Real Options Analysis:

Diversification of Energy Power Plants in the North of Chile

Final Application Portafolio Report

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Abstract:

The Chilean Government is currently analyzing the possibility to develop a nuclear program to satisfy the increasing electricity demand in the north of the country. The object of this study is to provide a first approach for the analysis of a nuclear option. It applies concepts in real options analysis to evaluate the construction of a nuclear power plant in the north of Chile, considering a fixed and a flexible design. Four major sections are addressed throughout the paper. First, it defines the project. Then it identifies and models the evolution of the three principal uncertainties that affect the project. In the next section the fixed and flexible approaches are compared using an excel simulation. Finally, the last section compares the results under multidimensional criteria. The study concludes that the flexible option is the most favorable decision in terms of profit, risk and return of investment, as shown in the following table:

	Fixed Option	Flexible Option
ENPV (millions)	$1,166	$2,325
P_5 ENPV (millions)	$-767	$943
P_{95} ENPV (millions)	$2,608	$3,509
Return of Investment	0.27	0.83

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I. Introduction

Chile’s rapid economic growth has caused a duplication in energy production during the last eight years. Chile's economy is mainly based on the export of minerals, which account for about half of the total value of exports. Copper is the nation's most valuable resource, and Chile is thlle world's largest producer. Copper mining activities are extremely energy-intensive and considering that there are important future projects in this field, the demand for electricity is expected to increase even more during the following years.

Most of the mining activity is located in the north of Chile, where an independent interconnected system named SING (Sistema Interconectado Norte Grande – Northern Interconnected System), supplies power and energy to these industrial clients. However, since the generation matrix of the SING depends 99.6% on fossil fuels, the system is particularly vulnerable to variations on the supply and in the increasing volatile price of diesel and natural gas.

Figure I-1 – SING Location in the north of Chile

The Chilean Government is currently analyzing different options to diversify the energy generation matrix in the SING and a special commission is currently studying the possibility to follow the nuclear path. The Nuclear alternative has become an attractive option in the north of Chile because it is able to satisfy the expected growing demand and, at the same time, create an increase in security and reliability in the energy supply of the region.

The object of this study is to provide a first approach for the analysis of a nuclear option. It will apply concepts in real options analysis to evaluate the construction of a nuclear power plant in the north of Chile, considering a fixed and a flexible design. It will also determine and model some of the uncertainties and contextual factors faced in a project like this. The major goal is to compare the results of the two different design approaches and evaluate flexibility in an environment affected by uncertainties.

II. Definition of the System

1. The System

The system under analysis in this study is the evaluation of two investment options of energy power plants for the SING. Both of them consider at least one nuclear power plant in its design and the ability to satisfy at least 70% of the extra demand expected between the years 2011 and 2030. The size and capacity of the power plants of the different options, respond to the forecast of the expected demand (2011-2030) emitted by one of the studies of the Chilean National Commission of Energy (CNE).

The two investment projects have different approaches in their design; while one is focused on a fixed design that privileges the benefits of an "economy of scale", the other considers the ability to adjust to some of the contextual factors during time.

1. Fixed Option: Considers building a large nuclear power plant with a capacity of 1,200 MW with no potential to be expanded in the future. Figure I.1 illustrates a power plant of these characteristics.

2. Flexible Option: Considers building a medium size nuclear plant with a capacity of 600 MW. This system has the potential to be expanded in the future to either of the following alternatives:

    a. Additional medium size nuclear power plant with a capacity of 600 MW.
    b. Additional medium size gas-fired power plant with a capacity of 600 MW.

http://energyfuture.wikidot.com/nuclear-resources

Figure I-1 – 1123 MW Nuclear Power Plant in Tennessee, US

2. Uncertainties – Contextual Factors

The evaluation of a project of this characteristic is not obvious because its results are affected with major uncertainties. To simplify the simulation process, in this study I will consider and model only three of the main contextual factors that directly affect the performance of the two investment options.

These uncertainties are:

a) Future demand of electricity.
b) Future price of natural gas.
c) Government regulation of carbon emissions.

In order to keep this project in a manageable size and since the price of electricity for large industrial clients is normally regulated, I will assume that it will remain constant for the time period under consideration.

3. Structure of the Analysis

In the next section, the three uncertainties previously mentioned are defined and their evolution is represented over time.

After that, the two investment options (fixed and flexible) are modeled in an excel simulation that includes both the technical parameters of each design and the effect on their performance considering the three uncertainties.

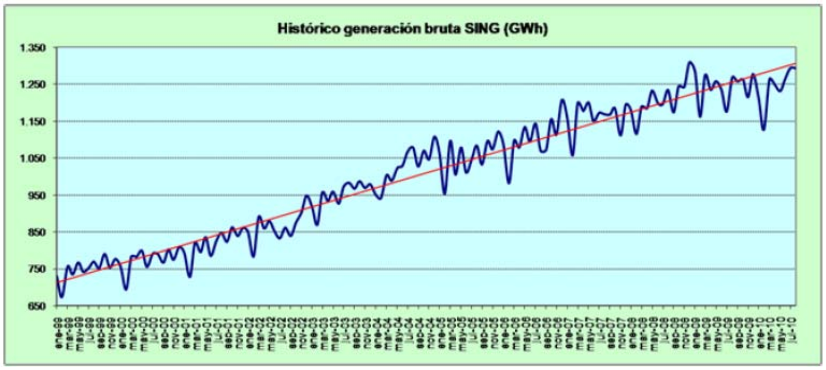
Finally, the last section compares the results using multidimensional criteria. I conclude the study with conclusions on the results.

III. Evolution of the Uncertainties

1. Future demand of Electricity

In this project, the main uncertainty is the demand of electricity that future industrial projects will require. Since decisions to invest in mining projects are subjected to different external factors, the uncertainty in the future demand of electrical power in the SING is significant.

There are two major sources of uncertainty in the demand of electricity. The first one is the annual volatility that exists with respect of the demand projection. Figure III-1 shows the historical data of demand during the last 10 years, where an average of 10% annual volatility can be observed.



http://www.minenergia.cl/minwww/export/sites/default/05_Public_Estudios/estadisticas_energeticas/

Figure III-1 –Historic data of demand of electricity for the years 1999-2010

The second source of uncertainty is the variability that exists in the projection of the demand of electricity for the next 20 years. Figure III-2 illustrates the forecast for the electricity demand (2010 - 2030) presented by one study of the Chilean National Commission of Energy (CNE). There is an important difference between the maximum and minimum demand projections expected for the following years; thus a significant level of uncertainty can be expected. Table III-3 provides a numerical representation of the variation that exists between the maximum and average demand for each 5 years period.

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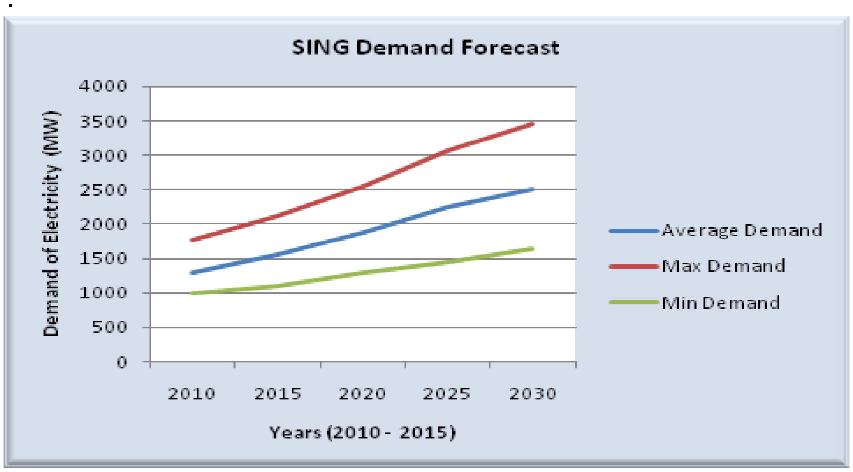


http://www.cne.cl/cnewww/opencms/05_Public_Estudios/introduccion.html

Figure III-2 –Demand of electricity for the years 2010-2030

Year	Average Demand (MW)	Max. Demand (MW)	Min. Demand (MW)	Variation between Max. and Average demand
2010	1300	1770	1000	36.2%
2015	1650	2200	1150	33.3%
2020	2050	2700	1370	31.7%
2025	2300	3120	1530	35.7%
2030	2500	3450	1700	38.0%

Table III-3 –Variation in the demand of electricity for the years 2010-2030

Representation of the evolution of the demand of electricity:

In order to simplify the representation of the additional demand projected for the following years, I will work in relative terms respect to current demand (year 2010). Since current demand is 1,300 MW, the relative demand will be the difference between the projected demand for any given year and 1,300 MW.

Table III-4 shows the static (without uncertainty) relative demand expected every 5 years until 2030, according to the CNE forecast.

