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Titolo

Rapporto sull'analisi di uno scenario nazionale che preveda l'utilizzo di reattori di grande taglia di III generazione e, successivamente, di reattori di piccola taglia di generazione III+

G. Locatelli, M. Mancini, A. Trianni, P. Trucco (DIPART. INGEGNERIA GESTIONALE – Politecnico di Milano))

S. Boarin, M. Ricotti (DIP. DI ENERGIA – Sezione INGEGNERIA NUCLEARE – Cesnef – Politecnico di Milano)

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Sommario

Il documento presenta una significativa applicazione del codice, basato sulla piattaforma MathLab, "*INtegrated model for the Competitiveness Analysis of Small-medium sized reactors*" (INCAS). Il lavoro, sviluppato presso il Politecnico di Milano, si riferisce al "*Low Variant Scenario*" elaborato nel 2009 da ENEA e trasferito ad IAEA nell'ambito del "*Coordinate Case Studies on Competitiveness of SMR in Different Applications*: *Case Study Italy*".
Lo scenario è caratterizzato da una potenza totale installata di origine nucleare di 15 GWe all'orizzonte degli anni 2014-2030.
Le tecnologie di reattore considerate in questo studio sono l'EPR francese (1600 MWe) ed il reattore IRIS (335 MWe): 6 EPR in siti con una singola unità piu' 4 siti con ognuno 4 moduli IRIS.

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Rapporto sull'analisi di uno scenario nazionale che preveda l'utilizzo di reattori di grande taglia di III generazione e, successivamente, di reattori di piccola taglia di generazione III+

Giorgio Locatelli^, Mauro Mancini^, Andrea Trianni^, Paolo Trucco^,
Sara Boarin*, Marco Ricotti*

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EXECUTIVE SUMMARY

This document presents an application of the INtegrated model for the Competitiveness Analysis of Small-medium sized reactors (INCAS). It comply with the "Low Variant scenario", elaborated by ENEA in 2009 and delivered to the IAEA, in the framework of the "Coordinated Case Studies on Competitiveness of SMR in Different Applications: Case Study Italy".

The scenario is characterized by a total installed capacity of 15 GWe, on a time horizon of 2014-2030.

The reactor technologies considered in this Case Study are the French EPR (1,600MWe) and the IRIS (335MWe): the nuclear fleet will result in 6 EPR stand-alone units and 4 IRIS sites composed by 4 IRIS modules per site.

This application has to be considered as a trial test of INCAS.

The country scenario is preceded by a comparative analysis of two alterative investments in SMRs or one single LR, with the same total power installed on a single site. The results of this preliminary, single-site analysis highlight some economic features of an investment in modular, small-medium sized reactors (SMR): financial investment effort is diluted on a staggered construction period thus accounting for lower financial distress; shorter PBT of each SMR plant account for lower IDC escalation; dis-economies of scale are substantially recovered by the "economy of multiples" thus granting an investment profitability in the same scale, considering the uncertainty that characterizes the input parameters; early deployed SMR may generate cash flow to invest in the construction of later units, thus lowering the recourse to financial debt and diluting the equity investment.

The investment profitability is equivalent between the two projects, in the scale of uncertainty that characterizes the input parameters of the model.

When applied to the Italian scenario, the deployment of SMR (IRIS) does not penalize the profitability of the whole NPP fleet, while granting the opportunity to dilute the up-front investment and benefit from self-financing contribution to the capital investment cost. Smaller NPP size means higher investment modularization, shorter Pay Back Time of each NPP module and higher contribution of self-financing to total capital investment cost.

The range of input data (construction costs and cost of capital) defines two sub-cases, in a way that a sensitivity analysis may be performed against the concerned input parameters: "Case MIN" and "Case MAX", the former characterized by lower unit construction costs and lower cost of financing; the latter to be considered a sort of "worst case scenario".

The financial appraisal of the project carries out the calculation the Levelized Cost Of Electricity (LCOE) in each scenario and the key investment performance indicators, such as Internal Rate of Return and Net Present Value of the whole investment project. Moreover INCAS provides a full set of time-series output data that reflect evolution of the project financial performance and highlight the financial stress of the project, such as the maximum cash outlay, the maximum debt-to-equity period, etc.

INCAS allows to appreciate the scale of impact of different scenario conditions on such indicators: the project profitability of Case MIN may be nearly doubled as compared to Case MAX.

The results of this study highlight that, under certain scenario conditions, given opportune risk-mitigation policies that justify lower cost of capital, given the benefits of the "economy of multiples" that contributes to lower construction

costs, the unit cost of electricity by nuclear technology may be competitive and the economics of the investment project may be satisfactory for shareholders and lenders.

Sensitivity analysis gives the measure of the extent of economic soundness, against changed scenario conditions, but a more exhaustive analysis need to rely on a fully stochastic model of the nuclear investing, necessary to introduce the multiple uncertainties that affect the parameter estimation.

