	0	0	0	0	0	0	0	0	-0.62	-0.41	-1.03
Europe	0	0	0	0	0	0.02	0	-0.02	-0.32	-0.38	-0.70
N America	0	0	0	0	0	0	0	-0.06	-0.69	-0.40	-1.15
S America	0	0	0	0	0	0.07	0	0	0	-0.15	-0.07
Oceania	0	0	0	0	0	0	0	0	0	-0.33	-0.34
										Average	-0.51

APPENDIX 6: ESTIMATED LOGISTIC REGRESSION MODEL FOR COST OVERRUN

Regression Model for predicting projects which go 50% over estimated development cost:

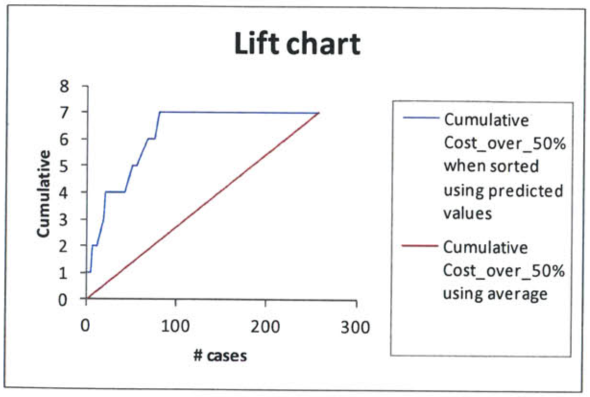
Input variables	Coefficient	Std. Error	p-value	Odds
Constant term	-4.50491858	1.37076914	0.00101471	*
Energy_Bi	0.04454155	1.62797785	0.97817254	1.04554844
Energy_Co	-13.5252972	832.9473877	0.98704463	0.00000134
Energy_Ge	-0.33628154	1.93788004	0.86223435	0.71442193
Energy_IH	-0.37940282	1.48267472	0.79803514	0.68426991
Energy_Nu	-14.4668551	2071.307617	0.99442732	0.00000052
Energy_Oi	-2.33459568	3580.267334	0.99947971	0.09684962
Energy_sH	-14.2462578	3296.608154	0.99655199	0.00000065
Energy_So	-0.38328022	1.61323094	0.81220263	0.68162191
Energy_Wi	-0.47748771	1.44681025	0.7413789	0.62033993
Continent_Af	3.93439579	2.05320168	0.05533648	51.13124847
Continent_As	1.10015357	0.98162466	0.26239523	3.00462747
Continent_Au	-13.8627014	1910.322632	0.99421	0.00000095
Continent_NA	-13.9464064	1001.772705	0.98889244	0.00000088
Continent_SA	-13.0698891	2413.147217	0.9956786	0.00000211
Size_0-100	1.8567301	1.39337122	0.18268108	6.40276623
Size_500-1000	2.5225513	1.42373371	0.07643009	12.46034718
Size_1000+	-11.6455813	856.0819702	0.98914641	0.00000876
Ownership_IOU	-0.03587344	1.23806024	0.97688413	0.96476239
Ownership_IPP	-13.2628012	1117.499512	0.99053073	0.00000174

Summary report of data scoring:

Cut off Prob.Val. for Success (Updatable)	0.5

Classification Confusion Matrix		
	Predicted Class	
Actual Class	1	0
1	1	6
0	0	251

Error Report			
Class	# Cases	# Errors	% Error
1	7	6	85.71
0	251	0	0.00
Overall	258	6	2.33



APPENDIX 7: ESTIMATED LOGISTIC REGRESSION MODEL FOR TIME OVERRUN

Regression Model for predicting projects which go 50% over estimated completion time:

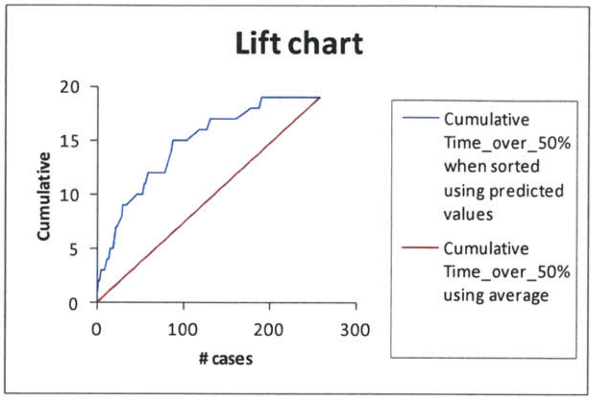
Input variables	Coefficient	Std. Error	p-value	Odds
Constant term	-3.73469114	0.83174735	0.00000712	*
Energy_Bi	1.03322029	1.17671514	0.37991399	2.81010079
Energy_Co	-1.51820564	1.39948261	0.27799541	0.21910469
Energy_Ge	1.0501436	1.15360725	0.36265749	2.85806155
Energy_IH	-0.91510403	1.24496603	0.46231309	0.40047497
Energy_Nu	-14.5572319	1510.115112	0.99230868	0.00000048
Energy_Oi	1.14688981	1.66864192	0.49188155	3.14838552
Energy_sH	1.58502853	1.50169301	0.29119927	4.87943077
Energy_So	0.0992498	1.06748927	0.92592341	1.1043421
Energy_Wi	0.85637689	0.87275004	0.32647464	2.35461402
Continent_Af	2.06890631	1.59765518	0.19533259	7.91616011
Continent_As	0.74112785	0.73486704	0.31320509	2.0983007
Continent_Au	0.45661157	1.15675235	0.69303787	1.57871556
Continent_NA	-0.31607354	0.88083178	0.71971828	0.72900581
Continent_SA	-13.5855484	1562.367554	0.99306208	0.00000126
Size_0-100	1.20283985	0.71018845	0.09032399	3.32955909
Size_500-1000	1.72677851	0.87720555	0.04901061	5.62251186
Size_1000+	1.39706135	1.15935683	0.22819118	4.04330063
Ow nership_IOU	-14.428278	765.140564	0.98495513	0.00000054
Ow nership_IPP	0.19283582	0.75403893	0.79815376	1.21268368

Summary report of data scoring:

Cut off Prob.Val. for Success (Updatable)	0.5

Classification Confusion Matrix		
	Predicted Class	
Actual Class	1	0
1	2	17
0	0	239