Year	Project Year	Relative Demand [MW]
2011	1	250
2015	5	350
2020	10	750
2025	15	1000
2030	20	1200

Table III-4 –Electricity requirements to supply demand for the years 2010-2030

Based on the information provided by table III-4, I will use a "dynamic demand model" to calculate the static projection of the demand to the year 2030. I will use this approach, based on the example of the garage case, where the dynamic model equation is:

$$demand\ (t) = final\ demand - (\alpha) * e^{(-\beta t)}$$

In this case, evaluating for t=0 and t=10, the value for α and β are as follow:
α= 950 and β = 0.083.

The static projection of the evolution of the demand is shown in Figure III-4, which I will use a starting reference.

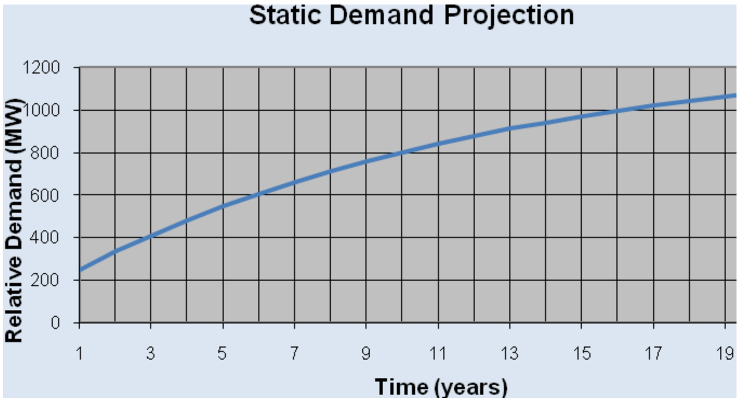


Figure III-5 –Static projection of the evolution of the relative demand of electricity

Now, from the analysis of table III-3, we know that there is a 36% average variation in the projection for the years 1, 10 and 20. By adding this form of uncertainty to the "dynamic demand model" the model becomes much representative of what we will expect in real life. Some samples of the results after running simulations in excel are shown in figures III-6 and III-7.

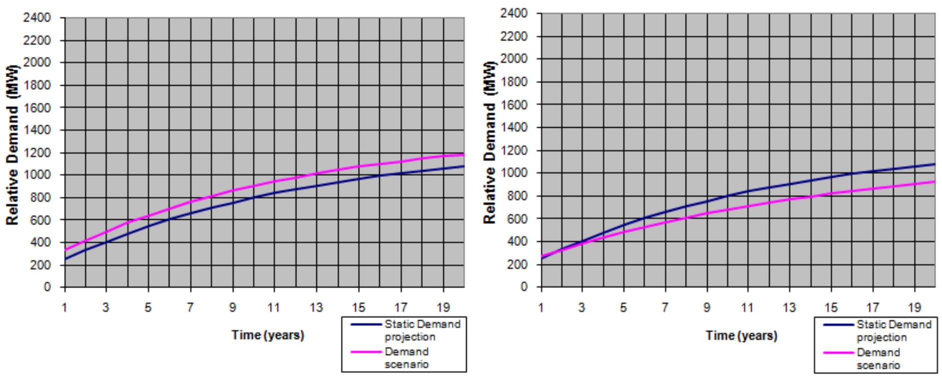


Figure III-6 and III-7 –Sample representations of the evolution of demand considering 36% variation

Finally, from the analysis of historical data (Figure III-1), it is also known that there is an average annual volatility of 10% respect the demand growth projection. The addition of this uncertainty to the model permits an even more realistic representation of the evolution of future electricity demand in the SING. Some sample results of this final model are shown in figures III-8 and III-9.

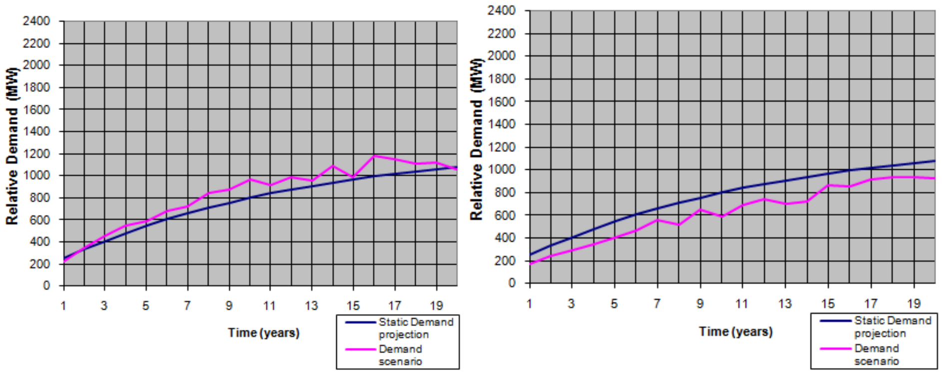
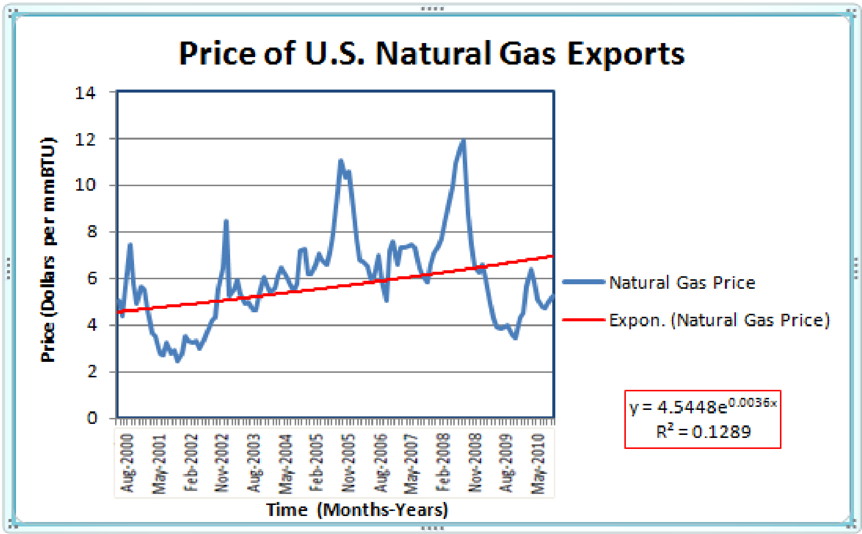


Figure III-8 and III-9 –Sample representations of the evolution of demand considering uncertainties

2. Future Price of Natural Gas

The second contextual factor that affects the evaluation of the two investment options is the future price of natural gas. The market price of natural gas has direct effects over the cost of producing power in the second alternative of the flexible investment option. This affects the final value of this alternative in comparison with the nuclear-nuclear or the fixed nuclear options.

To illustrate the historical variation of the price of the natural gas, I will use the statistics given by the EIA (Energy Information Administration) of the historical price of the US natural gas exports. From the information presented in Figure III-1, it can be seen that during the last 10 years, the price of the natural gas has varied from US$ 2.42 per mmBTU in February 2002 to US$ 11.58 per mmBTU in June 2008. This generates an uncertainty that has to be included in the analysis of the two investment option of our project.



http://www.eia.doe.gov/oil_gas/natural_gas/info_glance/natural_gas.html

Figure III-10 –Historical Price US Natural Gas Exports 2000-2010

Representation of the evolution of the Price of Natural Gas:

Since there is an increasing uncertainty on the future price of natural gas, I will use the historical data presented in Figure III-10 to develop a model that is based on the concepts of the Lattice Analysis for the representation of this uncertainty.

The red trendline shown in Figure III-10 is an exponential approximation of the evolution of the price during the last 10 years. The trendline equation sets the growth rate in 0.36% per month (the graph is made in a monthly basis), which means a growth rate of 4.3% per year. Then an analysis of the data is required to calculate the volatility of the historical price. Performing an exponential regression in excel, the volatility of the historical natural gas price was calculated as 34.11%.

With this two parameters (ν = 4.3% and σ = 34.11%), and considering a time period of one year (Δt = 1), the rest of the lattice parameters can be easily calculated.

Then,

$$u = e^{\sigma * \sqrt{\Delta t}} = 1.41$$

$$d = \frac{1}{u} = 0.71$$

$$p = 0.5 + 0.5 * \frac{v}{\sigma} * \sqrt{\Delta t} = 0.56$$

Starting Price: I will use US$ 4.22 per mmBTU as the starting natural gas price for the model, since it is the actual projection of the EIA for January 2011.

To model the evolution of the natural gas price over time, I will use these parameters to generate a lattice analysis within the simulation. The idea here is to generate random numbers for each of the 20 years of the project (that will change every time that we run the simulation) and depending if the number obtained for each year is higher or lower than 0.56 (value of p) the model will multiply the price of the previous year by 1.41 (value of u) if it is lower or 0.71 (value of d) of it is higher. This will generate a representation of the natural gas price over time, in the same way that a binominal lattice model does.