This approach would allow to appreciate the stochastic distribution of the key profitability indicators such as NPV and IRR and infer about the project risk: a correlation between investment risk and variance of profitability indicators is widely accepted. The expected value of profitability and its variance, as resulting from a Montecarlo simulation of each investment scenario, are two investment decision criteria that need to be evaluated comprehensively and are not necessarily concordant.

SINGLE-SITE INVESTMENT ANALYSIS

1 INPUT ASSUMPTIONS

This analysis focuses on the comparison between two alternative investment in NPP on a single site.
The same total power generation capacity (1,340MWe) is installed on a single site, through 4 SMR (IRIS) with are built through a staggered construction schedule, or alternatively, one single Large Reactor (LR) of the same technology (i.e. PWR). Reactor-specific inputs are summarized in the table below.

Tab.1: Reactor-specific data input for single-site analysis

Reactor type	*"Large Reactor"*	*IRIS*
Power output (MWe)	1,340	335
Capacity factor (%)	90%	90%
O&M unit cost (€/MWh)	7.92	7.92
Fuel cycle unit cost (€/MWh)	6.67	6.67
Decommissioning unit cost (€/MWh)	0.88	0.88
Expected construction period for nth unit	5 years	3 years
Plant operating life	60 years	60 years
Design saving factor on construction costs (%)	100%	80%
Cumulated capital expenditure profile	"S" curve	"S" curve

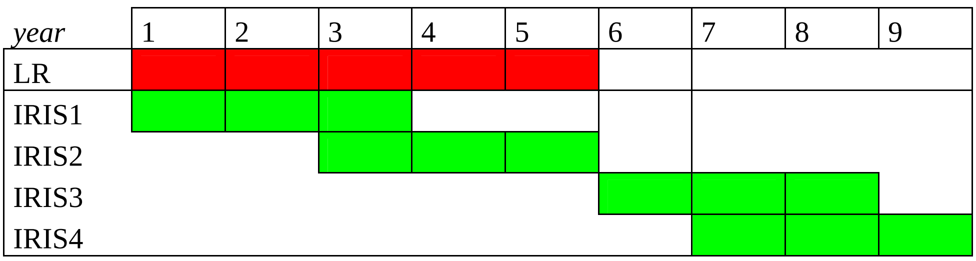


Fig. 1: Construction schedule for LR and SMR

Accordingly to the country scenario that is developed in the following of this paper, we assume for the single-site analysis as well, the same investment data inputs (Tab.2). we consider no escalation rate for construction costs and we develop a cash flow model based on real monetary values.
Electricity price is flat over the entire time horizon at 70€/MWh. Corporate tax rate is assumed to be 35%.

Tab.2: Investment-specific data input for single-site analysis

Cost of equity	15%
Cost of debt	8%
Financing mix: D/(D+E)	50%
Debt amortization period	10 years
Depreciation period for fixed assets	12.5 years
Escalation rate for capital costs	0%
Overnight capital costs of LR (€/kWe)	3,000
Overnight capital costs of IRIS (€/kWe)	Scaled from LR and adjusted

2 OUTPUT ANALYSIS

The so-called "Economy of multiples" consists of cost saving factors that intervene in the construction phase of modular, multiple NPPs to reduce their costs thus recovering from the loss of Economy of scale. The latter is responsible of some 67% construction cost increase, in term of €/kWe installed, passing from a 1,340MWe PWR to a single 335MWe IRIS.

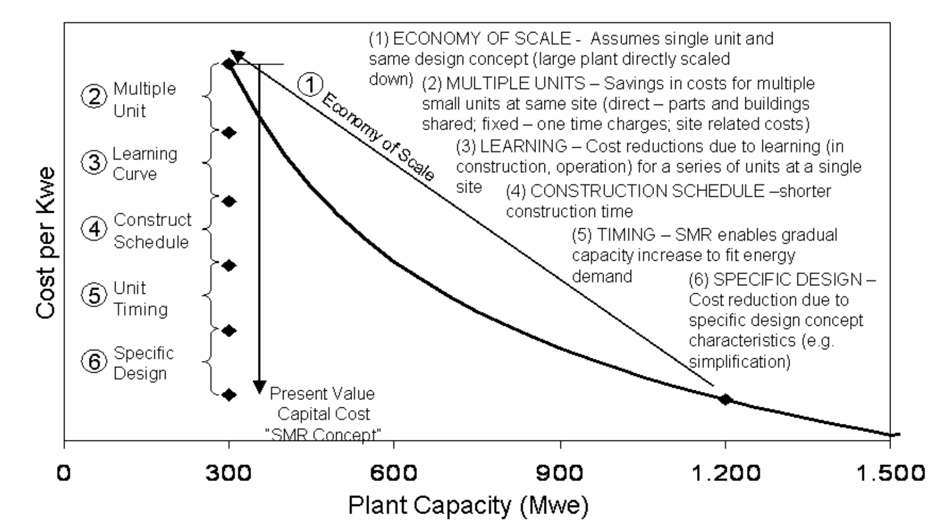


Fig.2: Components of the"Economy of Multiples"

If multiple SMR are built on the same site in order to achieve the same total power capacity as the LR, then other phenomena applies to the whole SMR fleet:

- ✓ Staggered construction allows for learning accumulation progressively reduces the construction cost of successive units
- ✓ Modularization accounts for cost savings in the factory fabrication phase
- ✓ Design simplifications produce further cost reduction in the fabrication/transportation/assembling of the plant
- ✓ The sharing of site-related costs between multiple units on the same site, reduces their incidence on the latter units

Figure 3 shows that total capital cost of each successive units is lower than the previous on account of the above mentioned phenomena.