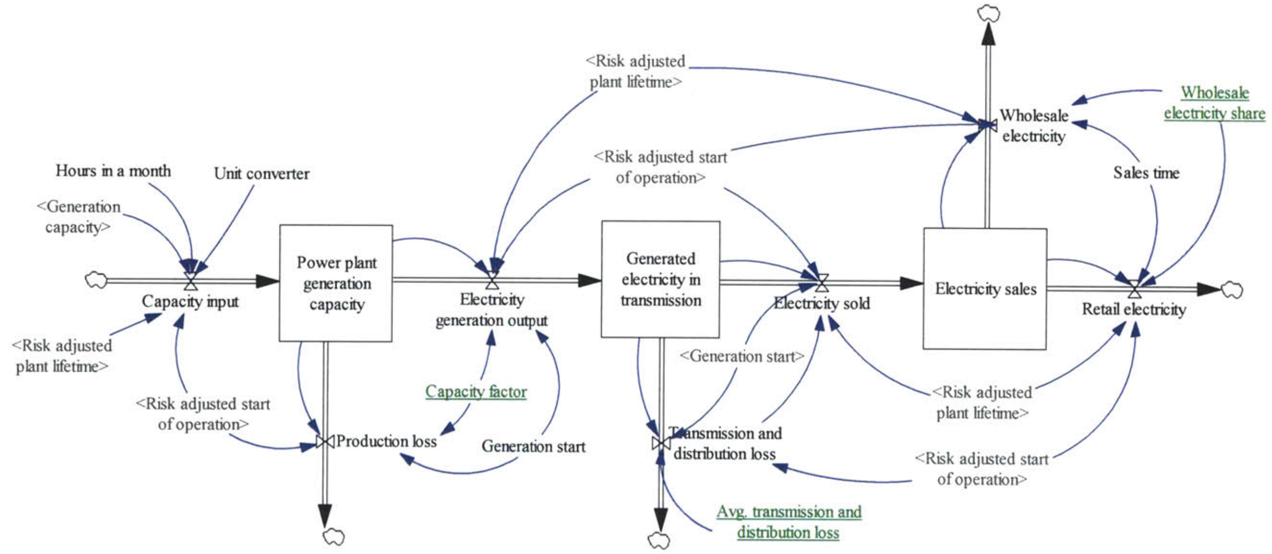
Error Report			
Class	# Cases	# Errors	% Error
1	19	17	89.47
0	239	0	0.00
Overall	258	17	6.59



APPENDIX 8: SYSTEM DYNAMICS ELECTRICITY GENERATION AND SALES MODEL

The following is a complete documentation of the System Dynamics model used to represent electricity generation, transmission/distribution, and sales throughout the power plant lifetime, as discussed in Section 4.4.3.

Model of electricity generation, transmission, and sales:



Documented equation listing for electricity generation sales model:

(01) "Avg. transmission and distribution loss"=0.065
Units: Dmnl
Input assumption about the average transmission and distribution loss.

(02) Capacity factor=0.4
Units: Dmnl
Capacity factor for the given energy technology.

(03) Capacity input=IF THEN ELSE(Risk adjusted start of operation>0,PULSE(Risk adjusted start of operation, Risk adjusted plant lifetime)*Generation capacity*Hours in a month*Unit converter,0)
Units: MWh/Month
Total monthly generating capacity of the power plant, before considering any losses.

(04) Electricity generation output=IF THEN ELSE(Risk adjusted start of operation>0, PULSE(Risk adjusted start of operation, Risk adjusted plant lifetime)*Power plant generation capacity*Capacity factor/Generation start,0)
Units: MWh/Month
Total electricity generation output per month which is sent to transmission.

(05) Electricity sales= INTEG (Electricity sold-Retail electricity-Wholesale electricity,0)
Units: MWh
Level of electricity being sold.

(06) Electricity sold= IF THEN ELSE(Risk adjusted start of operation>0, PULSE(Risk adjusted start of operation,Risk adjusted plant lifetime)*(Generated electricity in transmission/Generation start - Transmission and distribution loss),0)
Units: MWh/Month
Total electricity generated which gets sold, after taking into account all losses (production loss, and transmission/distribution loss).

(07) FINAL TIME = 100
Units: Month
The final time for the simulation.

(08) Generated electricity in transmission= INTEG (Electricity generation output-Electricity sold-Transmission and distribution loss,0)
Units: MWh
Level of generated electricity in transmission, less the transmission and distribution loss.

(09) Generation capacity=100
Units: MW
This constant is for the total generation capacity the power plant is initially designed for.

(10) Generation start=1
Units: Month
Dummy constant to initiate a monthly flow of electricity generation from stocks.

(11) Hours in a month=730
Units: h/Month
Constant to convert generation capacity to monthly generation output.

(12) INITIAL TIME = 0
Units: Month
The initial time for the simulation.

(13) Power plant generation capacity= INTEG (Capacity input-Electricity generation output-Production loss,0)
Units: MWh
Level of generation capacity of the power plant less the production loss and electricity sent to transmission.

(14) Production loss=IF THEN ELSE(Risk adjusted start of operation>0,PULSE(Risk adjusted start of operation,1)*Power plant generation capacity*(1-Capacity factor)/Generation start,0)
Units: MWh/Month
Loss to generating capacity as a result of the capacity factor for this energy technology.

(15) Retail electricity=IF THEN ELSE(Risk adjusted start of operation>0,PULSE(Risk adjusted start of operation,Risk adjusted plant lifetime)* (Electricity sales*(1-Wholesale electricity share)/Sales time),0)
Units: MWh/Month
Total electricity being sold in retail throughout the power plant lifetime.

(16) Risk adjusted plant lifetime = A FUNCTION OF( )
Risk adjusted plant lifetime= INTEG (Increasing duration of plant lifetime,0)
Units: Dmnl
This stock is empty until it receives a onetime inflow of the risk adjusted time to complete third stage. There's no outflow from this stock so it can be used for reference throughout the model for what was the risk adjusted duration of the third stage.

(17) Risk adjusted start of operation = A FUNCTION OF( )
Risk adjusted start of operation=INTEGER(Risk adjusted planning time+Risk adjusted construction time)*risk conversion
Units: Month
The variable uses the integer value of the level in the "risk adjusted first stage" and "risk adjusted second stage" stocks to represent the total duration of the first and second stages. That way it can be used as a time reference in the model showing how much time had passed from project initiation until completion of second stage.

(18) Sales time=1
Units: Month
Dummy constant to initiate a monthly flow of electricity sales.

(19) SAVEPER = TIME STEP
Units: Month [0,?]
The frequency with which output is stored.

(20) TIME STEP = 1
Units: Month [0,?]
The time step for the simulation.

(21) Transmission and distribution loss=IF THEN ELSE(Risk adjusted start of operation>0, PULSE(Risk adjusted start of operation,1)*Generated electricity in transmission*"Avg. transmission and distribution loss"/Generation start,0)

Units: MWh/Month
Loss of generated electricity in transmission and distribution due to resistance.

(22) Unit converter=1
Units: MWh/(h*MW)
Dummy constant to convert a unit.