Figure III-11 and Figure III-12 provide some sample results of two simulations obtained using this model.

Sample 1:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Random Entries for Lattice Simulation		0.66	0.74	0.81	0.61	0.51	0.18	0.62	0.08	0.45	0.11	0.71	0.62	0.54	0.13	0.66	0.84	0.93	0.17	0.71	0.68
Realised Price of Natural Gas ($/mmBTU)		4.22	3.00	2.13	1.51	2.12	2.98	2.11	2.97	4.17	5.85	4.15	2.95	4.14	5.81	4.13	2.93	2.08	2.92	2.07	1.47

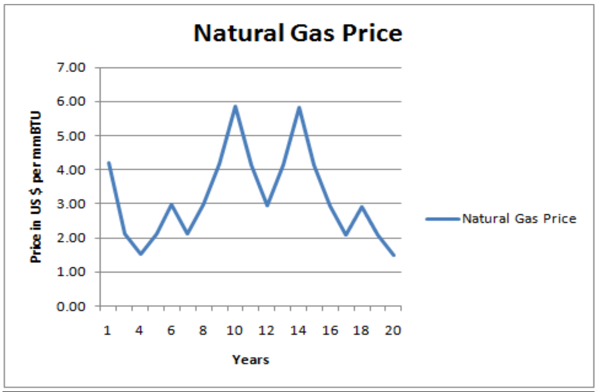


Figure III-11 –Sample 1 of the projection of natural gas price

<u>Sample 2:</u>

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Random Entries for Lattice Simulation		0.84	0.14	0.75	0.44	0.29	0.87	0.23	0.40	0.96	0.41	0.52	0.94	0.57	0.36	0.65	0.46	0.36	0.77	0.72	0.95
Realised Price of Natural Gas ($/mmBTU)		4.22	5.92	4.21	5.91	8.29	5.89	8.27	11.61	8.24	11.57	16.24	11.53	8.19	11.50	8.16	11.46	16.09	11.42	8.11	5.76

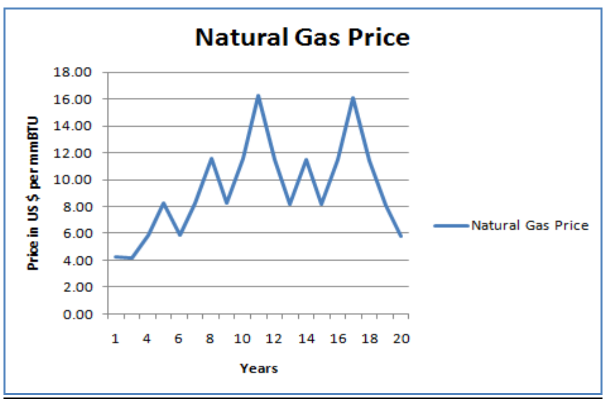


Figure III-12 –Sample 2 of the projection of natural gas price

3. Government Regulation of Carbon Emissions

Growing concerns about climate change could lead to modifications in environmental regulations in Chile. This could imply the introduction of carbon taxes, which will create additional producing costs to power plants that depend on fossil fuels. For the purpose of this study, this is the third contextual factor that will be analyzed. The approval of extra taxes to carbon emissions will affect the final value of the nuclear-gas option in comparison with the nuclear-nuclear or the fixed nuclear options.

There is uncertainty in this decision, because the Chilean Government is still analyzing the environmental situation with increasing CO2 emissions in the country.

Representation of the evolution of the possible approval of Carbon Taxes:

Since there is no clear position yet from the official regulators and for the purposes of this exercise, I will assume that there is a probability of approval of carbon taxes of 30% during each of the next 20 years. Considering international experiences, I will assume also a Carbon Tax of US$ 200 per tone-C.

To model the evolution of the possible approval of Carbon Taxes, I used the probability of approval to generate an analysis within the simulation. I generated random numbers for each of the 20 years of the project and assumed that the regulation was approved when the number obtained was lower than 0.3. (30%). The model simulated the idea that regulation has a 30% chance of being implemented each year and once implemented it is never repealed.

Figure III-13 and Figure III-14 provide some sample results of two simulations obtained using this model (“No” = Rejection; “Yes” = Approval).

Sample 1:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Random Entries for Tax Simulation		0.94	0.05	0.10	0.84	0.26	0.47	0.87	0.34	0.04	0.19	0.49	0.53	0.50	0.32	0.52	0.61	0.34	0.87	0.38	0.90
RealisedCarbon Emissions Tax ($200 / ton-C)		No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table III-13 –Sample 1 of the evolution of the possible approval of Carbon Taxes

Sample 2:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Random Entries for Tax Simulation		0.58	0.64	0.51	0.71	0.85	0.84	0.17	0.01	0.52	0.67	0.08	0.29	0.72	0.49	0.31	0.39	0.10	0.69	0.46	0.22
RealisedCarbon Emissions Tax ($200 / ton-C)		No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table III-14 –Sample 2 of the evolution of the possible approval of Carbon Taxes

IV. Simulation

In this section I will use an excel simulation to evaluate the performance of both fixed and flexible design options based on profit (final ENPV). I will include in the simulation the three uncertainty models explained in the past section.

Before moving to the evaluation of the two options, I will define the specifications of the power plants that will use to compare the two options.

Comment [HY1]: This was a very good and thorough explanation of your uncertainty model.

1. Specifications of the power plants

Based on the information provided in the MIT Center for Energy and Environmental Policy Research (CEEPR) website[1], I will use the following specifications to evaluate the two investment options:

Parameter	Large Nuclear Plant	Medium Nuclear Plant	Medium Gas Plant
Capacity (MW)	1200	600	600
Capital Cost (million $)	4400	2800	510
Fixed O&M Cost ($/KW/year)	56	56	13
Heat Rate (BTU/KWhr)	10400	10400	6800
Fuel Cost ($/ mmBTU)	0.67	0.67	Variable
Carbon Intensity (kg-C/mmBTU)	0	0	14.5
Electricity Price ($/KWhr)	0.16	0.16	0.16
Discount Rate (%)	12	12	12
Time Horizon (2010-2030)	20	20	20

Table IV-1 –Specifications of the Power Plants

Notes:

i. The capital costs were slightly changed for the nuclear plants to reflect the effect of the "economy of scale". According to the estimation of the CEEPR (July 2009), the capital or overnight cost for a base case assumption of a nuclear plant is US$ 4000 per KW of capacity. However, according to Charles Komanoff, "nuclear costs per KW decline 20 to 30 percent when reactor size is doubled"[2].

ii. There are others parameters that can be included in the comparison. However, in order to simplify calculations, I will use only some of the more important.

iii. Since capacity factors vary according with the model of each plant, for the purpose of this study I will assume hypothetical capacity factors of 100% and that the power plants are able to operate at full capacity 24/7.

Comment [HY2]: Application of a different capacity factor would be trivial. A simple fix would be to say that the actual nameplate capacity is 1200/(0.9) and so you are assuming 90% capacity factor.

2. Fixed Option

The fixed option considers building a large nuclear power plant with a capacity of 1,200 MW and no potential to be expanded in the future. Its design is based in the concept of "economy of scale" and its purpose is to serve the extra demand in the SING over the next 20 years.

[1] Financing New Nuclear Generation, John E. Parsons, MIT CEEPR, 2009.
[2] Capital Cost Projections of the US Atomic Energy Commission (AEC), Charles Komanoff, 1981, p.200)

To calculate its Expected Net Present Value (ENPV) in the simulation I used the specifications shown in table IV-1 and the following formulas:

Total Production (TWhr/year) = Capacity (MW)(8760/1,000,000)*

*Revenues ($ millions/year) = Total Production (TWhr/year)*Electricity Price ($/KWhr)*1000*

*Fuel Cost ($ millions/year) = (Total Production (TWhr/year)*Heat Rate (BTU/KWhr)*Fuel Cost ($/mmBTU))/1000*

Cash flow($ millions) = Revenues – (Capital Cost + Fixed Cost + Fuel Cost + Carbon Tax Cost)

The ENPV of the fixed option is affected by the variations of the demand. I run a simulation of 2000 samples, where the ENPV of this option was calculated considering the uncertainty in the demand (36% variations in projections and 10% annual volatility in the demand growth). In order to have a reference value, I also run a static simulation without considering the uncertainties.