Total capital investment cost for the whole 4 SMR fleet is comparable to the single LR, despite the loss of economy of scale; the economy of multiples has allowed the SMR to recover cost competitiveness.

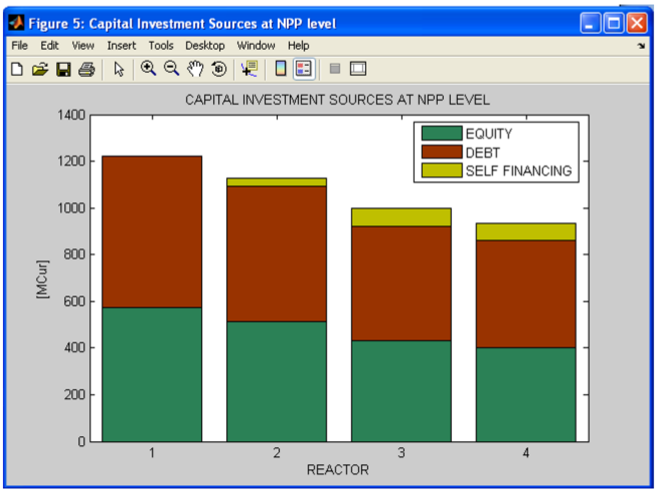


Fig.3: Capital investment costs for each SMR, by sources

Construction cost of SMR1 is about 3,500€/kWe, while SMR4 is 2,790€/kWe, lower than LR's cost of 3,000€/kWe. Moreover 185M€ of total capital investment cost are provided as self-financing, from the cash flow generated by the operation of early units.

Total capital investment cost for the SMR fleet is 4,283M€; this amount is equivalent to the total capital investment cost of LR (4,260M€), due to the "economy of multiples" cost savings. Shorter PBT of each plant allow SMR to better manage debt obligations: with 8% interest rate, total actualized financial interest expenses are 1,731M€ (i.e. 40% of total capital investment cost)) for SMR and 1,988M€ for LR (46% of total capital investment cost).