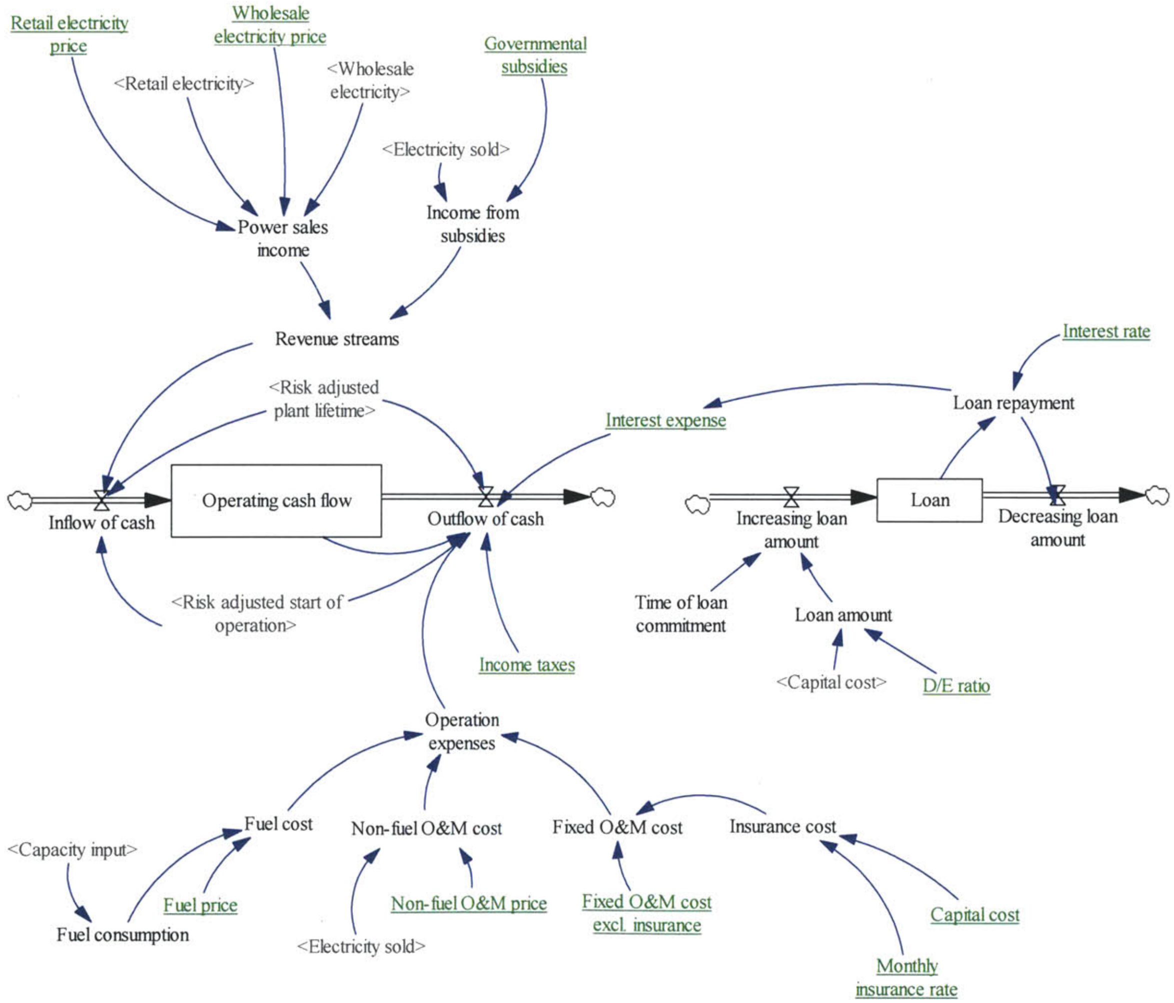
(23) Wholesale electricity=IF THEN ELSE(Risk adjusted start of operation>0, PULSE(Risk adjusted start of operation, Risk adjusted plant lifetime)*(Electricity sales*Wholesale electricity share)/Sales time,0)
Units: MWh/Month
Total electricity being sold in wholesale per month throughout the power plant operation.

(24) Wholesale electricity share=0.1
Units: Dmnl
Percentage share of electricity output of the power plant which gets sold as wholesale.

APPENDIX 9: SYSTEM DYNAMICS OPERATING CASH FLOW MODEL

The following is a complete documentation of the System Dynamics model used to represent operating cash flow throughout the power plant lifetime, as discussed in Section 4.4.3.

Model of operating cash flow throughout the power plant lifetime:



Documented equation listing for operating cash flow model:

(01) Capacity input = A FUNCTION OF(-Risk adjusted start of operation,-Risk adjusted plant lifetime)
Capacity input= IF THEN ELSE(Risk adjusted start of operation>0,PULSE(Risk adjusted start of operation, Risk adjusted plant lifetime)*Generation capacity*Hours in a month*Unit converter,0)
Units: MWh/Month
Total monthly generating capacity of the power plant, before considering any losses.

(02) Capital cost=1e+008
Units: USD
Capital Cost includes: Turbines, Balance of Plant (BOP), Transmission/ Gas/ Water Interconnection Costs, Land, Permitting/Siting, Interest During Construction (IDC)/Financing Cost, Environmental Reduction Credits (ERC), Initial Working Capital (IWC), Initial Spare Parts, Local benefit and mitigation costs, Insurance during construction

(03) "D/E ratio"=0.5
Units: Dmnl
Ratio of debt to equity.

(04) Decreasing loan amount=Loan repayment
Units: USD/Month
Loan repayments which lower the debt balance

(05) Electricity sold = A FUNCTION OF(-Risk adjusted start of operation,-Risk adjusted plant lifetime)
Electricity sold=IF THEN ELSE(Risk adjusted start of operation>0, PULSE(Risk adjusted start of operation,Risk adjusted plant lifetime)*(Generated electricity in transmission/Generation start - Transmission and distribution loss),0)
Units: MWh/Month
Total electricity generated which gets sold, after taking into account all losses (production loss, and transmission/distribution loss).

(06) FINAL TIME = 100
Units: Month
The final time for the simulation.

(07) "Fixed O&M cost excl. insurance"=300000/12
Units: USD/Month
Fixed O&M cost per month, such as Administrative and General (A&G), Labor, Other O&M, Station Power, Transmission O&M, Capital Additions (capital improvements, not Major Maintenance listed under Variable Cost), Negative Initial Working Capital in last year, if IWC included, On-going Spare Parts

(08) "Fixed O&M cost"="Fixed O&M cost excl. insurance"+Insurance cost
Units: USD/Month
Total fixed O&M cost

(09) Fuel consumption=Capacity input
Units: MWh/Month
Fuel consumption equals the total generation capacity of the power plant.

(10) Fuel cost=Fuel price*Fuel consumption
Units: USD/Month
Cost of fuel needed for power generation.

(11) Fuel price=10
Units: USD/MWh
Price of fuel for electricity generation

(12) Governmental subsidies=0
Units: USD/MWh
Total revenue stream from governmental subsidies

(13) Income from subsidies=Electricity sold*Governmental subsidies
Units: USD/Month
Income per month from government subsidies

(14) Income taxes=0.38
Units: Dmnl/Month
Corporate income tax on electricity production.

(15) Increasing loan amount=PULSE(0,1)*Loan amount/Time of loan commitment
Units: USD/Month
Total loan amount

(16) Inflow of cash=IF THEN ELSE(Risk adjusted start of operation>0,PULSE(Risk adjusted start of operation,Risk adjusted plant lifetime)*Revenue streams,0)
Units: USD/Month
Revenue stream starts increasing operational cash flow once development is completed and operation has begun and runs throughout the plant lifetime.