Table IV-2 and IV-3 show two of the 2000 samples used to calculate the ENPV for this option and Figures IV-4 and IV-5 illustrates the final results.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Demand projection (with 36% variation)		292	359	421	478	531	580	625	667	706	742	775	806	834	861	885	907	928	947	965	982
Demand growth projection year to year			23%	17%	14%	11%	9%	8%	7%	6%	5%	4%	4%	4%	3%	3%	3%	2%	2%	2%	2%
Demand projection (with 10% volatility)			24%	19%	23%	1%	-1%	13%	14%	4%	11%	11%	6%	-6%	8%	12%	11%	0%	9%	-4%	8%
Projected demand with Uncertainty		292	363	425	518	485	528	657	710	695	781	821	822	762	901	965	982	910	1,011	906	1,041
Capacity (MW)	0	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Total Production (TWhr/year)	0	2.56	3.18	3.73	4.54	4.25	4.63	5.75	6.22	6.09	6.85	7.19	7.20	6.67	7.89	8.45	8.60	7.97	8.86	7.94	9.12
Revenue ($ millions/year)	$0	$409	$509	$596	$726	$680	$740	$920	$995	$974	$1,095	$1,150	$1,152	$1,067	$1,262	$1,352	$1,376	$1,276	$1,417	$1,270	$1,460
Capital Cost ($ millions)	$4,400	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fixed O&M Cost ($ millions/year)	$0	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67
Fuel Cost ($millions/year)	$0	$18	$22	$26	$32	$30	$32	$40	$43	$42	$48	$50	$50	$46	$55	$59	$60	$56	$62	$55	$64
Carbon Emissions Tax ($ millions/year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cashflow	-$4,400	$324	$419	$503	$627	$583	$641	$813	$885	$864	$980	$1,033	$1,035	$954	$1,140	$1,226	$1,249	$1,153	$1,288	$1,148	$1,329
DCF	-$4,400	$290	$334	$358	$399	$331	$325	$368	$357	$312	$316	$297	$266	$219	$233	$224	$204	$168	$168	$133	$138
ENPV	$1,037																				

Table IV-2 –Sample result for the Fixed Option Simulation, in this case ENPV of $1,037 millions

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Demand projection (with 36% variation)		221	298	370	436	496	552	604	652	696	736	773	808	839	869	896	921	944	965	984	1,002
Demand growth projection year to year			35%	24%	18%	14%	11%	9%	8%	7%	6%	5%	4%	4%	3%	3%	3%	2%	2%	2%	2%
Demand projection (with 10% volatility)			27%	18%	18%	19%	8%	3%	11%	3%	0%	9%	9%	-3%	-2%	6%	-4%	-4%	3%	-2%	1%
Projected demand with Uncertainty		221	280	353	435	518	535	571	668	673	694	803	841	783	825	924	860	884	969	950	997
Capacity (MW)	0	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Total Production (TWhr/year)	0	1.94	2.45	3.09	3.81	4.54	4.69	5.00	5.85	5.90	6.08	7.03	7.36	6.86	7.23	8.10	7.53	7.74	8.49	8.32	8.73
Revenue ($ millions/year)	$0	$310	$392	$495	$609	$727	$750	$800	$936	$944	$973	$1,125	$1,178	$1,098	$1,157	$1,295	$1,205	$1,239	$1,359	$1,331	$1,397
Capital Cost ($ millions)	$4,400	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fixed O&M Cost ($ millions/year)	$0	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67
Fuel Cost ($millions/year)	$0	$13	$17	$22	$27	$32	$33	$35	$41	$41	$42	$49	$51	$48	$50	$56	$52	$54	$59	$58	$61
Carbon Emissions Tax ($ millions/year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cashflow	-$4,400	$229	$308	$406	$516	$628	$650	$698	$828	$835	$863	$1,009	$1,060	$983	$1,039	$1,172	$1,086	$1,118	$1,232	$1,206	$1,269
DCF	-$4,400	$205	$245	$289	$328	$356	$330	$316	$335	$301	$278	$290	$272	$225	$213	$214	$177	$163	$160	$140	$132
ENPV	$568																				

Table IV-3 –Sample result for the Fixed Option Simulation, in this case ENPV of $568 millions

Results of the simulation for the Fixed Option:

ENPV	US $ 1,166 millions
STANDARD DEVIATION	US $ 909 millions
STATIC SIMULATION	US $ 1,188 millions

Comment [HY3]: Why is this red? It make it seem like you are losing money here.

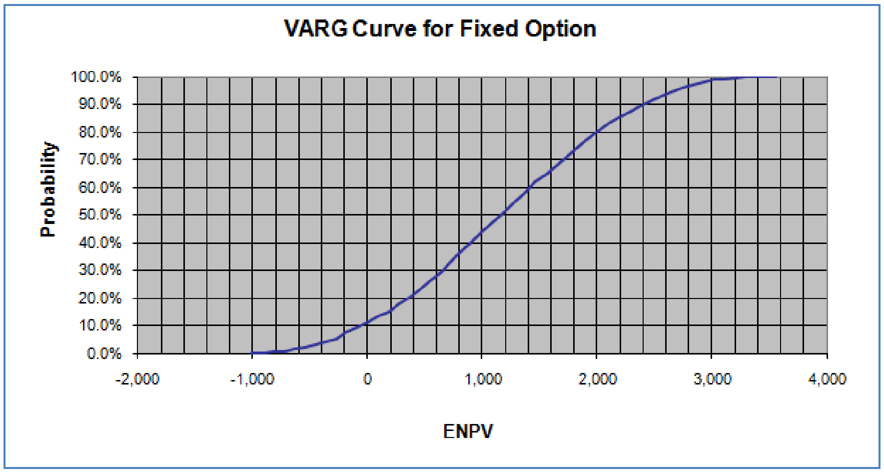


Figure IV-4 –Value at Risk and Gain Curve (VARG) for the Fixed Option

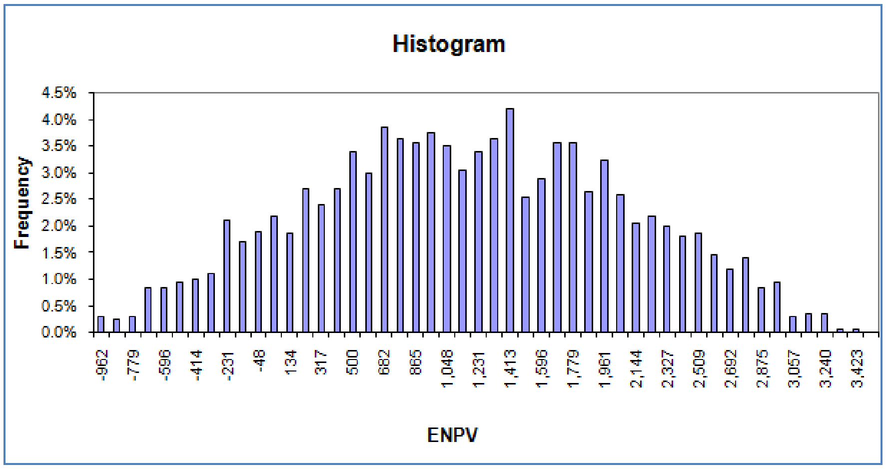


Figure IV-5 – Histogram of the ENPV results obtained for the Fixed Option

3. Flexible Option

The flexible option fixed option considers building a medium size nuclear power plant with a capacity of 600 MW. Depending on the evolution of the electricity demand, this investment option has the potential to be expanded in the future to either of the following alternatives:

a. Construction of an additional medium size nuclear power plant with a capacity of 600 MW.

b. Construction of an additional medium size gas-fired power plant with a capacity of 600 MW.

Its design is based to obtain the maximum benefits of a flexible design, by reducing the risk if the demand does not grow as expected and by taking advantage of deciding later, with more information, whether to expand to a gas or nuclear power plant.

To calculate the Expected Net Present Value (ENPV) of this option in the simulation I used the specifications shown in table IV-1 and the same formulas used for the evaluation of the fixed option. However, in the analysis of the flexible option there are two major differences with respect to the evaluation of the fixed option:

1. In this case I did a parallel analysis for the two alternatives of the flexible option (nuclear/nuclear and nuclear/gas). The first alternative (nuclear/nuclear) is only affected by the uncertainty in the electricity demand. Thus, its simulation included only the variation on the demand. On the other hand, the second alternative is affected by the three uncertainties explained in the past section (demand, price of natural gas, carbon taxes) and its simulation included variations on these three variables.

2. The simulation for this option considered the use of **"Decision Rules"**. I used two major rules:

    a. The final ENPV of the flexible option during each simulation was obtained comparing the ENPV obtained for the two alternatives (nuclear/nuclear, nuclear/gas). Once the ENPV of each alternative was calculated (using the formulas previously explained) the decision rule compared both results and selected the higher one as final result.

Comment [HY4]: You may want to briefly say how the rule calculates the ENPV for the two alternatives.

b. The second decision rule that I had to set was when to expand to the second power plant (nuclear or gas), considering that according to the requirements explained before, the investment option should be able to supply at least 70% of the demand for the next 20 years. I set this decision in three different levels and run different simulations to verify the best outcomes. The three levels were:

1. Expand to the second power plant when the electricity demand of any previous year is higher than the installed capacity of the first plant.

