Using real options to evaluate the flexibility in the deployment of SMR

Giorgio Locatelli
University of Lincoln
Lincoln School of Engineering
Brayford Pool - Lincoln LN6 7TS
United Kingdom
Phone;+441522837946
glocatelli@lincoln.ac.uk

Mauro Mancini
Politecnico di Milano
Department of Management,
Economics & Industrial Engineering
Via Lambruschini 4/B Milano – Italy
Phone;+390223994057
Fax: +39 02 2399 4083
mauro.mancini@polimi.it

Felipe Ruiz
Universidad politécnica de Madrid
Dep. de ingeniería de organización,
administración de empresas y
estadísticaC/ José Gutiérrez Abascal,
2. 28006-Madrid -SPAIN
Phone; +34 91 3363140
fruiz@etsii.upm.es

Pablo Solana
Universidad politécnica de Madrid
Dep. de ingeniería de organización,
administración de empresas y
estadísticaC/ José Gutiérrez Abascal,
2. 28006-Madrid -SPAIN
Phone: +34 91 3363136
psolana@etsii.upm.es

Abstract – *According to recent estimations the financial gap between Large Reactors (LR) and Small Medium Reactors (SMRs) seems not as huge as the economy of scale would suggest, so the SMRs are going to be important players of the worldwide nuclear renaissance. POLIMI's INCAS model has been developed to compare the investment in SMR with respect to LR. It provides the value of IRR (Internal Rate of Return), NPV (Net Present Value), LUEC (Levelised Unitary Electricity Cost), upfront investment, etc. The aim of this research is to integrate the actual INCAS model, based on discounted cash flows, with the real option theory to measure flexibility of the investor to expand, defer or abandon a nuclear project, under future uncertainties. The work compares the investment in a large nuclear power plant with a series of smaller, modular nuclear power plants on the same site. As a consequence it compares the benefits of the large power plant, coming from the economy of scale, to the benefit of the modular project (flexibility) concluding that managerial flexibility can be measured and used by an investor to face the investment risks.*

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I INTRDUCTION

Small Medium Reactors (SMRs) could be an important component of the worldwide nuclear renaissance because they require a lower upfront capital cost. Respect to Large Reactors (LRs) they are also somewhat simpler and safer, offering on top of that an option to increase the power generation capacity by adding successive NPP modules on the same site. One of the main issues is to assess their competitiveness since the economies of scale labels these reactors as not economically competitive with respect to larger ones. However SMRs have the attractive feature of flexibility in the deployment. An economic model (INCAS - Integrated model for the Competitiveness Assessment of SMRs) is currently developed by Politecnico di Milano (POLIMI) in the framework of an international effort fostered by IAEA on SMRs competitiveness. INCAS is suitable to compare the economic performance of SMRs with respect to LRs. INCAS performs an investment project simulation and assessment of SMRs and LRs deployment scenarios, providing monetary indicators (e.g. IRR, LUEC, total equity invested) with not-monetary indicators (e.g. design robustness, required spinning reserve).

I.A Aim of the work

Regarding the comparison between 4 SMR (of 335 MWe each) and a LR (of 1340 MWe) Boarin and Ricotti analysed the problem in detail using the INCAS model[1] . They use a sensitivity analysis to show that SMRs project's NPV improves against LR with increasing Debt-to-Equity ratio, by reducing the financial risk and increasing the investment profitability (TABLE 1). We aim to deal with the same comparison: 4 SMR of 335 MWe each and 1 LR of 1340 MWe (even if the approach is obviously valid for any kind of plant of any size) focusing on the flexibility value.

TABLE 1 INCAS result with a DCF analysis. Data from [1]

	4x335MWe SMRs		1x1340MWe LR
	Base case (*)	**Concentration schedule (*)**	
IRR	13,1%	13,4%	14,5%
NPV	240 M€	318 M€	608 M€
Debt (**)	1827 M€	2211 M€	2115 M€
Self-financing (***)	19%	11%	0%
(*) Base case scenario: 13 years, Concentration schedule: 10 years (**) E/(E+D) = 45% (***) Calculated with an electricity price of 80 $/MWh			

I.B Limits of a DCF methodology

The present version of INCAS is based on a "Discounted Cash Flow (DCF)" approach. DCF is a capital budget method looking at projects in isolation [2,3]. It determines the future cash flows that the project may generate and discounts them to today's value at a project-specific discount rate reflecting their perceived risk. So risk is measured indirectly since the discount rate represents the opportunity cost of capital, which is the rate of return expected by an investor. In this context, traditional project appraisal assumes that the firm will embark on a rigid and inflexible path forward, without the possibility to respond and adjust to any changes in e.g. market, supplier, regulation, etc. DCF ignores that the risk-pattern of the project is likely to change over time and the value of managerial flexibility to react to future uncertainties. These limits are partially reduced by probabilistic DCF approaches but even in this context the approach is unrealistic since: (1) new information may be available in the future and the original investment plan could change accordingly (2) investments often come in natural, sequential steps with multiple "go" or "no-go" decision points that allow management to respond to any changes in the market or in regulation, or to adapt to technological breakthroughs. Managers have the right, but not the obligation, to adjust to the environment by accelerating, expanding, contracting or even abandoning the project along the way. Hence, a DCF-based project assessment would be appropriate if there is uncertainty but not managerial flexibility; ROA considers and evaluates this flexibility.