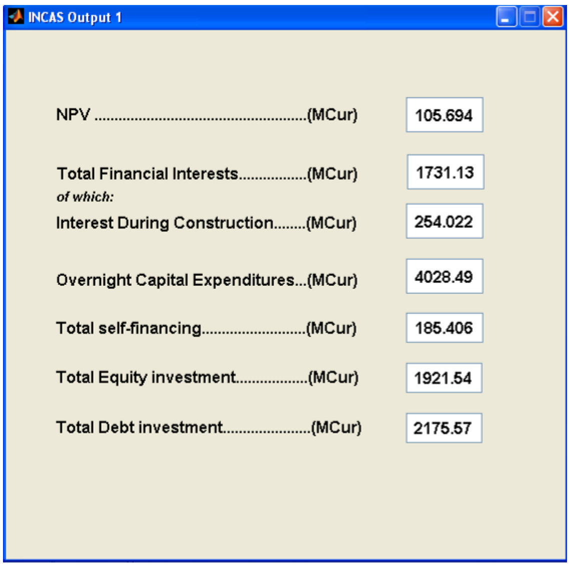


Fig.4: SMR, key financial indicators 1

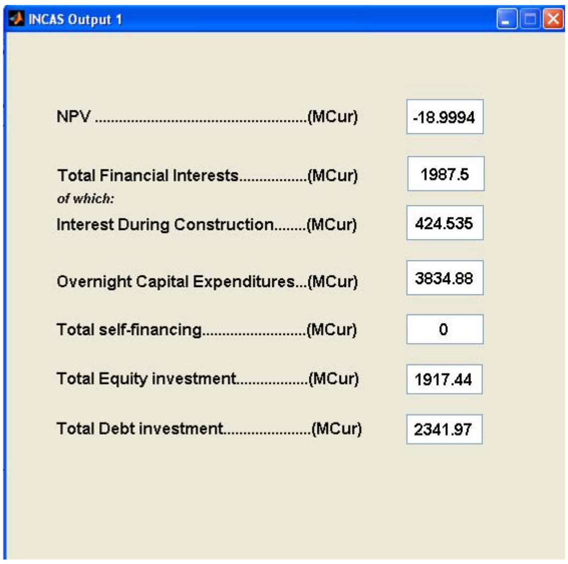


Fig.5: LR, key financial indicators 1

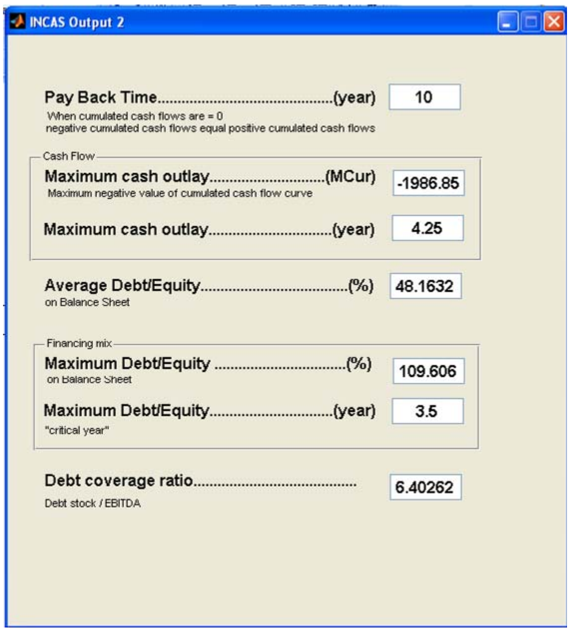


Fig.6: SMR, key financial indicators 2

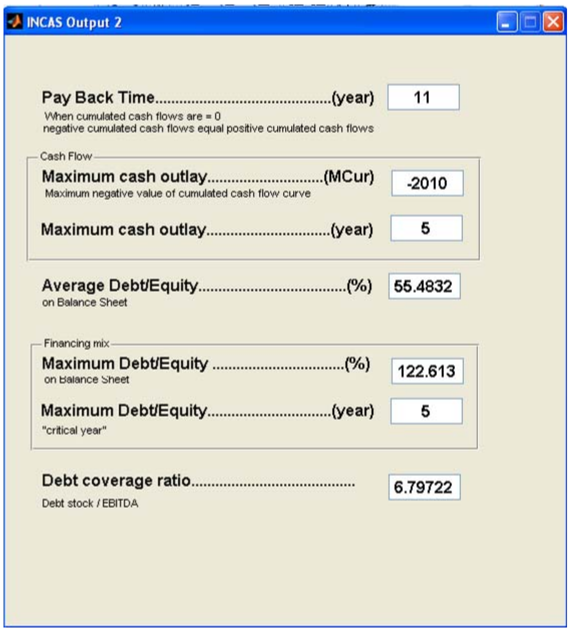


Fig.7: LR, key financial indicators 2

Levelized Cost Of Electricity (LCOE) is 67.2€/MWh with SMR and 70.6€/MWh with LR. Accordingly to the higher cost effectiveness of SMR, their investment profitability is slightly higher than LR: IRR is 15.75% for SMR and 14.97% for LR, but in the scale of uncertainty of input parameters, they may be considered as substantially equivalent. Shareholders' NPV of SMR is positive (106M€) on account of IRR higher than the cost of equity (that represents the actualization rate used in the NPV calculation). NPV is slightly negative for LR meaning that investment profitability is slightly lower than the 15% target equity remuneration rate (i.e. cost of equity).
Despite staggered construction, PBT of SMR investment project is 10 years, corresponding to the construction period of the 4 modules, whilst PBT is 11 years for LR, 6 years more than its 5 year construction period.

All the indicator of financial distress show a lower probability of financial default for SMR, with lower debt-to-equity ratios. Maximum cash outlay, that represent the maximum financial exposure, is lower for SMR as well: 1,987M€ against 2,010M€ for LR. Average Debt-to-Equity ratio calculated (during the debt duration) is only 48% for SMR and 55% for LR. Thither capital structure is correlated with higher risk of financial default, should some scenario conditions worsen the economic performance of the project.

Figure 9 shows a higher debt outstanding amount for LR that generates higher financial obligations. Debt duration is aligned with SMR construction period, while it extends much over 5 year construction period of LR.