2. Expand to the second power plant when the electricity demand of any previous year is 15% higher than the installed capacity of the first plant.

3. Expand to the second power plant when the electricity demand of any previous year is 30% higher than the installed capacity of the first plant.

NOTE: Under each of this decision rules, the system operates with the following design structure:

i. Do not expand again if the demand of any given year is higher than the installed capacity of the two power plants (1,200 MW). In other words, expand only once.

ii. When expanded to the second plant, employ the first nuclear plant until full capacity is reached (600 MW), and then use the second plant to satisfy the remaining demand.

Comment [HY5]: Does this mean that you can only expand once?

Comment [HY6]: I would not classify this as a decision rule. This is more a way of how the system operates in a given state (when there are two small plants built).

Table IV-6 illustrates one of the 2000 samples used to calculate the ENPV of the flexible option using the expanding decision rule 1.

Table IV-7 illustrates one of the 2000 samples used to calculate the ENPV of the flexible option using the expanding decision rule 2.

Table IV-8 illustrates one of the 2000 samples used to calculate the ENPV of the flexible option using the expanding decision rule 3.

OPTION 1: Medium Nuclear Plant + Expansion to a second Medium Nuclear Plant when demand more than 600 MW

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Demand projection		273	344	409	470	527	581	630	676	719	759	796	831	863	893	921	948	972	995	1,016	1,035
Demand growth projection			26%	19%	15%	12%	10%	9%	7%	6%	6%	5%	4%	4%	3%	3%	3%	3%	2%	2%	2%
Realised demand growth			31%	11%	17%	4%	2%	-1%	6%	9%	12%	4%	3%	-5%	-5%	6%	0%	-6%	2%	-4%	-5%
Realised demand		273	358	382	479	492	538	574	667	734	805	787	821	787	822	947	921	890	995	953	962
Expansion?		No	No	No	No	No	No	No	Expand	No	No	No	No	No	No	No	No	No	No	No	No
Capacity (MW)	0	600	600	600	600	600	600	600	600	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Total Production (TWhr/year)	0	2.39	3.14	3.34	4.19	4.31	4.72	5.03	5.26	6.43	7.05	6.90	7.19	6.90	7.20	8.30	8.07	7.80	8.72	8.35	8.43
Revenue ($ millions/year)	$0	$383	$502	$535	$671	$689	$755	$805	$841	$1,029	$1,128	$1,104	$1,151	$1,103	$1,152	$1,327	$1,290	$1,248	$1,395	$1,336	$1,348
Capital Cost ($ millions)	$2,800	$0	$0	$0	$0	$0	$0	$0	$2,800	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fixed O&M Cost Plant(s) ($ millions/year)	$0	$34	$34	$34	$34	$34	$34	$34	$34	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67
Fuel Cost ($millions/year)	$0	$17	$22	$23	$29	$30	$33	$35	$37	$45	$49	$48	$50	$48	$50	$58	$56	$54	$61	$58	$59
Carbon Emissions Tax ($ millions/year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cashflow	-$2,800	$332	$446	$478	$608	$625	$688	$736	-$2,029	$917	$1,012	$988	$1,034	$988	$1,035	$1,202	$1,167	$1,126	$1,267	$1,211	$1,222
DCF	-$2,800	$297	$356	$340	$387	$355	$349	$333	-$820	$331	$326	$284	$265	$226	$212	$220	$190	$164	$165	$141	$127
Net present value	**$1,447**																				

OPTION 2: Medium Nuclear Plant+ Expansion to a Medium Gas Nuclear Plant when demand more than 600 MW

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Demand projection		273	344	409	470	527	581	630	676	719	759	796	831	863	893	921	948	972	995	1,016	1,035
Demand growth projection			26%	19%	15%	12%	10%	9%	7%	6%	6%	5%	4%	4%	3%	3%	3%	3%	2%	2%	2%
Realised demand growth			31%	11%	17%	4%	2%	-1%	6%	9%	12%	4%	3%	-5%	-5%	6%	0%	-6%	2%	-4%	-5%
Realised demand		273	358	382	479	492	538	574	667	734	805	787	821	787	822	947	921	890	995	953	962
Expansion?		No	No	No	No	No	No	No	Expand	No	No	No	No	No	No	No	No	No	No	No	No
Nuclear Capacity (MW)	0	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
Gas Capacity (MW)	0	0	0	0	0	0	0	0	0	600	600	600	600	600	600	600	600	600	600	600	600
Total Production Nuclear (TWhr/year)	0.00	2.39	3.14	3.34	4.19	4.31	4.72	5.03	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26
Total Production Gas (TWhr/year)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	1.18	1.79	1.64	1.94	1.64	1.95	3.04	2.81	2.54	3.46	3.10	3.17
Revenue ($ millions/year)	$0	$383	$502	$535	$671	$689	$755	$805	$935	$1,029	$1,128	$1,104	$1,151	$1,103	$1,152	$1,327	$1,290	$1,248	$1,395	$1,336	$1,348
Capital Cost ($ millions)	$2,800	$0	$0	$0	$0	$0	$0	$0	$510	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fixed O&M Cost Nuclear Plant($ millions/y	$0	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34
Fuel Cost Nuclear Plant ($millions/year)	$0	$17	$22	$23	$29	$30	$33	$35	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37
Random Entries for Lattice Simulation		0.40	0.93	0.05	0.83	0.48	0.85	0.50	0.31	0.92	0.61	0.19	0.48	0.60	0.68	0.00	0.86	0.13	0.57	0.11	0.33
Realised Price of Natural Gas ($/mmBTU)		4.22	3.00	4.21	2.99	4.19	2.98	4.18	5.87	4.17	2.96	4.15	5.83	4.14	2.94	4.13	2.93	4.11	2.92	4.10	5.76
Fuel Cost Gas Plant ($millions/year)	$0	$0	$0	$0	$0	$0	$0	$0	$23	$33	$36	$46	$77	$46	$39	$85	$56	$71	$69	$86	$124
Random Entries for Tax Simulation		0.80	0.88	0.21	0.62	0.72	0.60	0.69	1.00	0.09	0.03	0.11	0.74	0.54	0.95	0.96	0.60	0.25	0.63	0.41	0.77
RealisedCarbon Emissions Tax ($200 / ton-C)		No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Carbon Emissions Tax ($ millions/year)		$0	$0	$0	$0	$0	$0	$0	$12	$23	$35	$32	$38	$32	$38	$60	$55	$50	$68	$61	$63
Cashflow	-$2,800	$332	$446	$478	$608	$625	$688	$736	$320	$903	$986	$955	$966	$955	$1,005	$1,112	$1,109	$1,056	$1,188	$1,119	$1,091
DCF	-$2,800	$297	$356	$340	$387	$355	$349	$333	$129	$325	$318	$274	$248	$219	$206	$203	$181	$154	$154	$130	$113
Net present value	**$2,270**																				

Table IV-6 – Sample Result for the Flexible Option considering Expansion Decision Rule 1. In this case, ENPV $ 2,270 millions (Nuclear/Gas Alternative)

OPTION 1: Medium Nuclear Plant + Expansion to a second Medium Nuclear Plant when demand more than 600 MW

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Demand projection		172	259	340	414	484	547	607	661	712	759	802	843	880	914	946	976	1,003	1,028	1,051	1,073
Demand growth projection			51%	31%	22%	17%	13%	11%	9%	8%	7%	6%	5%	4%	4%	3%	3%	3%	3%	2%	2%
Realised demand growth			58%	37%	13%	13%	23%	16%	10%	7%	5%	13%	9%	2%	2%	-5%	-6%	13%	1%	1%	2%
Realised demand		172	272	355	383	468	593	637	665	705	748	857	876	856	901	864	887	1,099	1,010	1,042	1,074
Expansion?		No	No	No	No	No	No	No	No	No	Expand	No	No	No	No	No	No	No	No	No	No
Capacity (MW)	0	600	600	600	600	600	600	600	600	600	600	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Total Production (TWhr/year)	0	1.51	2.38	3.11	3.36	4.10	5.19	5.26	5.26	5.26	5.26	7.51	7.67	7.50	7.89	7.57	7.77	9.63	8.85	9.12	9.41
Revenue ($ millions/year)	$0	$241	$381	$497	$537	$656	$831	$841	$841	$841	$841	$1,202	$1,227	$1,200	$1,263	$1,211	$1,243	$1,540	$1,415	$1,460	$1,505
Capital Cost ($ millions)	$2,800	$0	$0	$0	$0	$0	$0	$0	$0	$0	$2,800	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fixed O&M Cost Plant(s) ($ millions/year)	$0	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67
Fuel Cost ($millions/year)	$0	$10	$17	$22	$23	$29	$36	$37	$37	$37	$37	$52	$53	$52	$55	$53	$54	$67	$62	$64	$66
Carbon Emissions Tax ($ millions/year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cashflow	-$2,800	$197	$330	$442	$480	$594	$761	$771	$771	$771	-$2,029	$1,082	$1,106	$1,081	$1,140	$1,091	$1,122	$1,406	$1,287	$1,329	$1,372
DCF	-$2,800	$176	$263	$315	$305	$337	$386	$349	$311	$278	-$653	$311	$284	$248	$233	$199	$183	$205	$167	$154	$142
Net present value	**$1,393**																				