Surely, in the scenario in which many 335 MWe SMRs are compared to a few 1340 MWe LRs, an investor has the possibility to schedule the construction of the different reactors considering at each step the value of some relevant parameters such as licensing time and cost, electricity price, equipment cost, etc.

The final research question that this paper addresses is therefore: **"What is the difference in profitability between SMRs and LRs calculated using the ROA approach versus DCF approach?"**

II LITERATURE REVIEW

The main inadequacy to capital budgeting of the DCF approaches (e.g. NPV) is that they ignore, or cannot properly capture, management's flexibility to adapt and revise later decisions [4] and so it is inappropriate in valuing the flexibility given to managers by the SMR. The methodology based on the concept of ROA is a new paradigm shift in the way of thinking about and evaluating projects[5]. The Real Options value is always higher than the NPV and the difference becomes more obvious for projects with higher uncertainty; in fact, valuing decisions in a deterministic view, assuming that all outcomes are static and decisions made are irrevocable, may potentially grossly underestimate the intrinsic value of a project. Strategic options can provide decision-makers the opportunity to hedge their bets in the face of uncertainty by making midcourse corrections. They reduce the negative side of the risk increasing the returns of the project[5]. These important aspects can be properly analysed by considering investment opportunities as collections of options on real assets (or real options). Gollier[6] also suggests the use of the theory of Real Options to value the option to invest in successive modules. The analysis however is limited to electricity price uncertainty, while the hereto presented model takes into account different sources of uncertainty.

II.A Choosing the options

This section presents the options that we consider more practical and useful to analyse an investment in nuclear reactors. *Acquiring licenses* for the construction of four reactors is the basic condition which provides the possibility to exercise options. The license's cost is the price of acquiring the chance to decide when to exercise or not an option.

An investor has several options; we focused on the two that seems more relevant and intuitive.

WAIT TO EXPAND: until the licenses are not yet expired exists the possibility to choose whether to go on with the project and increase capacity with new reactors or not. When there is uncertainty and risk, it may be a good idea waiting until these uncertainties partially decrease with time.

ABANDON: if it is not convenient to go on with the construction of all the four reactors, the project can be abandoned; this could happen for instance after a long deferment, following a collapse in electricity price or after a substantial increase in equipment cost.

II.B Real options pricing model

The most popular methods to evaluate real options are: Binomial lattice, partial-differential equations, closed-form solutions and simulations [5].

Analytical methods are based on equations that can be solved through a set of input assumptions; they are exact, quick, and easy to implement. However they apply sophisticated mathematical weaponry and they are very specific in nature, with limited modeling flexibility. Moreover, in real option models the usually high number of stochastic variables make it impossible to obtain closed-form analytical solutions[5,7,8].

TABLE 2 summarises the main methods. The Least Squares Method (LSM) is proposed to valuing multi-options and multi-assets problems based on the simulation approach as presented by Longstaff and Schwartz[9]. This simulation method requires a computational effort which is linear with respect to the dimension of the state space. This approach has been utilized in similar contexts [10,11].

TABLE 2 Real options valuation methods [5,12,13,14,15,9,16,17]

	Advantages	Disadvantages
Closed-form solutions	They are exact, not approximation Quick and easy to implement Widely used for pricing financial options	Difficult to explain Very specific in nature They need specific distribution assumption for the underlying to be applied They can't be applied if the strike price behaves stochastically
Binomial or Multinomial	Highly flexible Easy to implement Easy to explain	Impractical in situations where there are multiple factors They need specific distribution assumption for the underlying to be applied
Simulation	Highly flexible Transparent Simple Permits a wide set of value drivers Allows state variables to follow general stochastic processes	It could require a high computational effort It approximates the real value

II.C The state variables choice

State Variables are the parameters influencing the investor strategy. The correct management of the uncertainty linked to them is the strength of ROA. The state variables analysed in this section are the ones combining the greatest impact and uncertainty on the economic and financial parameters. These state variables are: Electricity Price, Equipment Cost, Licensing Time and Cost

II.C.1 The Electricity Price

The most fundamental parameter jeopardising the value of investment in liberalised market is the uncertainty about electricity prices [18].