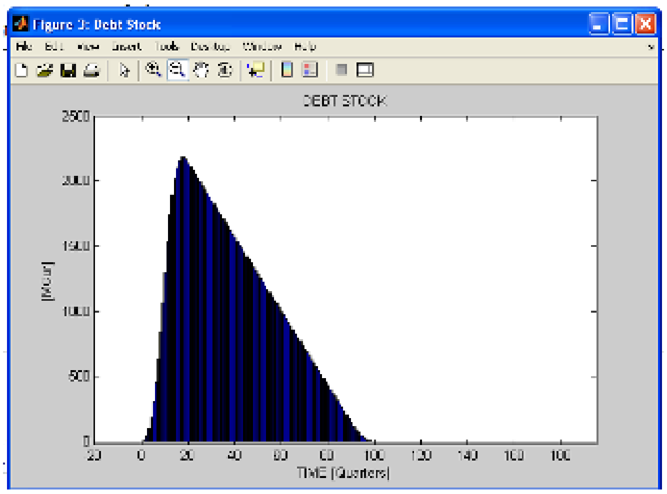


Fig.8: SMR - Financial Debt stock evolution

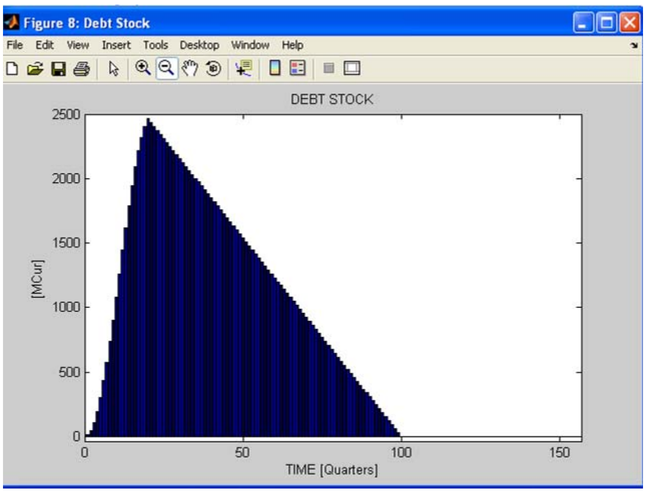


Fig.9: LR - Financial Debt stock evolution

We may conclude that the same power generation capacity may be built on a site through two alternative investment projects in one single LR or 4 SMR modules. Economic profitability of the two project is comparable, but the SMR modules prove to be a sounder financial option as far as capital structure and debt obligation are concerned.

COUNTRY SCENARIO

3 SCENARIO ASSUMPTIONS

Hereafter we report about a trial test of INCAS, applied to an "Italian Case Study" of NPP deployment. For the purpose of this analysis, we comply with the "Low Variant scenario" delivered by ENEA in the framework of the IAEA "Coordinated Case Studies on Competitiveness of SMR in Different Applications: Case Study Italy".

The scenario is characterized by a total installed capacity of 15 GWe, on a time horizon of 2014-2030.

The reactor technologies considered in this Case Study are the French EPR (1,600MWe) and the IRIS (335MWe): the nuclear fleet will result in 6 EPR stand-alone units and 4 IRIS sites composed by 4 IRIS modules per site.

Detailed scenario inputs are summarized in the following paragraphs.

Capital costs (overnight construction costs) are defined in a range of 2000-3,500€/kWe and cost of capital may reflect higher profitability rate requirements by shareholders and lenders (15% and 8% respectively) or may reflect lower investment risk to compensate (10% and 6% respectively).

As a consequence, a series of variants may be generated that depend on the combinations of maxima/minima.

Hereafter, we identify and analyse the two different sub-cases:

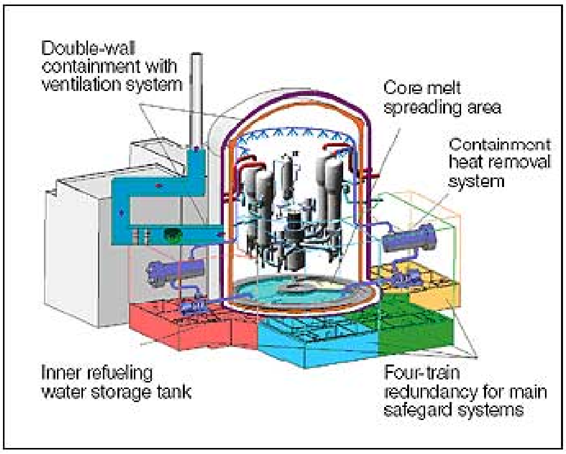
- ✓ Case "MAX", corresponding to the highest capital cost (3,500 €/kWe) and to the highest cost of capital (cost of equity=15%; cost of debt=8%; with 50% debt on total capital employed)
- ✓ Case "MIN", corresponding to the lowest capital cost (2,000 €/kWe) and to the lowest cost of capital (cost of equity=10%; cost of debt=6%; with 80% debt on total capital employed)

3.1 Reactor-specific inputs:

EPR is a Large Reactor concept which is already being built or planned in France in the next future (Flamanville and Penly) and is a candidate to an Italian scenario, due to the 2009 agreement between EdF and Enel.

IRIS (335 MWe) is an innovative PWR belonging to Small Medium Reactor class, which is under development by an international consortium led by Westinghouse, whit the participation of research institutions, university and national industry (ENEA, CIRTEN, Ansaldo Nucleare, Mangiarotti Spa), and expected to receive design certification from NRC by 2016.

EPR (European Pressurized Reactor) is a 1600 MWe PWR, developed by Areva. The concept derives from French N4 and German Konvoi reactors, with a 10% cost reduction objective. EPR is designed for a flexible operating mode (load following) and for achieving a fuel burnup of 60 MWd/kg (45-50 MWd/kgis is the current Gen II PWRs level). The estimated plant efficiency is 37%, due to an advanced turbo-generator which enables a gain of some 70 MWe capacity. The reactor core is designed to host either enriched UOX fuel (4.4% enriched) or MOX (Mixed-Oxide) plutonium bearing fuel up to 100% of the core loading. Targeted capacity factor in operations is 92% and plant lifetime is 60 yr.