OPTION 2: Medium Nuclear Plant+ Expansion to a Medium Gas Nuclear Plant when demand more than 600 MW

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Demand projection		172	259	340	414	484	547	607	661	712	759	802	843	880	914	946	976	1,003	1,028	1,051	1,073
Demand growth projection			51%	31%	22%	17%	13%	11%	9%	8%	7%	6%	5%	4%	4%	3%	3%	3%	3%	2%	2%
Realised demand growth			58%	37%	13%	13%	23%	16%	10%	7%	5%	13%	9%	2%	2%	-5%	-6%	13%	1%	1%	2%
Realised demand		172	272	355	383	468	593	637	665	705	748	857	876	856	901	864	887	1,099	1,010	1,042	1,074
Expansion?		No	No	No	No	No	No	No	No	No	Expand	No	No	No	No	No	No	No	No	No	No
Nuclear Capacity (MW)	0	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
Gas Capacity (MW)	0	0	0	0	0	0	0	0	0	0	0	600	600	600	600	600	600	600	600	600	600
Total Production Nuclear (TWhr/year)	0.00	1.51	2.38	3.11	3.36	4.10	5.19	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26
Total Production Gas (TWhr/year)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.57	0.92	1.30	2.25	2.41	2.25	2.64	2.31	2.52	4.37	3.59	3.87	4.15
Revenue ($ millions/year)	$0	$241	$381	$497	$537	$656	$831	$893	$933	$988	$1,048	$1,202	$1,227	$1,200	$1,263	$1,211	$1,243	$1,540	$1,415	$1,460	$1,505
Capital Cost ($ millions)	$2,800	$0	$0	$0	$0	$0	$0	$0	$0	$0	$510	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fixed O&M Cost Nuclear Plant($ millions/y	$0	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34
Fuel Cost Nuclear Plant ($millions/year)	$0	$10	$17	$22	$23	$29	$36	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37
Random Entries for Lattice Simulation		0.27	0.03	0.66	0.96	0.01	0.95	0.85	0.79	0.63	0.90	0.82	0.13	0.28	0.70	0.12	0.04	0.44	0.44	0.37	0.35
Realised Price of Natural Gas ($/mmBTU)		4.22	5.92	4.21	2.99	4.19	2.98	2.11	1.50	1.07	0.76	0.54	0.75	1.06	0.75	1.06	1.48	2.08	2.92	4.10	5.76
Fuel Cost Gas Plant ($millions/year)	$0	$0	$0	$0	$0	$0	$0	$5	$6	$7	$7	$8	$12	$16	$13	$17	$25	$62	$71	$108	$163
Random Entries for Tax Simulation		0.56	0.49	0.89	0.21	0.03	0.80	0.15	0.25	0.15	1.00	0.66	0.90	0.27	0.79	0.32	0.42	0.57	0.98	0.75	0.87
RealisedCarbon Emissions Tax ($200 / ton-C)		No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Carbon Emissions Tax ($ millions/year)		$0	$0	$0	$0	$0	$0	$6	$11	$18	$26	$44	$48	$44	$52	$46	$50	$86	$71	$76	$82
Cashflow	-$2,800	$197	$330	$442	$480	$594	$761	$812	$845	$893	$436	$1,079	$1,097	$1,070	$1,127	$1,079	$1,098	$1,322	$1,203	$1,206	$1,191
DCF	-$2,800	$176	$263	$315	$305	$337	$386	$367	$341	$322	$140	$310	$282	$245	$231	$197	$179	$193	$156	$140	$123
Net present value	**$2,208**																				

Table IV-7 – Sample Result for the Flexible Option considering Expansion Decision Rule 2. In this case, ENPV $ 2,208 millions (Nuclear/Gas Alternative)

OPTION 1: Medium Nuclear Plant + Expansion to a second Medium Nuclear Plant when demand more than 600 MW

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Demand projection		166	258	344	422	495	562	624	681	733	782	827	868	906	941	974	1,004	1,031	1,057	1,080	1,102
Demand growth projection			56%	33%	23%	17%	14%	11%	9%	8%	7%	6%	5%	4%	4%	3%	3%	3%	2%	2%	2%
Realised demand growth			64%	30%	29%	18%	7%	10%	3%	3%	-1%	1%	-5%	12%	3%	-3%	8%	6%	12%	3%	4%
Realised demand		166	272	337	444	499	530	620	646	704	730	786	787	972	935	915	1,056	1,064	1,160	1,091	1,124
Expansion?		No	No	No	No	No	No	No	No	No	Expand	No	No	No	No	No	No	No	No	No	No
Capacity (MW)	0	600	600	600	600	600	600	600	600	600	600	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Total Production (TWhr/year)	0	1.45	2.38	2.95	3.89	4.37	4.65	5.26	5.26	5.26	5.26	6.89	6.89	8.52	8.19	8.02	9.25	9.32	10.16	9.55	9.85
Revenue ($ millions/year)	$0	$233	$381	$472	$623	$699	$743	$841	$841	$841	$841	$1,102	$1,103	$1,363	$1,310	$1,283	$1,479	$1,491	$1,625	$1,528	$1,576
Capital Cost ($ millions)	$2,800	$0	$0	$0	$0	$0	$0	$0	$0	$0	$2,800	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fixed O&M Cost Plant(s) ($ millions/year)	$0	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$67	$67	$67	$67	$67	$67	$67	$67	$67	$67
Fuel Cost ($millions/year)	$0	$10	$17	$21	$27	$30	$32	$37	$37	$37	$37	$48	$48	$59	$57	$56	$64	$65	$71	$67	$69
Carbon Emissions Tax ($ millions/year)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Cashflow	-$2,800	$189	$331	$418	$562	$635	$677	$771	$771	$771	-$2,029	$987	$988	$1,236	$1,186	$1,160	$1,348	$1,359	$1,487	$1,395	$1,440
DCF	-$2,800	$169	$264	$297	$357	$360	$343	$349	$311	$278	-$653	$284	$253	$283	$243	$212	$220	$198	$193	$162	$149
Net present value	**$1,472**																				

OPTION 2: Medium Nuclear Plant+ Expansion to a Medium Gas Nuclear Plant when demand more than 600 MW

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Demand projection		166	258	344	422	495	562	624	681	733	782	827	868	906	941	974	1,004	1,031	1,057	1,080	1,102
Demand growth projection			56%	33%	23%	17%	14%	11%	9%	8%	7%	6%	5%	4%	4%	3%	3%	3%	2%	2%	2%
Realised demand growth			64%	30%	29%	18%	7%	10%	3%	3%	-1%	1%	-5%	12%	3%	-3%	8%	6%	12%	3%	4%
Realised demand		166	272	337	444	499	530	620	646	704	730	786	787	972	935	915	1,056	1,064	1,160	1,091	1,124
Expansion?		No	No	No	No	No	No	No	No	No	Expand	No	No	No	No	No	No	No	No	No	No
Nuclear Capacity (MW)	0	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
Gas Capacity (MW)	0	0	0	0	0	0	0	0	0	0	0	600	600	600	600	600	600	600	600	600	600
Total Production Nuclear (TWhr/year)	0.00	1.45	2.38	2.95	3.89	4.37	4.65	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26
Total Production Gas (TWhr/year)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.40	0.91	1.14	1.63	1.64	3.26	2.93	2.76	3.99	4.06	4.90	4.30	4.59
Revenue ($ millions/year)	$0	$233	$381	$472	$623	$699	$743	$869	$905	$986	$1,023	$1,102	$1,103	$1,363	$1,310	$1,283	$1,479	$1,491	$1,625	$1,528	$1,576
Capital Cost ($ millions)	$2,800	$0	$0	$0	$0	$0	$0	$0	$0	$0	$510	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fixed O&M Cost Nuclear Plant($ millions/y	$0	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34	$34
Fuel Cost Nuclear Plant ($millions/year)	$0	$10	$17	$21	$27	$30	$32	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37	$37
Random Entries for Lattice Simulation		0.56	0.08	0.96	0.51	0.28	0.46	0.80	0.00	0.47	0.08	0.05	0.91	0.87	0.13	0.98	0.38	0.42	0.31	0.51	0.12
Realised Price of Natural Gas ($/mmBTU)		4.22	5.92	4.21	5.91	8.29	11.64	8.27	11.61	16.29	22.88	32.12	22.80	16.19	22.73	16.14	22.66	31.82	44.67	62.72	88.05
Fuel Cost Gas Plant ($millions/year)	$0	$0	$0	$0	$0	$0	$0	$10	$32	$101	$177	$356	$254	$359	$453	$303	$615	$879	$1,489	$1,833	$2,751
Random Entries for Tax Simulation		0.98	0.53	0.82	0.99	0.29	0.13	0.94	0.31	0.04	0.83	0.15	0.31	0.44	0.30	0.96	0.37	0.93	0.20	0.07	0.44
RealisedCarbon Emissions Tax ($200 / ton-C)		No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Carbon Emissions Tax ($ millions/year)		$0	$0	$0	$0	$0	$0	$4	$8	$18	$22	$32	$32	$64	$58	$54	$79	$80	$97	$85	$91
Cashflow	-$2,800	$189	$331	$418	$562	$635	$677	$786	$795	$798	$243	$643	$747	$869	$729	$855	$716	$462	-$30	-$459	-$1,336
DCF	-$2,800	$169	$264	$297	$357	$360	$343	$355	$321	$288	$78	$185	$192	$199	$149	$156	$117	$67	-$4	-$53	-$138
Net present value	**$903**																				