INCAS model assumes that all the electricity produced is sold in the market. Several papers have pointed out some general characteristics of the power price behaviour that should be considered. Some authors[19-21] argue that a model for electricity prices should incorporate a form of time-dependant volatility and the possibility of jumps in prices. Others, on the contrary, have stressed the importance of the periodic seasonal behaviour of electricity prices, and its reversion to mean levels[22]. The main models are:

- ARIMA Models and Others [23-25]
- Mean reverting regime switching Process [26, 27]
- Mean reverting jump diffusion Process [19-21, 28-30]
- Mean Reverting Process [22, 31, 32]
- Brownian Motion Process [6], [33 34]

The main stochastic processes used to value commodity derivatives are: Geometric Brownian Motion, Mean-Reversion, Mean Reverting Jump Diffusion and Mean Reverting Regime Switching. The most known process is the Geometric Brownian Motion (GBM) which has been used in multiple fields, including finance, to model the behaviour of security prices.

The main properties of this process are: price changes are independent of each other (no memory) and price changes have a constant mean and volatility[33]. Prices follow a Markov chain in the sense that the expected price level at given time in the future depends only on today's price. Mean reversion models, however, allow for a dependency of price jumps as prices tend to revert to a certain mean level with a strength that depends upon the distance to such mean level. In the jump diffusion model, price change dynamics can be divided into two distinct forms: a 'normal', continuous price diffusion process and an 'abnormal', discontinuous jump process modelled by a Poisson distribution[19, 21, 28]. Historically, electricity prices do not jump, but 'spike'. That is, they do not jump to a new level and stay there, but rather quickly revert to their previous levels. The use of mean reversion alongside jumps allows us to simulate this spiking behaviour.

Mean reverting jump diffusion processes are able to capture a spike behaviour but it is assumed that all shocks affecting the price series die out at the same rate. In reality two types of shocks exist implying different reversion rates: large disturbances, which diminish rapidly due to economic forces, and moderate ones, which might persist for a while[30]. For this reason the best process to model the electricity price is a Mean reverting regime switching process.

Random Walk with Mean Reversion

$$\boldsymbol{S_{t+1} - S_t = \alpha\,(S^* - S_t) + \sigma\varepsilon_t}$$

Where:

S^* is the mean reversion level or the long run equilibrium price

S_t is the spot price

α is the mean reversion rate

σ is the volatility

ε is the random shock to price from (t) to (t+1)

The mean reversion component or 'drift' term is driven by the distance between the current price and the mean reversion level as well as by the mean reversion rate. If the spot price is below the mean reversion level, the mean reversion component will be positive, resulting in an upward influence on the spot price. Alternatively, if the spot price is above the mean reversion level, the mean reversion component will be negative, thus exerting a downward influence on the spot price[31].

The Mean Reversion Rate is the speed at which prices revert and can be calculated in a very simple and robust manner by regressing electricity price changes and previous price levels; the negative of the slope of the regression line is the Mean Reversion Rate. The Mean

Reversion Level is the long-run equilibrium price and is the price value (x_value) in the regression equation when the electricity price (y_value) change is nil. Finally, the volatility of price changes is given by the residual standard deviation, which is the standard error of the forecast 'y_value' for each 'x_value' in the regression.

II.C.2 Equipment cost

The investment cost can be divided into different cost items. The Equipment Cost accounts for 40% of the Total Overnight Investment Cost [35] and has a large volatility. It makes sense to use a GBM; generally this assumption is more appropriate for the project value but it can be used also for investment cost, following Schwartz and Trigeorgis[36].

$$\Delta \boldsymbol{S} = \boldsymbol{\mu S}\Delta t + \boldsymbol{\sigma}\, \boldsymbol{S}\, \boldsymbol{\varepsilon}\sqrt{\Delta t}$$

Where:
$\boldsymbol{\mu}$ is the mean or the drift
σ is the annual standard deviation
Δt is the time step in years

In order to simulate possible future Equipment Cost, the GBM process was chosen because it requires only two parameters: the starting cost and the expected variability. For what concerns the expected volatility, there are several methods to estimate it. Some authors prefer to use estimates based on historical prices ('historical volatilities'), while others prefer to use the volatilities implied by indicators for the volatility of commodities ('implied volatilities')[33]. Because of the lack of data and considering that nowadays there is no small-reactor under construction or operation, it's not possible to estimate accurately these two variables. Therefore it was assumed a reasonable value as starting cost, according to Boarin and Du[37,38]. A sensitivity analysis with simulations for different values of volatility has been performed, assessing how the volatility affects the option value.

II.C.3 Licensing Time and Cost

The licensing time is an underlying a little bit different from the other two previously discussed, because it doesn't follow a particular process like a Mean Reverting Process or a GBM but rather it should be modelled as a probability distribution. The probability distribution for this state variable is a PERT distribution (also known as Beta PERT), a typical default choice to model time distribution [39].