TECHNICAL DATA	
Reactor thermal output:	4300 MW
Net electric output:	approx. 1600 MW
Main steam pressure:	78 bar
Main steam temperature:	290°C
Reactor pressure vessel height:	13 m
Reactor core height:	4.2 m
Number of fuel assemblies:	241
Uranium inventory in reactor:	128 t UO_2
Number of control rods:	89
Containment height:	63 m
Containment inside width:	49 m
Outer Containment wall thickness:	2 m

Fig.10: EPR reactor, scheme and technical data

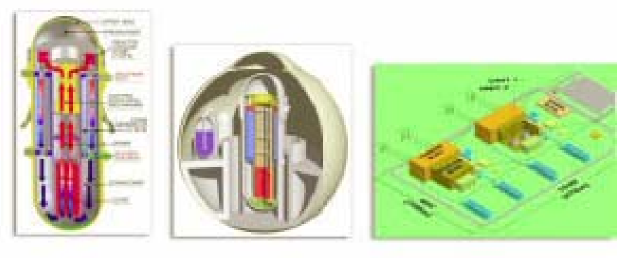
The EPR safety strategy relies on a quadruple redundancy concept of the active safety systems and on a double-wall reinforced concrete containment structure strongly improved: 1 meter thickness with internal steel liner. As a consequence the reactor presents:

- ✓ CDF (core damage frequency) level less than 10-5 events/reactor.yr
- ✓ reduced severe accident effects and confined within the reactor containment thanks also to the core catcher system aimed at collecting and cooling down the corium in case of core melting
- ✓ reduced volume of spent fuel (about 30% vol.) at equal energy output
- ✓ reduced dose to personnel and radioactive release (collective dose is 0.4 man.Sv against about 1 man.Sv for current western NPPs).

The quadruple redundancy safety concept (instead of double in current reactors) ensures for safe immediate reactor shutdown and core cooling, while keeping temperature and pressure in the containment system below the design limits. Adding to this is the reinforced protection of the sensitive buildings (reactor and control room) against possible external aggressions and large aircraft impact, the just cited core catcher (under the reactor vessel) devoted to collect and safely isolate corium in case core melting should occur. EPR design complies with European Utility Requirements (EUR), the stringent rules set up by european utilities under the franco-german initiative during the ‘90s. An American version (US-EPR) of the reactor has been submitted to US-NRC for certification in 2007.

IRIS (International Reactor Innovative and Secure) belongs to Gen III+ Near Term Deployment systems expected to be deployed in the next 10-15 years with a sort of forerunner role with respect to Gen IV systems. It is a modular Small Medium Size Reactor, PWR type, with a 335 MWe capacity under development by an international consortium of some 20 partners from 10 countries, led by Westinghouse. The reactor size is particularly suitable to be connected to small electric grids and to provide cogeneration of electricity, process/district heating and potable water. IRIS reactor concept is suitable to be deployed as in developing countries, as in developed countries in a multiple-module configuration on a single site.

Safety by Design is the inspiring concept for IRIS, made explicit through a simplified, compact system configuration where all primary loop components (steam generators, pumps, pressurizer, control rods) are housed within the reactor vessel.



TECHNICAL DATA	
Core thermal power	1000 MWt
Net electrical output	335 MWe
Main steam pressure	58 bar
Main steam temperature	317 °C
Reactor Pressure vessel height	21.3 m
Reactor core active height	4.27 m
Number of fuel assemblies	89
Fuel inventory	48.5 tU
Fissile Content (U-235)	4.95%
Core Lifetime (single batch)	4 years
Containment diameter	25 m (spherical)

Fig.11: IRIS reactor, scheme and technical data

This enables eliminate the majority of pipes and valves of the primary loop (possible source of major accident leading to loss of coolant) and drastically reduce or mitigate higher class accidents (88% of Class IV accidents is outright eliminated). This results in a CDF (Core Damage Frequency) as low as ~10-8, vs. 10-6-10-7 of Advanced PWRs, outages each 4 years with minor maintenances possible during operation, all leading to capacity factors higher than 90%. The absence of boron in the primary loop enables to avoid risk of stress corrosion fracture (see Davis Besse, 2002).

IRIS development program started in 1999 and foresees the design certification release by NRC in 2016. The modularity of IRIS makes good potential for a strong economic competitiveness trough possibility of staggered investment for deployment of a stated capacity, with respect to monolithic Large Reactors that would require huge upfront investment.

Tab.3: Reactor-specific key data input for country scenario simulation

Reactor type	*EPR*	*IRIS*
Power output (MWe)	1,600	335
Capacity factor (%)	90%	90%
O&M unit cost (€/MWh)	7.90	7.92
Fuel cycle unit cost (€/MWh)	6.65	6.67
Decommissioning unit cost (€/MWh)	1.06	0.88
Expected construction period for n^{th} unit	5 years	3 years
Plant operating life	60 years	60 years
Design saving factor on construction costs (%)	100%	80%
Cumulated capital expenditure profile	"S" curve	"S" curve

3.2 Country-specific inputs:

We assume no escalation rate for construction costs and consider a cash flow model based on real monetary values.

Electricity price is considered flat over the entire time horizon at 70€/MWh. Corporate tax rate is assumed to be 35%.

3.3 Investment-specific inputs:

As mentioned above, in this Case Study we explore two opposite investment scenarios.