Table IV-8 – Sample Result for the Flexible Option considering Expansion Decision Rule 3. In this case, ENPV $ 1,472 millions (Nuclear/Nuclear Alternative)

Results of the simulation for the Fixed Option:

1. Results Flexible Option with Expanding Decision Rule 1:

AVERAGE ENPV	**US $ 2,179 millions**	
STANDARD DEVIATION	**US $ 741 millions**	
AVERAGE YEAR OF EXPANSION	**6.71 years**	
EXPANSION OPTION	**Nuclear:**	**17.55%**
	Gas:	**82.45%**

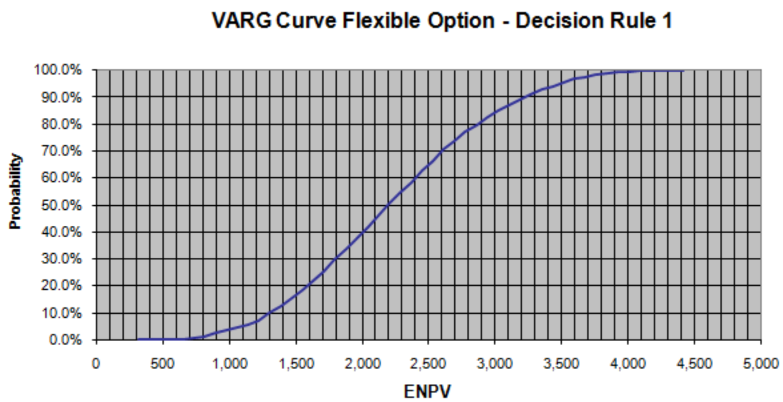


Figure IV-9 –Value at Risk and Gain Curve (VARG) for the Flexible Option with the expanding decision rule 1

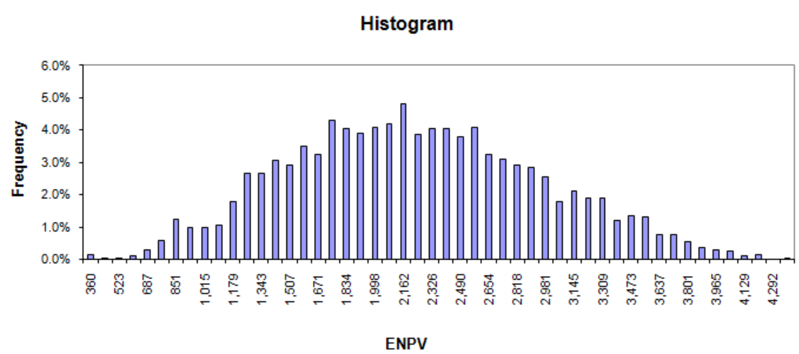


Figure IV-10 –Histogram of the ENPV for the Flexible Option with the expanding decision rule 1

2. Results Flexible Option with Expanding Decision Rule 2:

AVERAGE ENPV	US $ 2,267 millions	
STANDARD DEVIATION	US $ 709 millions	
AVERAGE YEAR OF EXPANSION	8.87 years	
EXPANSION OPTION	Nuclear:	19.40%
	Gas:	80.60%

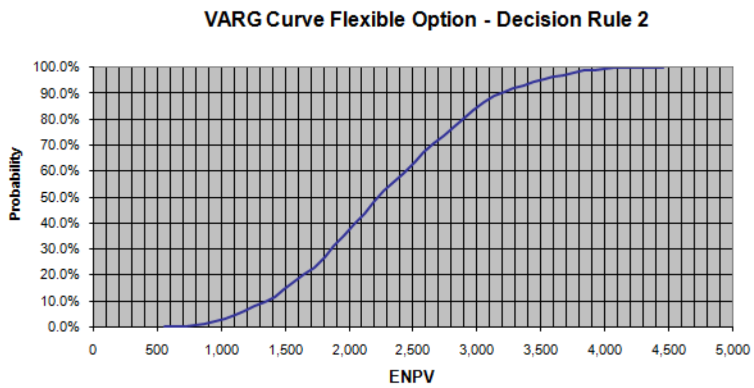


Figure IV-11 –Value at Risk and Gain Curve (VARG) for the Flexible Option with the expanding decision rule 2

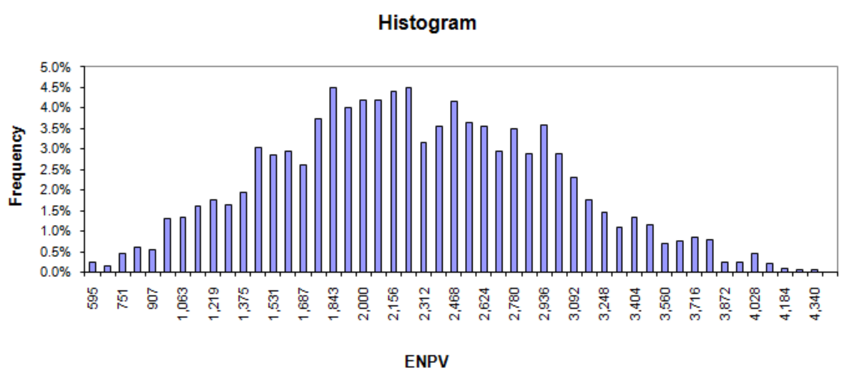


Figure IV-12 –Histogram of the ENPV for the Flexible Option with the expanding decision rule 2

3. Results Flexible Option with Expanding Decision Rule 3:

AVERAGE ENPV	US $ 2,325 millions	
STANDARD DEVIATION	US $ 705 millions	
AVERAGE YEAR OF EXPANSION	12.51 years	
EXPANSION OPTION	Nuclear:	20.31%
	Gas:	79.69%

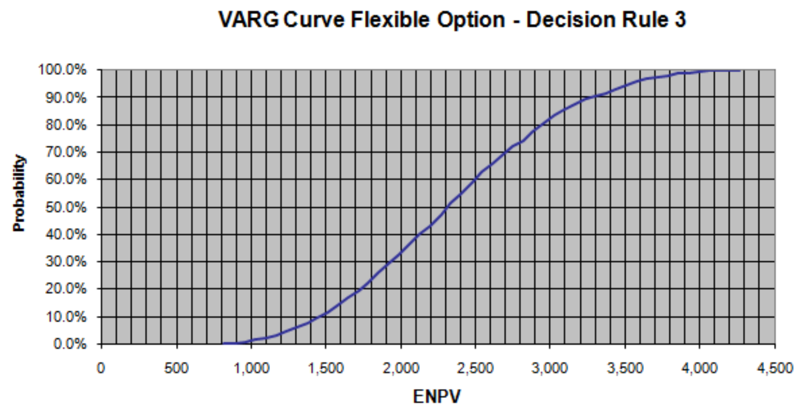


Figure IV-13 –Value at Risk and Gain Curve (VARG) for the Flexible Option with the expanding decision rule 3

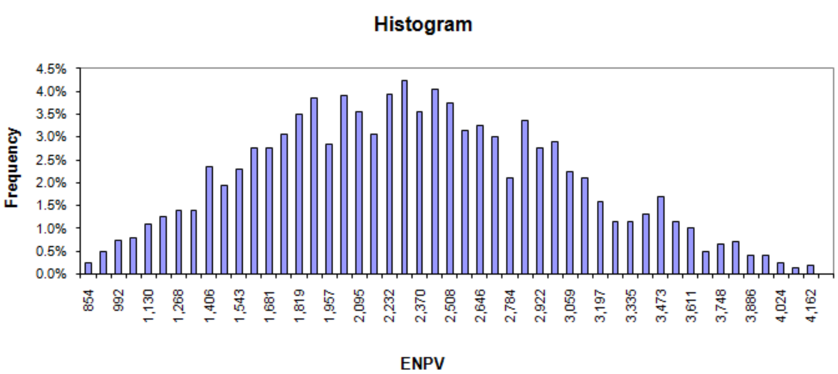


Figure IV-14 –Histogram of the ENPV for the Flexible Option with the expanding decision rule 3

V. Comparison of Performance of the two Options

1. Expected Net Present Value

Table V-1 illustrates the summary of the results obtained in the excel simulation in terms of profits (ENPV) for the fixed and flexible investment options.