(17) INITIAL TIME = 0
Units: Month
The initial time for the simulation.

(18) Insurance cost=Capital cost*Monthly insurance rate
Units: USD/Month
Monthly insurance charges.

(19) Interest expense=Loan repayment
Units: USD/Month
Monthly interest expense

(20) Interest rate=0.004868
Units: Dmnl/Month

Monthly interest rate for the loan repayment.

(21) Loan= INTEG (Increasing loan amount-Decreasing loan amount, 0)
Units: USD
Level of remaining loan amount.

(22) Loan amount=Capital cost*"D/E ratio"
Units: USD
Total amount of the loan needed for this project.

(23) Loan repayment=Loan*Interest rate
Units: USD/Month
Monthly repayments of the loan

(24) Monthly insurance rate=0.00165158
Units: Dmnl/Month
Cost of insurance as percentage of capital cost per month.

(25) "Non-fuel O&M cost"=Electricity sold*"Non-fuel O&M price"
Units: USD/Month
Total of non-fuel O&M cost, such as maintenance and consumption of water, consumables or chemicals.

(26) "Non-fuel O&M price"=10
Units: USD/MWh
Price of non-fuel O&M expenses

(27) Operating cash flow= INTEG (Inflow of cash-Outflow of cash,0)
Units: USD
Level of operational cash flow throughout the plant's lifetime

(28) Operation expenses=Fuel cost+"Non-fuel O&M cost"+"Fixed O&M cost"
Units: USD/Month
Total operation expenses per month.

(29) Outflow of cash=IF THEN ELSE(Operating cash flow>0,PULSE(Risk adjusted start of operation ,Risk adjusted plant lifetime)*(Income taxes*Operating cash flow+Operation expenses+Interest expense),0)
Units: USD/Month
Outflow of operating cash increases with higher operation expenses, income tax rate, and interest expense from loan repayments. It begins when plant becomes operational and ends when the power plant retires.

(30) Power sales income=Retail electricity price*Retail electricity+Wholesale electricity*Wholesale electricity price
Units: USD/Month
Income per month from power sales of both wholesale and retail electricity.

(31) Retail electricity = A FUNCTION OF(-Risk adjusted start of operation,-Risk adjusted plant lifetime)
Retail electricity=IF THEN ELSE(Risk adjusted start of operation>0,PULSE(Risk adjusted start of operation,Risk adjusted plant lifetime)* (Electricity sales*(1-Wholesale electricity share)/Sales time),0)
Units: MWh/Month
Total electricity being sold in retail throughout the power plant lifetime.

(32) Retail electricity price=120
Units: USD/MWh
Input assumption for electricity price.

(33) Revenue streams=Power sales income+Income from subsidies
Units: USD/Month
Revenue streams from power sales and government subsidies.

(34) Risk adjusted plant lifetime = A FUNCTION OF( )
Risk adjusted plant lifetime= INTEG (Increasing duration of plant lifetime,0)
Units: Dmnl
This stock is empty until it receives a onetime inflow of the risk adjusted time to complete third stage. There's no outflow from this stock so it can be used for reference throughout the model for what was the risk adjusted duratiaon of the third stage.

(35) Risk adjusted start of operation = A FUNCTION OF( )
Risk adjusted start of operation=INTEGER(Risk adjusted planning time+Risk adjusted construction time)*risk conversion
Units: Month
The variable uses the integer value of the level in the "risk adjusted first stage" and "risk adjusted second stage" stocks to represent the total duration of the first and second stages. That way it can be used as a time reference in the model showing how much time had passed from project initiation until completion of second stage.

(36) SAVEPER = TIME STEP
Units: Month [0,?]
The frequency with which output is stored.

(37) Time of loan commitment=1
Units: Month
Constant to initiate loan commitments.

(38) TIME STEP = 1
Units: Month [0,?]
The time step for the simulation.

(39) Wholesale electricity = A FUNCTION OF(-Risk adjusted start of operation,-Risk adjusted plant lifetime)

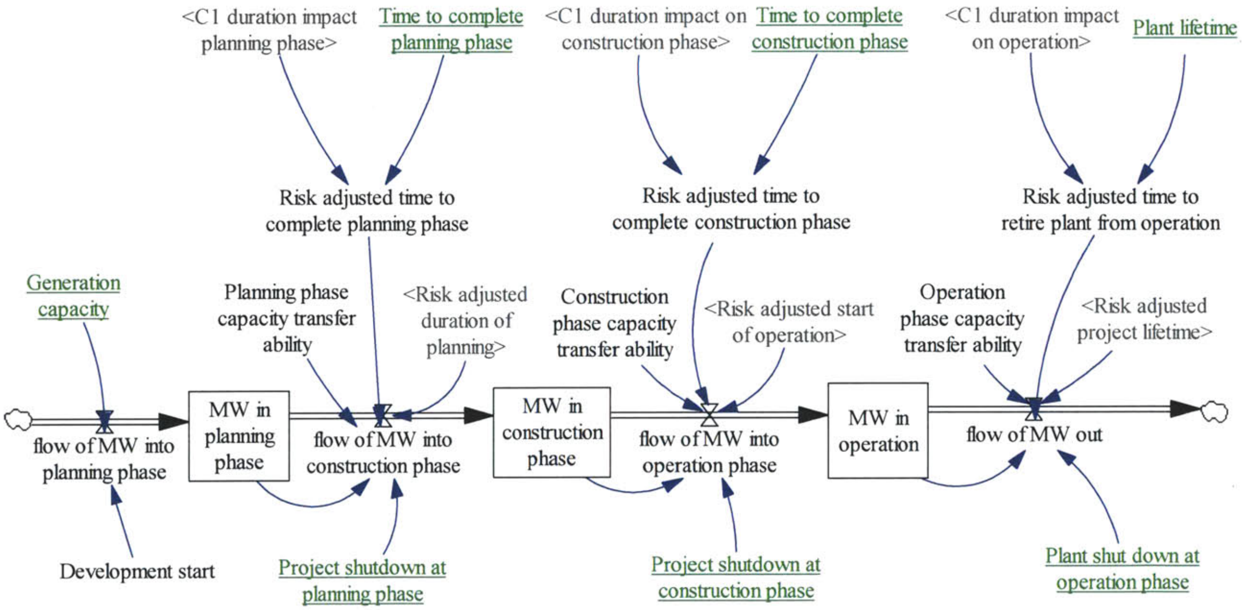
Wholesale electricity=IF THEN ELSE(Risk adjusted start of operation>0, PULSE(Risk adjusted start of operation, Risk adjusted plant lifetime)*(Electricity sales*Wholesale electricity share)/Sales time,0)
Units: MWh/Month
Total electricity being sold in wholesale per month throughout the power plant operation.