The first (Case MAX) may represent the conditions of liberalized electricity and capital markets, with high cost of debt and high equity remuneration required to compensate for higher investment risk. In situations where risk perception is high, as for example in a country where nuclear investing has to be resumed after decades and operating capabilities have to be recovered, investment promoters must give strong commitment signals such as high equity stake in the project, to gain the confidence of lenders. Despite higher cost of debt as compared to scenario situations with lower risk perception, this kind of scenarios embrace lower, allowed debt-to-equity financing ratio; above a given threshold of debt-to-equity ratio in the financing mix the cost of debt would be so high as to debar the investment project. For this reason, the Case MAX financing mix would employ no more than 50% debt.

On the contrary, Case MIN may represent a "supported" business case, e.g. where public guarantee on financial debt may lower its interest rate to 6% and an effective risk-allocation scheme may allow investors to accept lower remuneration rate for their invested capital (10%). In this case a more efficient financing mix would include higher debt-to-equity ratio.

Tab.4: Investment-specific data input used in country scenario simulation

	Case MAX	*Case MIN*
Cost of equity	15%	10%
Cost of debt	8%	6%
Financing mix: D/(D+E)	50%	80%
Debt amortization period	10 years	10 years
Depreciation period for fixed assets	12.5 years	12.5 years
Escalation rate for capital costs	0%	0%
Overnight capital costs of EPR (€/kWe)	3,500	2,000
Overnight capital costs of IRIS (€/kWe)	Scaled from EPR and adjusted	Scaled from EPR and adjusted

This case study considers all the fleet of 6 EPR and 16 IRIS. INCAS calculates the capital cost for each NPP based on a reference cost for a stand-alone LWR of a given power output. For the purpose of this analysis, we therefore assume the first EPR of the fleet as the reference LWR and derive the cost of other NPP depending on the scale factor, on the learning effect in the construction of subsequent units of the same kind, on the fixed costs sharing by multiple units on a single site, on the modularization cost savings and on the design cost savings.

Depending on capital costs we consider two cases:

3.4 Construction schedule:

For EPR first units we assume a cautious construction time period of 7 years, that will drop down to 6 yrs for 3-rd unit and to 5 yrs from 4-th unit on.

Likewise we assume that first 4 units of IRIS reactor, ready for construction from 2020, will come online in 4 years, while from the 5-th unit on the construction time will be reduced to 3 years.

Given the above constraints, construction of first EPR unit is assumed to be started in 2014 in order it be connected to grid by 2020. Lifetime for all reactors is assumed to be 60 years, this meaning that operation time for the entire fleet will span from 2020 to 2090.

A NPP is assumed to host either 1 EPR unit (1600 MWe) or 2 twin-IRIS units (1340 MWe).

The total power accounts for 14.96 GWe consistent with the 1.0 % electricity growth rate and 25% electricity demand target at 2030, for a nuclear electricity output of 118 TWh.