	ENPV (millions)	Standard Deviation (millions)	Average Year of Expansion	Best Alternative to Expand based on ENPV Comparison
Fixed Option	$1,166	$909	---	---
Flex Option (Exp. DR 1)	$2,179	$741	6.71 years	Nuclear Option: 17.55% Gas Option: 82.45%
Flex Option (Exp. DR 2)	$2,267	$709	8.87 years	Nuclear Option: 19.40% Gas Option: 80.60%
Flex Option (Exp. DR 3)	$2,325	$705	12.51 years	Nuclear Option: 20.31% Gas Option: 79.69%

Figure V-1 –Summary of Results obtained in the Simulation

Comment [HY7]: Specify units.

Comment [HY8]: Average year of expansion.

Comparing the results, it is clear that in terms of ENPV the flexible option is the most favorable decision. Focusing only in profits, the results show that the flexible option may generate a return that doubles the expected return of the fixed option.

Now, within the flexible option, the best results were obtained using the decision rule 3, which expand to a second plant when demand is 30% higher than the installed capacity of the first plant. This could be explained mainly because of the effect of the discount rate. Since the average year of expansion moved from 6.71 to 12.51 years, the negative effect in the ENPV of the capital cost of the second power plant is reduced. This “benefit” outweighed the losses caused by producing less during the delay of the construction of the second plant.

Comment [HY9]: This is an interesting conclusion.

For the same reason, there is a correlation in the increase of the nuclear-nuclear option of being chosen with the delay in time of the decision to expand. The high initial investment required for a nuclear plant has a less negative impact in the ENPV when the decision to expand moves to the right.

Since the best ENPV results were obtained using the expansion decision rule 3, I will use that alternative as representative for the Flexible Option of the project during the next comparisons.

2. Value at Risk and Gain

Although ENVP is a good metric for an initial analysis, the comparison of the VARG curves of each option and the analysis of their extreme values can provide important complementary information to investors. Figure V-2 and Table V-3 illustrates de VARG curves of each option and their minimum and maximum ENPV values.

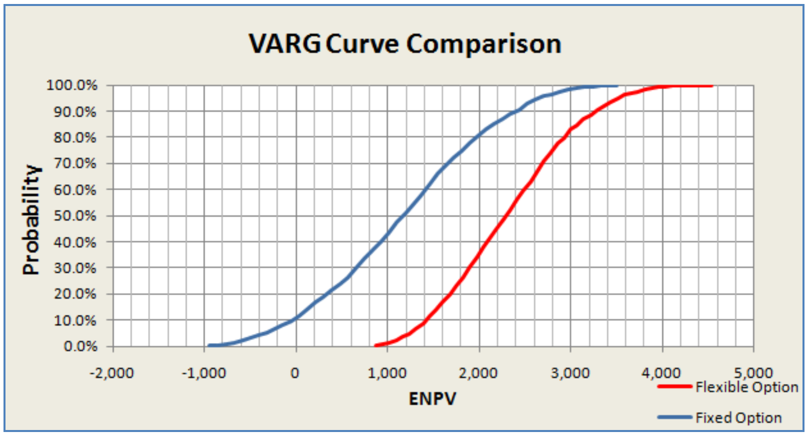


Figure V-2 –VARG Curve Comparison between the Fixed and Flexible Option

	ENPV (millions)	P_5 Value (millions)	P_{95} Value
Fixed Option	$1,166	$ -767	$2,608
Flexible Option	$2,325	$ 943	$3,509

Table V-3 –Extreme Values of the Fixed and Flexible Options

The results show that the flexible option is stochastically dominant because is better than the fixed option in all dimensions.

The main difference can be observed in the "value of risk" of the two curves. The P_5 value (minimum) of the flexible option is positive and considerable higher than the P_5 value of the fixed option. This makes it a much better option in particular if the electricity demand does not grow as expected.

At the same time, the flexible option has also a higher "value at gain" or P_{95} value (maximum). The possibility to decide with more information whether to expand to a nuclear or gas power plant allows investors to take advantages of different scenarios according with the evolution of the natural gas price.

3. Return of Investment

Finally, in terms of return of investment, the flexible option shows again better results. It has a lower initial capital investment and a higher ENPV. The return of investment of the flexible investment option is 0.83, considerably higher than the 0.27 obtained by the fixed option. Table V-4 illustrates these results.

	Initial Capital Investment (CAPEX)	ENPV/CAPEX
Fixed Option	$4,400	0.27
Flexible Option	$2,800	0.83

Table V-4 –Return of Investment of the Fixed and Flexible Options

VI. Conclusions

The study shows that a nuclear option to satisfy the increasing demand in the north of Chile might be worth enough to investors. Although the results of this project are not conclusive and have to be seen as an initial approach to this possibility, the two investment options showed positive ENPVs.

The results of the study demonstrate that a flexible approach in design is a more favorable option when uncertainty is present. In this particular case, the average ENPV calculated for the flexible option was twice as high as the one for the fixed option. At the same time, the analysis of the extreme values of the two alternatives showed that the flexible approach was a better option in all the dimensions (stochastically dominant). The main difference was that the minimum value (P_5) of the flexible option was positive and considerable higher compared with the fixed option. This is particularly attractive for risk averse investors because it avoids the risk of losses if the electricity demand does not grow as expected. The flexible option showed also a higher value of gain, mainly because it provides the opportunity to investors to decide with more information whether to expand to a nuclear or gas power plant in the future. Finally, in terms of return of investment the flexible option presented a result three times higher than the fixed option. The summary of the results are shown in the following table:

	Fixed Option	Flexible Option
ENPV (millions)	$1,166	$2,325
P_5 ENPV (millions)	$-767	$943
P_{95} ENPV (millions)	$2,608	$3,509
Return of Investment	0.27	0.83

The results obtained in the simulation illustrated also how variations in the decision rule that determines the moment of expansion could improve the final ENPV. In this case, simulations were made using three different decision rules. Surprisingly, the best results were obtained using the decision rule 3, which expand to a second plant only after the demand is 30% higher than the installed capacity of the first plant. Increasing the requirements to expand to a second plant moved the average year of expansion to the right. The simulation showed that in this case this delay in the decision was beneficial to the final ENVP because the discount rate reduced the effect of the capital cost of the second plant. The results showed that in this case this "benefit" outweighed the losses caused by producing less during the delay of the construction of the second plant.

Comment [HY10]: This is an interesting conclusion.

Finally, the results of this study indicate not only that a flexible approach to design is more convenient in this scenario, but also provide guidance based on probability estimation of whether a nuclear (20.3%) or gas power plant (79.7%) is going to be more appropriate if the decision to expand arrives. These results were calculated with the current information available and have to be seen as an initial reference by investors. Although the gas option has more probabilities to be the most convenient, the results are not categorical. Investors have to keep observation in time before taken a decision in order to take advantage of the flexible design and use opportunities appropriately.

VII. Course Reflections

- Where do you see the most use for the flexible approach to design and valuations options that the course has stressed?

  I can see many applications for the flexible approach presented throughout the course, in particular in the design of projects that have to deal with significant sources of uncertainty through their projected life. As we saw from the results of this study, the application of this approach in the design of production plants (power, manufacturing, water) can importantly increase the expected value of the project. However, the application of these concepts is not restricted only to engineering projects. It could have also important application in business, especially in the design of company's strategies that allow them to adapt to unexpected changes in the market. In both cases the concepts are the same, to limit downside risk and to be flexible enough to take advantage of the growth opportunities.

- What do you feel that you have learned from the process of doing the application portafolio?

  The process of doing this study has been a really valuable learning experience. After finishing this application portafolio, I believe that I have a much better understanding of both the influence of uncertainty in the results of a project and the value of a flexible approach. In particular, I really enjoyed building the simulation in excel and "playing" with the different parameters and formulas. By looking on how variations in different parameters affected the results, I was able to understand much better the key concepts of the course and how to relate different sources of uncertainty to a real and practical problem.

Comment [HY11]: Great report. Look over my comments – mostly they are presentation issues as I think your analysis and conclusions are sound.

Grade: A.

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