(40) Wholesale electricity price=80
Units: USD/MWh
Input assumption for wholesale electricity price.

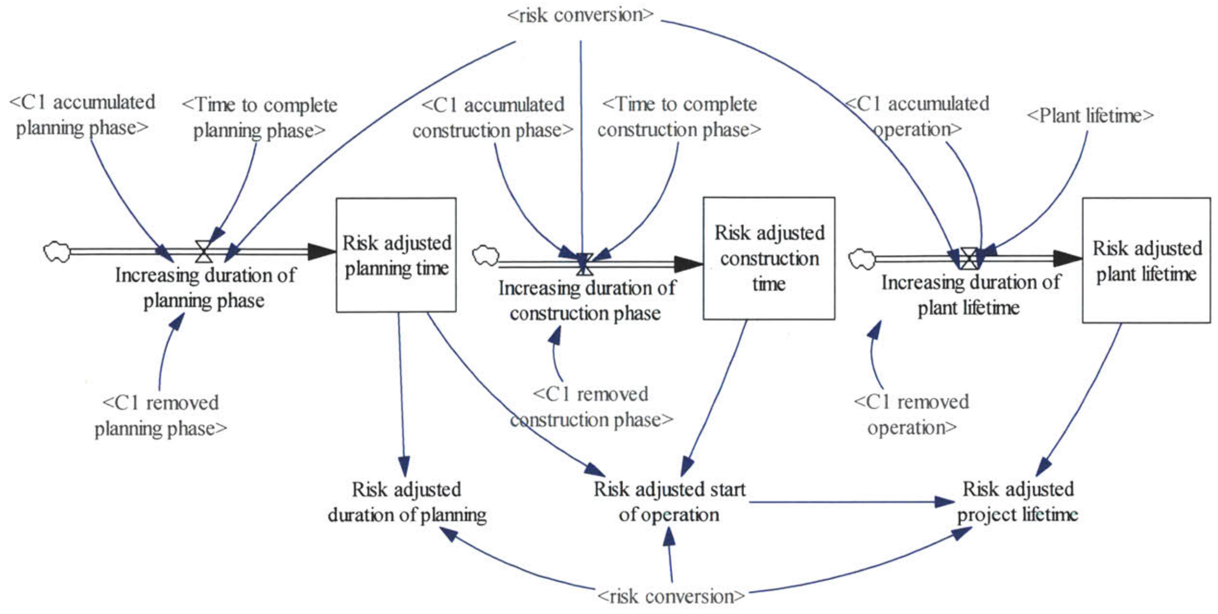
APPENDIX 10: SYSTEM DYNAMICS MODEL EXAMPLE OF RISK MANAGEMENT

The following is a complete documentation of the model example used in Section 4.4.5 showing how risks in a power plant development project may impact its performance, and how different risk management methodologies help to mitigate the negative impact.

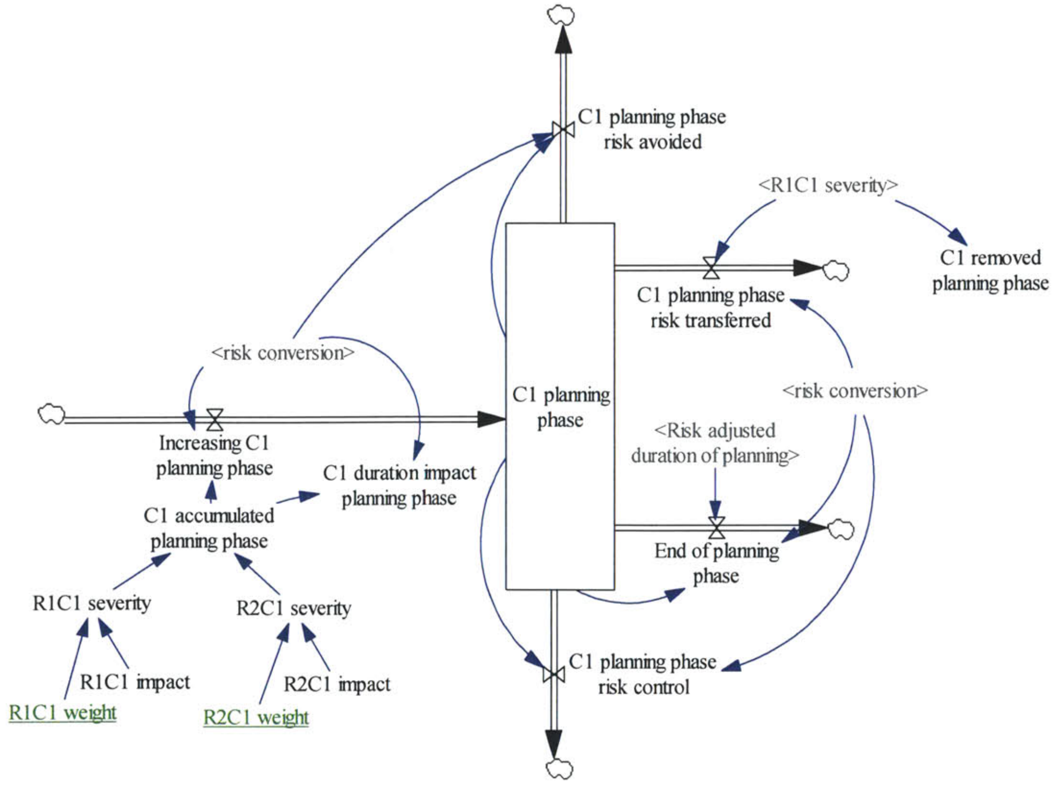
Model of the power plant development process:



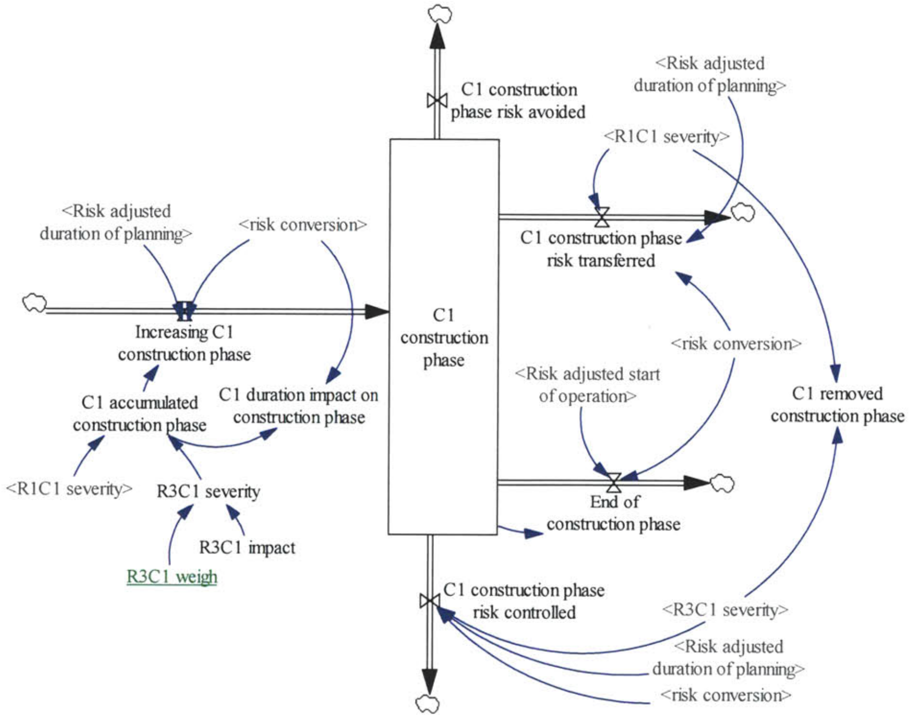
Model to capture risk adjusted duration of each development stage:



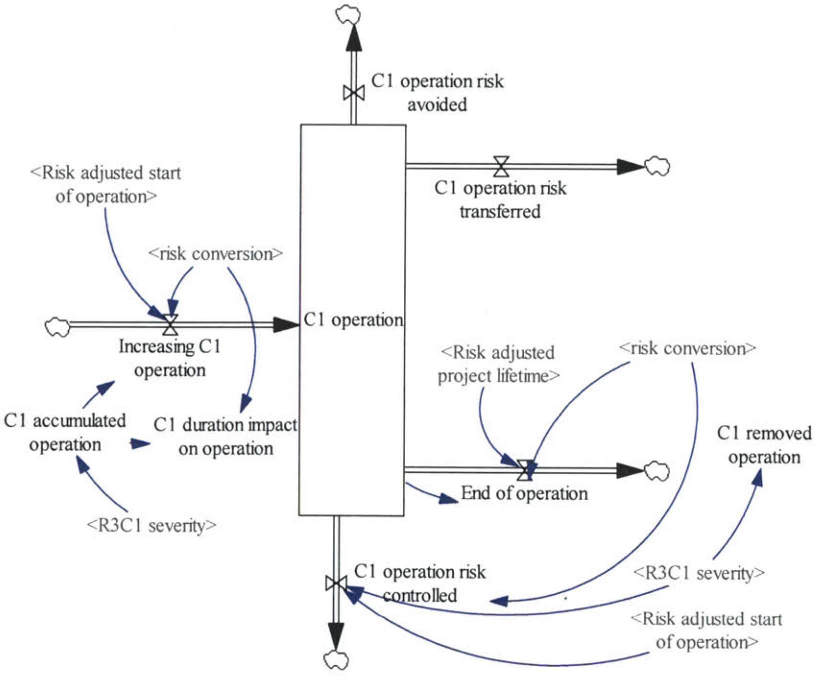
Model to capture level of risk C1 present during planning phase of development:



Model to capture level of risk C1 present during construction phase of development:



Model to capture level of risk C1 present during power plant's operation:



Model equations sorted alphabetically:

(01) C1 accumulated construction phase=R1C1 severity+R3C1 severity
Units: Dmnl
This is variable sums up all C1 risk in second stage of development before considering any risk management methodologies.

(02) C1 accumulated operation=R3C1 severity
Units: Dmnl
This is variable sums up all C1 risk in third stage of development before considering any risk management methodologies.

(03) C1 accumulated planning phase=R1C1 severity+R2C1 severity
Units: Dmnl
This is variable sums up all C1 risk in first stage of development before considering any risk management methodologies.

(04) C1 construction phase= INTEG (Increasing C1 construction phase-C1 construction phase risk avoided-C1 construction phase risk controlled-C1 construction phase risk transferred-End of construction phase,0)
Units: Dmnl
This stock has shows the level of risk C1 during the second stage of development.

(05) C1 construction phase risk avoided=0
Units: Dmnl/Month
Outflow of those risk factors in category C1 during second stage which were avoided through the project design.

(06) C1 construction phase risk controlled=PULSE(Risk adjusted duration of planning,1)*R3C1 severity/risk conversion
Units: Dmnl/Month
Outflow of those risk factors in category C1 during second stage which were controlled through the use of alternative contract strategies, use of training programs, different methods of construction, prototyping, project redesign, more detailed and further in-depth site investigation, or technical due diligence.

(07) C1 construction phase risk transferred=PULSE(Risk adjusted duration of planning,1)*R1C1 severity/risk conversion
Units: Dmnl/Month
Outflow of those risk factors in category C1 during second stage which were transferred using various contracts, insurance mechanisms, or financial architecture instruments.

(08) C1 duration impact on construction phase=C1 accumulated construction phase*risk conversion
Units: Month
This is a time variable showing the accumulated C1 risk in second stage of development before considering any risk management methodologies.

(09) C1 duration impact on operation=C1 accumulated operation*risk conversion

Units: Month
This is a time variable showing the accumulated C1 risk in third stage of development before considering any risk management methodologies.

(10) C1 duration impact planning phase=C1 accumulated planning phase*risk conversion
Units: Month
This is a time variable showing the accumulated C1 risk in first stage of development before considering any risk management methodologies.

(11) C1 operation= INTEG (Increasing C1 operation-C1 operation risk avoided-C1 operation risk controlled-C1 operation risk transferred-End of operation,0)
Units: Dmnl
This stock has shows the level of risk C1 during the third stage of development.

(12) C1 operation risk avoided=0
Units: Dmnl/Month
Outflow of those risk factors in category C1 during third stage which were avoided through the project design.

(13) C1 operation risk controlled=PULSE(Risk adjusted start of operation,1)*R3C1 severity/risk conversion
Units: Dmnl/Month
Outflow of those risk factors in category C1 during third stage which were controlled through the use of alternative contract strategies, use of training programs, different methods of construction, prototyping, project redesign, more detailed and further in-depth site investigation, or technical due diligence.

(14) C1 operation risk transferred=0
Units: Dmnl/Month
Outflow of those risk factors in category C1 during third stage which were transferred using various contracts, insurance mechanisms, or financial architecture instruments.

(15) C1 planning phase= INTEG (Increasing C1 planning phase-C1 planning phase risk avoided-C1 planning phase risk control-C1 planning phase risk transferred-End of planning phase,0)
Units: Dmnl [0,?]
This stock has shows the level of risk C1 during the first stage of development.

(16) C1 planning phase risk avoided=0*C1 planning phase/risk conversion
Units: Dmnl/Month
Outflow of those risk factors in category C1 during first stage which were avoided through the project design.

(17) C1 planning phase risk control=C1 planning phase/risk conversion*0
Units: Dmnl/Month
Outflow of those risk factors in category C1 during first stage which were controlled through the use of alternative contract strategies, use of training programs, different methods of construction, prototyping, project redesign, more detailed and further in-depth site investigation, or technical due diligence.

(18) C1 planning phase risk transferred=PULSE(0,1)*R1C1 severity/risk conversion
Units: Dmnl/Month
Outflow of those risk factors in category C1 during first stage which were transferred using various contracts, insurance mechanisms, or financial architecture instruments.