The licensing cost is the option price of the real option model, i.e. the price which an investor is willing to pay, reserving in the future the right but not the obligation to exercise the option. In this case, this means that an investor is willing to pay this sum, obtaining the right to decide the best moment to build a reactor. Hence, the option price is a sunk cost and normally an investor requires that the option value will exceed it. It is possible to estimate this cost as a function of time, as [40] shows. Therefore, taking in to consideration the U.S.A. scenario, the licensing cost is modelled as a linear function of time simply obtained by multiplying the professional staff-hour rate of $259

III MODEL

The model proposed can be integrated with INCAS, the Discounted cash flow model developed by POLIMI in collaboration with IAEA[41]. TABLE 19 shows a comparison with this model and previous studies. Figure 1 presents the black box of the model. It shows that the main inputs are the state variables and, as outputs, the value of flexibility for LR and SMR

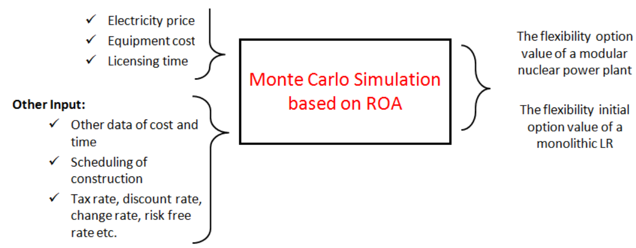

Figure 1 Black-box of the model

This model evaluates the option on a project with one reactor each time. Evaluating more options and reactors is simple: the algorithm is the same, the only difference being that in the comparison between exercising and waiting, the value to exercise has to be increased by an amount equal to the option value on remaining reactors. For example to assess the flexibility of a project with four reactors, the value of the third reactor must be increased by the value of the fourth reactor, the second reactor embeds the value to build the third etc. back to the first.

IV RESULTS AND SENSITIVITY ANALYSIS

IV.A Static Results

. Due to the discount rate, the more expanded is the scheduling the lower is the Free Cash Flows from Operations (FCFO) without option, and as consequence the higher is the Option Value. However it is important to underline that a more diluted scenario has other advantages (like more self-financing and a lower financial exposure) which are not taken into account in this model. Starting from these results the following sensitivity analysis shows the effects on the Option Value.

TABLE 3 and TABLE 4 report the values which characterize the evolution of the state variables and the other most important variables. On the basis of these values the outputs are in TABLE 5. Due to the discount rate, the more expanded is the scheduling the lower is the Free Cash Flows from Operations (FCFO) without option, and as consequence the higher is the Option Value. However it is important to underline that a more diluted scenario has other advantages (like more self-financing and a lower financial exposure) which are not taken into account in this model. Starting from these results the following sensitivity analysis shows the effects on the Option Value.

TABLE 3 State variable values

Underlying	Parameter	Value
Licensing time		7-12 semesters (Pert distribution)
Electricity price	Speed Long Run Mean	28% / year 69,90 €/MWh
Equipment cost	Drift Volatility %on investment cost	2% /year 15% /year 40%

TABLE 4 Other input variables' values

Variable	Value
Inflation	2%
Risk free rate	3%
Tax rate	30%
Equity cost	15%
Equity / (Equity + Debt)	50%
Debt cost	7%

TABLE 5 Base case results

Scheduling deployment scenario	FCFO without option [M€]	Option value [M€,%]
1 (9 years)	502,8	107,4 (21,4%)
2 (12 years)	495	115,2 (23,3%)
3 (15 years)	487,4	122,8 (25,2%)

IV.B Sensitivity Analysis

IV.B.1 Financial Parameters

In this section we analyse how the costs of debt and equity and they relative percentages affect the results. In particular it will be considered a "Merchant case", where the project is subjected to the laws of the free market, a "Supported case", where the state guarantees bank loans, (both scenarios are taken from Boarin[37]) and two intermediate cases, where two intermediate Weighted Average Costs of Capital (WACC) have been considered, in order to better understand the influence of this parameters. TABLE 6 summarizes the four scenarios.

TABLE 6 Financial cases

Case	Ke	%Equity	Kd	% Debt	WACC
Merchant	15%	50%	7%	50%	9,95%
Supported	10%	20%	5%	80%	4,80%
Intermediate 1	13%	50%	7%	50%	7,55%
Intermediate 2	15,8%	50%	7%	50%	8,95%

In the Merchant case scenario both shareholders and lenders will require a high capital remuneration to cover long-term business risk. For this reason financing this nuclear project would only be possible through corporate financing with nuclear business risk being diluted within a diversified business portfolio of shareholders and with shareholders' assets as collateral to guarantee bank loans (TABLE 7)

TABLE 7 Merchant case's output

FCFO without option	502,8	*[M€]*
Licensing cost 1st reactor	1,4	*[M€]*
Licensing cost other reactors	0,4	*[M€]*
FCFO with option	610,2	*[M€]*
OPTION VALUE	107,4 (+21%)	*[M€]*

The Supported case takes its name from the fact that the state 'supports' the investment in a nuclear plant, guaranteeing the bank loan, and that long-term electricity sale contracts are assumed. For this reason, the probability of financial default decreases and there is a high growth of the FCFO (TABLE 8)

TABLE 8 Supported case's output

FCFO without option	6202,3	*[M€]*
Licensing cost 1st reactor	1,4	*[M€]*
Licensing cost other reactors	0,4	*[M€]*
FCFO with option	6202,4	*[M€]*
OPTION VALUE	0,1 (<0,01%)	*[M€]*

Finally the other two scenarios have been analysed, considering a WACC value between the two previous ones, in order to have a more complete view of how this parameters affect the option value (TABLE 9).