(19) C1 removed construction phase=R1C1 severity+R3C1 severity
Units: Dmnl
This is variable sums up all the C1 risk which is removed from second stage of development through the use of various risk management methodologies.

(20) C1 removed operation=R3C1 severity
Units: Dmnl
This is variable sums up all the C1 risk which is removed from third stage of development through the use of various risk management methodologies.

(21) C1 removed planning phase=R1C1 severity
Units: Dmnl
This is variable sums up all the C1 risk which is removed from first stage of development through the use of various risk management methodologies.

(22) Construction phase capacity transfer ability=1
Units: Month
This switch can be used to control how much capacity can flow from second stage to the third.

(23) Development start=1
Units: Month

(24) End of construction phase=PULSE(Risk adjusted start of operation, 1)*C1 construction phase/risk conversion
Units: Dmnl/Month
One time outflow of all remaining risk C1 at second stage at the end of that development stage.

(25) End of operation=PULSE(Risk adjusted project lifetime, 1)*C1 operation/risk conversion
Units: Dmnl/Month
One time outflow of all remaining risk C1 at third stage at the end of that development stage.

(26) End of planning phase=PULSE(Risk adjusted duration of planning, 1)*C1 planning phase/risk conversion
Units: Dmnl/Month
One time outflow of all remaining risk C1 at first stage at the end of that development stage.

(27) FINAL TIME = 100
Units: Month
The final time for the simulation.

(28) flow of MW into construction phase=PULSE(Risk adjusted duration of planning, 1)*(IF THEN ELSE(Project shutdown at planning phase>Risk adjusted time to complete planning phase,(MW in planning phase/Planning phase capacity transfer ability),0))
Units: MW/Month
This is a onetime flow of the power plant development capacity from first stage to the second. It timing is controlled by the risk adjusted duration of the first stage of development. If that time exceeds the developer's risk tolerance, the project gets shut down so there's no flow of capacity to be developed at second stage.

(29) flow of MW into operation phase=IF THEN ELSE(Project shutdown at construction phase>Risk adjusted time to complete construction phase, PULSE(Risk adjusted start of operation,1)*MW in construction phase/Construction phase capacity transfer ability,0)
Units: MW/Month
This is a onetime flow of the power plant development capacity from second stage to the third. Its timing is controlled by the risk adjusted duration of the second stage of development. If that time exceeds the developer's risk tolerance, the project gets shut down so there's no flow of capacity to go into operation at third stage.

(30) flow of MW into planning phase=PULSE(0, 1)*Generation capacity/Development start
Units: MW/Month
This is a onetime flow at time zero of the capacity size the power plant will be designed for.

(31) flow of MW out=PULSE(Risk adjusted project lifetime, 1)*IF THEN ELSE(Risk adjusted time to retire plant from operation<Plant shut down at operation phase, 0 ,(MW in operation/Operation phase capacity transfer ability))
Units: MW/Month
This is a onetime flow of the power plant development capacity out of third stage. Its timing is controlled by the risk adjusted lifetime of the power plant at third stage. If that time is less than the developer's risk tolerance the project is retired early.

(32) Generation capacity=100
Units: MW
This constant is for the total generation capacity the power plant is initially designed for.

(33) Increasing C1 construction phase=IF THEN ELSE(Risk adjusted duration of planning>2, PULSE(Risk adjusted duration of planning, 1)*C1 accumulated construction phase/risk conversion,0)
Units: Dmnl/Month
This is a onetime inflow at the beginning of second stage of development of severy of risk C1 in the second stage of development before considering any risk management methodologies.

(34) Increasing C1 operation=IF THEN ELSE(Risk adjusted start of operation>1,PULSE(Risk adjusted start of operation,1)*C1 accumulated operation/risk conversion,0)
Units: Dmnl/Month
This is a onetime inflow at the beginning of third stage of development of severity of risk C1 in the third stage of development before considering any risk management methodologies.

(35) Increasing C1 planning phase=PULSE(0, 1)*C1 accumulated planning phase/risk conversion
Units: Dmnl/Month

This is a onetime inflow at time zero of severity of risk C1 in the first stage of development.

(36) Increasing duration of construction phase=PULSE(0,1)*(Time to complete construction phase/risk conversion+C1 accumulated construction phase-C1 removed construction phase)/risk conversion
Units: Dmnl/Month
At time zero there is a onetime inflow of what the model will assume is the risk adjusted time to complete second stage. Its inflow is the sum of the originally estimated duration time, and the delay caused by risks in this development stage (adjusted for risk management).

(37) Increasing duration of planning phase=PULSE(0,1)*(C1 accumulated planning phase-C1 removed planning phase+Time to complete planning phase/risk conversion)/risk conversion
Units: Dmnl/Month
At time zero there is a onetime inflow of what the model will assume is the risk adjusted time to complete first stage. Its inflow is the sum of the originally estimated duration time, and the delay caused by risks in this development stage (adjusted for risk management).

(38) Increasing duration of plant lifetime=PULSE(0,1)*(-C1 accumulated operation+C1 removed operation+Plant lifetime/risk conversion)/risk conversion
Units: Dmnl/Month
At time zero there is a onetime inflow of what the model will assume is the risk adjusted time to complete third stage. Its inflow is the sum of the originally estimated duration time, and the delay caused by risks in this development stage (adjusted for risk management).

(39) INITIAL TIME = 0
Units: Month
The initial time for the simulation.

(40) MW in construction phase= INTEG (flow of MW into construction phase-flow of MW into operation phase,0)
Units: MW
This stock shows the level of power plant capacity under development at second stage.

(41) MW in operation= INTEG (flow of MW into operation phase-flow of MW out,0)
Units: MW
This stock shows the level of power plant capacity under development at third stage.

(42) MW in planning phase= INTEG (flow of MW into planning phase-flow of MW into construction phase,0)
Units: MW
This stock shows the level of power plant capacity under development at first stage.

(43) Operation phase capacity transfer ability=1
Units: Month
This switch can be used to control how much capacity can flow out from third stage

(44) Planning phase capacity transfer ability=1
Units: Month

This switch can be used to control how much capacity can flow from first stage to the second.

(45) Plant lifetime=36
Units: Month
This constant is for the originally estimated lifetime of the plant through third stage, without considering potential risk impact.

(46) Plant shut down at operation phase=24
Units: Month
This switch shows the maximum risk tolerance of the developer at third stage. It is used to retire the power plant early if the risk impact on development duration exceeds their threshold.

(47) Project shutdown at construction phase=48
Units: Month
This switch shows the maximum risk tolerance of the developer at second stage. It is used to shut the development project down if the risk impact on development duration exceeds their threshold.

(48) Project shutdown at planning phase=24
Units: Month
This switch shows the maximum risk tolerance of the developer at first stage. It is used to shut the development project down if the risk impact on development duration exceeds their threshold.

(49) R1C1 impact=5
Units: Dmnl
This is an estimate of what could be the impact of risk event R1C1 on the development performance.