TABLE 9 E and D Costs and Percentage's sensitivity results

Case	WACC	FCFO without option	FCFO with option	% Option Value
Merchant	9,95%	502,8	610,2	21%
Supported	4,80%	6202,3	6202,5	<0,01%
Intermediate 1	7,55%	2178,8	2200,5	1%
Intermediate 2	8,95%	1062,9	1117,4	5%

The value of optionality stands in the ability of the management to react to business conditions and in particular to the possibility to abandon the project if these conditions are not as good as requested. So, the greater is the probability of default the greater will be the option value. In the "Supported case" the low cost of capital makes the investment very convenient, and so the consequence is a low value of optionality. Vice versa, in a situation subjected to the laws of free market, it becomes extremely important for the management to value accurately business conditions.

Moreover, it is important to note that the WACC has a strong impact on the percentage value of the option. A reduction of 10% of the cost of capital (from 9,95% to 8,95%) causes a corresponding reduction of 76% of the percentage of the option value (from 21% to 5%) and a decrease of 25% of WACC (from 9,95% to 7,50%) causes a corresponding decrease of 95% in the option value (from 21% to 1%). This is summarized in Figure 2

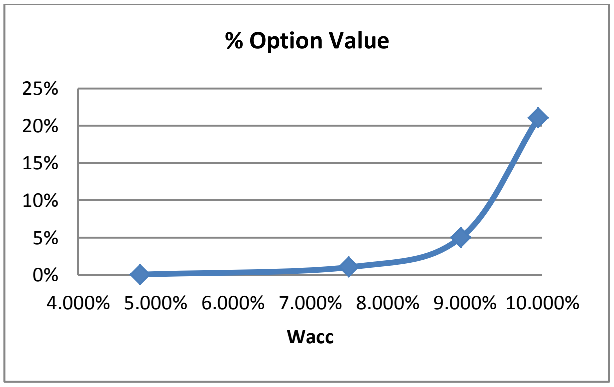

Figure 2 Option Value with different WACC

IV.B.2 Licensing

In this section it will be shown how the first of the three state variables impacts on the option value. The licensing time can vary from a minimum of 7 semesters and a maximum of 12. TABLE 10 summarizes the results.

TABLE 10 Licensing time's sensitivity results

Licensing time	FCFO without option	FCFO with option	% Option Value
7 semesters	502,8	610,2	21%
9 semesters	498	609,4	22%
11 semesters	492,5	609,5	24%
12 semesters	489,2	609,2	24,5%

The licensing time seems not to affect the FCFO with option. Indeed, despite small differences in licensing costs and different discount rates, the scheduling flexibility allows to mitigate these effects. Vice versa, FCFO without option, not having scheduling flexibility, is affected by the discount rate and the longer licensing time is the lower its value becomes (and so the higher is the percentage of option value) as shown in Figure 3. However licensing time is not such an important variable driving the optionality value. Figure 3 shows how FCFO with option is independent from licensing time, while FCFO without option shows a slight decreasing.

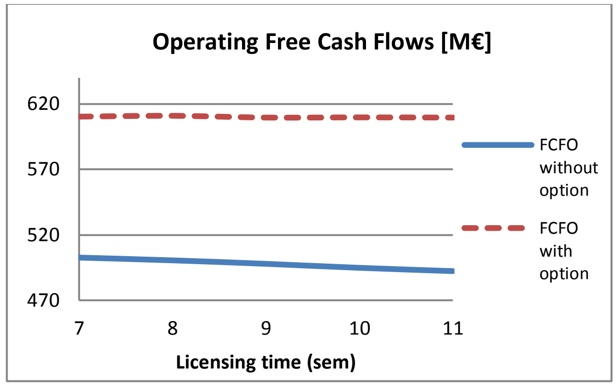

Figure 3 FCFOs with different licensing times

IV.B.3 Electricity price

It is important to check whether the option model is sensitive to the mean reversion rate, which is one important feature the electricity price behaviour. The results are shown in TABLE 11.

TABLE 11 Electricity speed's sensitivity results

Electricity Mean Reversion Rate	FCFO without option	FCFO with option	% Option Value
7%	452,3	690,3	53%
14%	488,9	629,3	29%
28%	502,8	610,2	21%
42%	503,2	604,4	20%
56%	503,1	603,6	20%

A slower Mean Reversion Rate involves a higher optionality. As long as the electricity price is low, the scheduling will be postponed until the price grows, avoiding a low profitability situation. On the other hand, if the price is high the reactors will be scheduled as soon as possible in order to take advantage of this temporary extra-profitability situation. For speeds greater than 30%, this parameter seems not to have an effect on the option value (Figure 4)

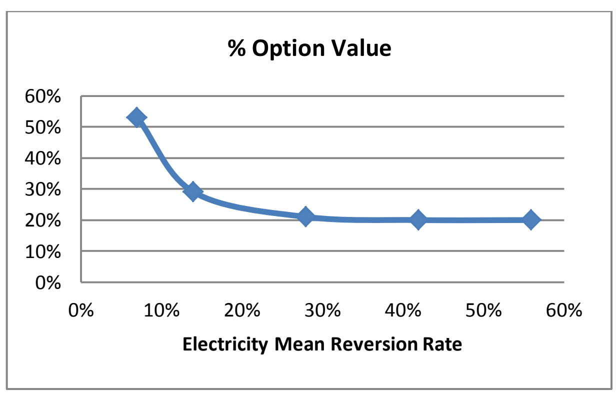

Figure 4 Option Value with different Mean Reversion Rates

The Long run mean or Mean reversion level is the long-run equilibrium price. Starting from the reference value of 69,9 €/MWh, it has been increased 15% and 30%

and decreased of 15% as shown in TABLE 12. This value has not been decreased more than 15% because in this case the project will result strongly no-profitable.

TABLE 12 Electricity Long Run mean's sensitivity results

Electricity Long Run Mean	FCFO without option	FCFO with option	% Option Value
59,4 €/MWh	-317,9	117,9	137%
69,9 €/MWh	502,8	610,2	21%
80,4 €/MWh	1293,8	1337,8	3,4%
90,9 €/MWh	2054,3	2088,7	1,7%

A higher long run mean makes the project more profitable, reducing the probability of default and so the optionality. Vice versa, a lower reversion level leads to a lower profitability but increases the option value (see Figure 5). In particular results for a Long Run Mean of 59,4 €/MWh (see TABLE 13) illustrate a very meaningful example showing the difference between DCF and ROA. Indeed, while an evaluation including management flexibility leads to positive results, an evaluation based on DCF leads to a negative expected FCFO, underestimating the project value.

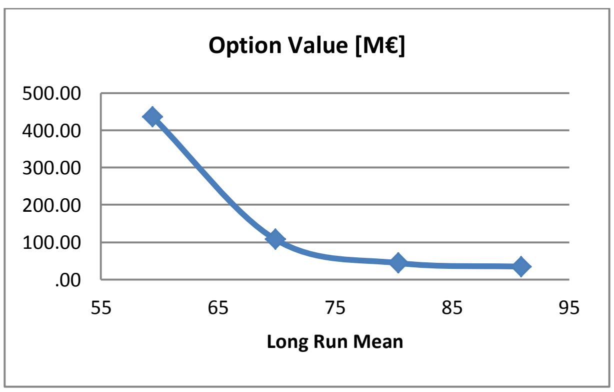

Figure 5 Option value with different Long Run Means. The Percentage Option Value is not reported because when FCFO are negative it cannot be calculated

TABLE 13 Long Run Mean 59,4 €/MWh

FCFO without option	[M€]	-317,9
Licensing cost 1st reactor	[M€]	1,4
Licensing cost other reactors	[M€]	0,4
FCFO with option	[M€]	117,9
OPTION VALUE	[M€]	435,8

IV.B.4 Equipment cost

Finally it is important to check the variations of the third underlying on optionality. Equipment cost is the most influential underlying because it is the higher source of uncertainty. The reference value for the drift is +2%, equal to the inflation value. Two other scenarios have been tested, with no drift and with a negative drift. Results are summarized in TABLE 14.

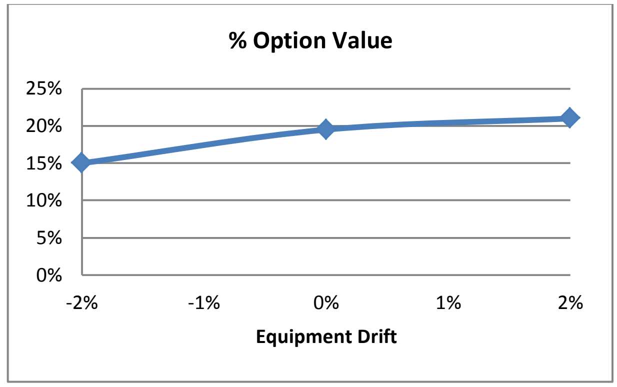

Figure 6 Option value with different Equipment Drifts

TABLE 14 Equipment volatility's sensitivity results

Equipment volatility	FCFO without option	FCFO with option	% Option Value
7,5%	501,3	536,7	7%
10%	499,8	556,4	11%
15%	502,8	610,2	21%
20%	488,3	670,3	37%
22,5%	487,4	712,1	46%

After the WACC, equipment volatility is the most important factor that affects optionality. This is a consequence of the choice of the Equipment cost as the most uncertain factor, assuming a Brownian Motion as the process which drives its evolution. The relationship between equipment volatility and Percentage Option Value is shown in Figure 7.