(50) R1C1 severity=R1C1 impact*R1C1 weight
Units: Dmnl
This variable calculates the severity of risk factor R1C1.

(51) R1C1 weight=0.35
Units: Dmnl
This is weight of risk event R1C1 as generated by the ANP model.

(52) R2C1 impact=10
Units: Dmnl
This is an estimate of what could be the impact of risk event R2C1 on the development performance.

(53) R2C1 severity=R2C1 impact*R2C1 weight
Units: Dmnl
This variable calculates the severity of risk factor R2C1.

(54) R2C1 weight=0.15
Units: Dmnl

This is weight of risk event R2C1 as generated by the ANP model.

(55) R3C1 impact=15
Units: Dmnl
This is an estimate of what could be the impact of risk event R3C1 on the development performance.

(56) R3C1 severity=R3C1 impact*R3C1 weigh
Units: Dmnl
This variable calculates the severity of risk factor R3C1.

(57) R3C1 weigh=0.50
Units: Dmnl
This is weight of risk event R3C1 as generated by the ANP model.

(58) Risk adjusted construction time= INTEG (Increasing duration of construction phase,0)
Units: Dmnl
This stock is empty until it receives a onetime inflow of the risk adjusted time to complete second stage. There's no outflow from this stock so it can be used for reference throughout the model for what was the risk adjusted duration of the second stage.

(59) Risk adjusted duration of planning=INTEGER(Risk adjusted planning time)*risk conversion
Units: Month
The variable uses the integer value of the level in the "risk adjusted first stage" stock to represent the duration of the first stage. That way it can be used as a time reference in the model showing how much time had passed from project initiation until completion of first stage.

(60) Risk adjusted planning time= INTEG (Increasing duration of planning phase,0)
Units: Dmnl
This stock is empty until it receives a onetime inflow of the risk adjusted time to complete first stage. There's no outflow from this stock so it can be used for reference throughout the model for what was the risk adjusted duration of the first stage.

(61) Risk adjusted plant lifetime= INTEG (Increasing duration of plant lifetime,0)
Units: Dmnl
This stock is empty until it receives a onetime inflow of the risk adjusted time to complete third stage. There's no outflow from this stock so it can be used for reference throughout the model for what was the risk adjusted duration of the third stage.

(62) Risk adjusted project lifetime=INTEGER(Risk adjusted start of operation+Risk adjusted plant lifetime*risk conversion)
Units: Month
The variable is a sum of the integer value of the level in the "risk adjusted third stage" stock plus the variable representing the time at the start of third stage. That way it can be used as a time reference in the model showing how much time had passed from project initiation until completion of third stage.

(63) Risk adjusted start of operation=INTEGER(Risk adjusted planning time+Risk adjusted construction time)*risk conversion
Units: Month
The variable uses the integer value of the level in the "risk adjusted first stage" and "risk adjusted second stage" stocks to represent the total duration of the first and second stages. That way it can be used as a time reference in the model showing how much time had passed from project initiation until completion of second stage.

(64) Risk adjusted time to complete construction phase=Time to complete construction phase+C1 duration impact on construction phase
Units: Month
This is a time variable showing the risk adjusted duration of the second stage.

(65) Risk adjusted time to complete planning phase= Time to complete planning phase+C1 duration impact planning phase
Units: Month
This is a time variable showing the risk adjusted duration of the first stage.

(66) Risk adjusted time to retire plant from operation=Plant lifetime-C1 duration impact on operation
Units: Month
This is a time variable showing the risk adjusted duration of the third stage.

(67) risk conversion=1
Units: Month
This variable is used to convert risk impact into a time variable.

(68) SAVEPER = TIME STEP
Units: Month [0,?]
The frequency with which output is stored.

(69) TIME STEP = 1
Units: Month [0,?]
The time step for the simulation.

(70) Time to complete construction phase=24
Units: Month
This constraint is for the originally estimated duration of second stage, without considering potential risk impact.

(71) Time to complete planning phase=12
Units: Month
This constraint is for the originally estimated duration of first stage, without considering potential risk impact.

APPENDIX 11: RISK SEVERITY ESTIMATE FOR CONSTRUCTING RISK PROFILE

							Occurrence of risk impact across development			
Category	**REF**	**Risks**	**Impact score**	**ANP score**	**Category score**	**Risk severity**	**P**	**C**	**O**	**D**
World System Risks	C1	Political conditions	4	3%	9%	12	x	x	x	x
	C2	Trade regimes	3	3%		9		x	x	
	C3	Global demand	3	3%		9	x		x	
World Price Risks	C4	Commodity prices	2	4%	11%	8		x	x	
	C5	Exchange rates	2	3%		6	x	x	x	
	C6	Interest rates	2	3%		6	x	x	x	
	C7	Risk premium	2	1%		2	x	x	x	
Country Risks	C8	Political stability, terrorism, civil unrest	4	12%	26%	48		x	x	
	C9	Financial, economic stability, inflation	4	7%		28	x	x	x	
	C10	Expropriation, taxation	2	3%		6		x	x	
	C11	Repatriation policies	2	4%		8			x	
Instit. & Regul. Risks	C12	Regulatory stability or intervention	2	7%	17%	14	x		x	
	C13	Contract enforcement	2	4%		8	x	x	x	
	C14	Legal stability	2	6%		12	x	x	x	
Indust. & Comp. Risks	C15	Industry evolution	1	5%	21%	5	x	x	x	
	C16	Demand, growth rates	2	3%		6	x	x	x	
	C17	Supply conditions	4	1%		4		x	x	
	C18	Costs	3	3%		9	x	x	x	
	C19	Distribution	3	1%		3			x	
	C20	Prices	3	4%		12			x	
	C21	Infrastructure	4	3%		12	x	x	x	x
Project Risks	C22	Construction	4	3%	17%	12		x		
	C23	Operations	4	2%		8			x	
	C24	Partner/ally	1	4%		4		x	x	
	C25	Contract negotiation, partner conflict	1	5%		5		x	x	
	C26	Project management	1	3%		3	x	x	x	x
		Total score		100%	100%					

APPENDIX 12: ABSOLUTE RISK SEVERITY PER RISK CATEGORY

		Risk severity per risk category						
Energy Technology	Development Phase	World System Risk	World Price Risk	Country Risk	Institutional & Regulatory Risk	Industry & Competitive Risk	Project Risk	Absolute Risk
Geothermal	Planning	21	14	28	34	32	3	132
	Construction	21	22	82	20	36	24	205
	Operation	30	22	90	34	51	20	247
	Decommissioning	12	0	0	0	12	3	27
Wind	Planning	27	14	8	34	59	4	146
	Construction	18	24	34	20	63	13	172
	Operation	33	24	38	34	102	13	244
	Decommissioning	12	0	0	0	40	4	56
Oil & Gas	Planning	27	14	28	34	24	11	138
	Construction	24	22	82	20	56	11	215
	Operation	39	22	90	34	77	1	263
	Decommissioning	12	0	0	0	4	0	16