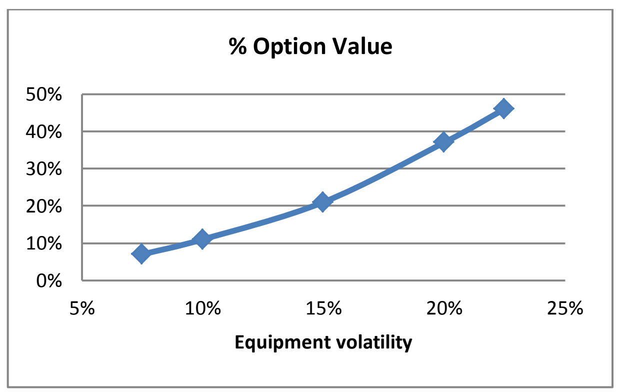

Figure 7Option value with different Equipment Volatilities

Equipment Percentage on Investment cost: up to now, the best estimates suggest that the equipment costs are about 40% of the total investment cost. However it is interesting to see how by modifying this percentage, results change (TABLE 15).

The analysis shows a linear increase of the Option value percentage with Equipment percentage on the Total Investment Cost. This relation appears clear in Figure 8

TABLE 15 Equipment percentage on Investment cost's sensitivity results

Equipment percentage on Investment cost	FCFO without option	FCFO with option	% Option Value
30%	501,3	566,7	13%
35%	498,4	581,9	17%
40%	502,8	610,2	21%
45%	502,6	629,4	25%
50%	500,6	649,3	30%

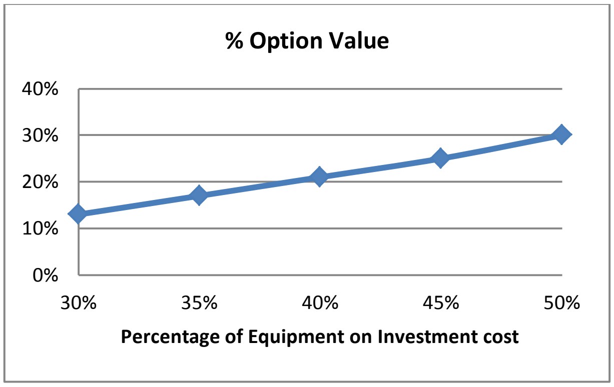

Figure 8 Option value with different percentages of Equipment on Investment cost

Finally the last section of the Sensitivity Analysis compares the LR case to the SMR case. TABLE 16 summarizes the results obtained by modifying the variables with a bigger impact on optionality and compares a LR project versus a 4 SMRs one.

TABLE 16 LR VS SMR

Scenario		FCFO without option			FCFO with option		
		LR project	SMRs project	Difference	LR project	SMRs project	Difference
Base case	-	641,8	502,8	21,7%	747,4	610,2	18,4%
Electricity	Speed 14%	632,8	488,9	22,7%	792,8	629,3	20,6%
	Speed 56%	642,5	503,1	21,7%	746,3	603,6	19,1%
	Long Run Mean 59,4 €	-52,6	-317,9	504%	263,9	117,9	55,3%
	Long Run Mean 80,4 €	1328,3	1293,8	2,6%	1357,6	1337,8	1,5%
Equipment	Volatility 10%	639,7	499,8	21,9%	685,7	556,4	18,9%
	Volatility 20%	640,7	488,3	23,8%	844,7	670,3	20,6%
	Percentage on Investment 30%	638,8	501,3	21,5%	702,7	566,7	19,4%
	Percentage on Investment 50%	644,7	500,6	22,4%	795,4	649,3	18,4%

On the basis of these results it is evident that modelling flexibility implies an important increase of LR and SMRs project assessments. Moreover an evaluation based on ROA shows a lower gap between LR and SMRs. However the gap reduction is not so marked because a SMRs project not only has flexibility, but also an LR project can take advantage due to the embedded options as shown above.

V CONCLUSION

Is it now possible to answer to the research question: **How much does the profitability of SMRs change with respect to LRs, if a ROA approach is used instead of a DCF approach?**

The profitability is measured in terms of FCFO obtained with a Real Option Approach and FCFO obtained with a Discounted Cash Flow methodology. The option value is the difference between the two FCFOs. The profitability index is the ratio of the FCFO with option to the total investment cost.

TABLE 17 SMRs and LR, DCF and ROA Profitability in the base case scenario

Type of Project	FCFO [M€] with DCF Methodology	FCFO [M€] with Real Option	Option value M€ (%)	Profitability Index
4 SMRs 1340 MWe	495,0 (2)	610	115,2 (23,3%)	13,12%
1 LR 1340 MWe	641,8	747,4	105,6 (16,5%)	15,99%
(1), (2), (3) Scheduling scenarios (9- 12- 15 years deployment)				

As can be seen in TABLE 17 the option value is bigger in a project of four SMRs, but it's also significant for a large reactor. This happens to be so because for LR there is also a first option, in which management has the right, but not the obligation, to identify the right moment in which to start the construction. The profitability index is bigger for LR because SMRs' total investment cost is 7% higher. TABLE 18 reports the value of the managerial flexibility given by a modular nuclear power plant of four 335 MWe SMR with respect to a large reactor of 1340 MWe.

TABLE 18 LR VS SMRs Project GAP Analysis

Scenario	DCF Methodology [M€]			ROA [M€]			GAP Reduction
	LR project	SMRs project	GAP	LR project	SMRs project	GAP	
Merchant	642	502,8	21,7%	747,4	610,2	18,4%	-3,3%
Intermediate 1	2408	2179	9,5%	2413	2200	8,8%	-0,7%
Intermediate 2	1120	1063	5,14%	1162,9	1117	3,9%	-1,24%
Supported	6924	6202	10,4%	6924	6202	10,4%	0%

All the values obtained applying real option theory, except for the one in the Supported case, are larger than the ones obtained applying DCF. In the Supported scenario a nuclear power plant project is encouraged from the government and therefore for an investor the risk is very low. For this reason the policy is to invest now, without any need to wait until future uncertainties are resolved. For a small-medium reactors project, results suggest to construct all the reactors sequentially, following a concentrate schedule. For this reason the managerial flexibility value is very small. In general, accounting for managerial flexibility reduces the gap between single phase and modular nuclear projects. The greater the probability of default or uncertainty is, the higher the optionality value is.

In conclusion, the research presented in this paper proves that managerial flexibility has a value and this value is always higher in a modular project (where management can take advantage of more strategic options) than in a one-reactor project (where there is only one starting option). The analysis of results taking account of flexibility as well as "external factors", together with other important aspects (self-financing, a lower financial exposure, etc.) make a project of four SMRs interesting by itself even if a LR project still remains more profitable from a purely financial point of view.

The results of this research seems even more interesting if considered as recent research show as SMR can be competitive with other base load technologies[49]. In particular the SMR seem a valuable investment in case of high CO2 cost[49] and to diversify the investment portfolio[50].

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APPENDIX

TABLE 19 Model's Literature Review

		This work	[42]	[43]	[44]	[45]	[46]	[47]	[48]
INPUT	Fuel cost	Deterministic	Deterministic	Deterministic	Historical data	Normal Distribution	Historical data	Normal Distribution	Normal Distribution
	Capital cost	Model as a Brownian Motion process - Underlying	Model as a Brownian Motion process - Underlying	Discrete/ Continuous Distribution	Considered but unspecified	Deterministic	Historical data	Normal Distribution	Normal Distribution
	O&M cost	Deterministic	Deterministic	Deterministic	Considered but unspecified	Deterministic	Historical data	Normal Distribution	Normal Distribution
	D&D Cost	Deterministic	Deterministic	Deterministic	Unspecified	Deterministic	Historical data	Deterministic but unspecified	Not considered
	Technologies	Nuclear, but adaptable	Nuclear	Nuclear	CCGT, Coal, Wind, Oil, Nuclear, Biomass	CCGT, Coal, Nuclear,	Coal, Wind, Oil, Nuclear, Hydro, Gas	Coal, Wind, Gas, Nuclear, Biomass	CCGT, Coal, Wind, Oil, Nuclear
	Plant Size	Large & Small	Large & Small	Large & Small	Large	Large	Large	Large	Large
	Countries	USA, Italy	OECD Countries	OECD Countries	UK / Sweden	UK	Switzerland / USA	Netherlands	USA / Europe
	Licensing time	Continuous Distribution/ Scenario dependent - Underlying	Not considered	Not considered	Not considered	Not considered	Not considered	Not considered	Not considered
	Electricity Price	Model as Mean reverting process/Scenario dependent - Underlying	Model as a Brownian Motion process - Underlying	Discrete/ Continuous Distribution	Historical data	Normal Distribution	Not considered	Not considered	Not considered
	Emission Cost	Not Considered	Not Considered	Not Considered	Historical Data	Normal Distribution	Unspecified	Scenario dependent	Not considered
	Learning effect	Not considered	Unspecified	Considered	Unspecified	Unspecified	Unspecified	Unspecified	Unspecified
MODEL	Economical model type	Real Option approach	Real Option approach	Discounted cash flow methodology	Cost Drivers	Cost Drivers and discounted cash flow	Cost Drivers	Cost Drivers	Cost Drivers
	Input correlation	Not considered	Not Considered	Not Considered	Not considered	Considered	Considered	Considered	Considered
	# Iterations	Enough to obtain robust results	Unspecified	Enough to obtain robust results	Unknown	100.000	Not required	Not required	Not required
OUTPUT	KPI	Option Value (abs, %)	ENPV [€/ KW]	LUEC, IRR	Return/Output [€/MWh	Net Present Value	LUEC	LUEC	Return [KWh/US Cent]
	Sensitive analysis of different scenario	Considered	Considered	Considered	Considered	Not considered	Considered	Considered	Considered