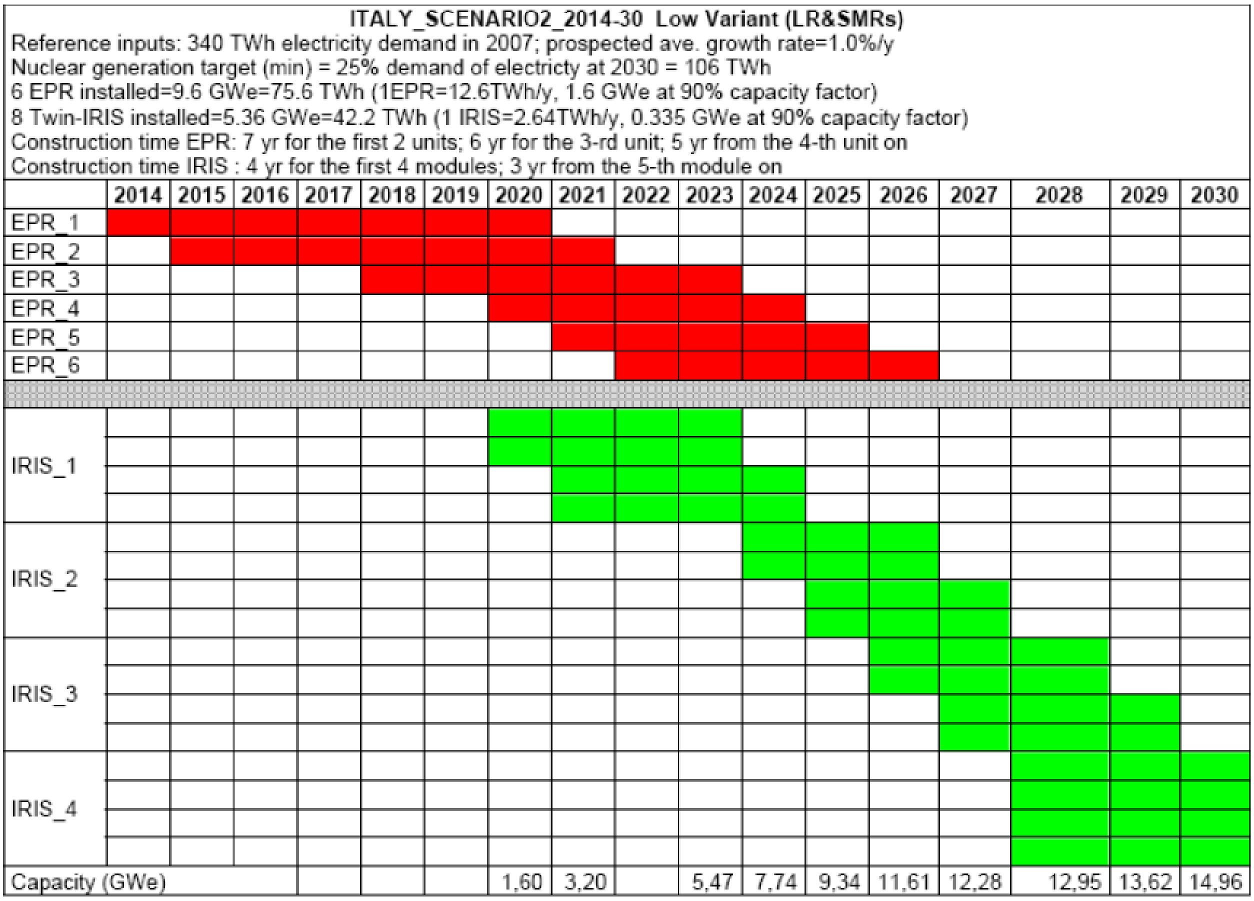


Fig.12: Construction schedule for EPR and IRIS

This construction schedule corresponds to Tab.5 as input table for INCAS.

We consider that no more than 2 EPR may be hosted on a single nuclear site in Italy; the IRIS NPP are distributed on 2 sites (8 units each).

Therefore 5 sites are needed: 3 for the 6 EPR (3,200MWe each) and 2 for the 16 IRIS (2,680MWe each).

We highlight that the construction of first 3 EPR has a delay as compared to the expected duration of construction for this kind of reactor-plant: 7 and 6 years against 5 years expected for a n-th of a kind.

The same happens for the first IRIS 4 units, with 1 year delay as compared to 3 years expected construction period for a n-th of a kind.

Tab.5: Construction schedule input to INCAS

#	REACTOR TYPE	SITE	START quarter	DURATION quarter
1	EPR1	1	1	28
2	EPR2	1	5	28
3	EPR3	2	17	24
4	EPR4	2	25	20
5	EPR5	3	29	20
6	EPR6	3	33	20
7	IRIS1	4	25	16
8	IRIS2	4	25	16
9	IRIS3	4	29	16
10	IRIS4	4	29	16
11	IRIS5	4	41	12
12	IRIS6	4	41	12
13	IRIS7	4	45	12
14	IRIS8	4	45	12
15	IRIS9	5	49	12
16	IRIS10	5	49	12
17	IRIS11	5	53	12
18	IRIS12	5	53	12
19	IRIS13	5	57	12
20	IRIS14	5	57	12
21	IRIS15	5	57	12
22	IRIS16	5	57	12

The location of each NPP on the national sites has a relevant impact on the economics of the whole investment project because learning and site-related fixed-costs sharing are cost-saving factors that depend on the number of units of the same kind that are built on the same site.

As a consequence, construction cost reduction applies as much as the number of NPP of the same type on the same site is high.

4 SIMULATION RESULTS

Hereafter we resume the key distinctive inputs for Case MIN and Case MAX of the ENEA's Italian "Low Variant" scenario and report related results.

Case MIN:

- ✓ capital cost=2000€/kWe for a reference 1000 LWR,
- ✓ 6% cost of debt,
- ✓ 10% cost of equity
- ✓ 80% debt on total capital employed.

Case MAX:

- ✓ capital cost=3000€/kWe for a reference 1000 LWR,
- ✓ 8% cost of debt,
- ✓ 15% cost of equity
- ✓ 50% debt on total capital employed.

The construction costs of the EPR and IRIS fleets give an interesting example on how "economy of multiples" may contribute to compensate dis-economy of scale.

Table 6 shows the unit overnight costs of each EPR and IRIS plant, in the Case MAX.

The cost of a reference, standard 1,600MWe LWR is assumed to be 3,500 €/kWe; due to the economy of scale, the cost of the first EPR (1,600MWe) would be lower than reference LWR (that's to say lower than 3500€/kWe), but delay in the construction period increase unit costs above 4000€/kWe for first 3 EPR units.

The same applies to first IRIS units 1-4, that bear a construction delay and dis-economy of scale as compared to EPR.

Learning accumulation on the construction activity allows to decrease construction costs for both multiple EPR and IRIS NPP.

Co-siting economies (fixed costs sharing) contribute to decrease capital costs for NPPs on the same site.

On account of site changes, construction costs present discontinuities (Fig.5): the first NPP on a new site bears all the fixed, site-related costs. Successive NPP on the same site will benefit of cost reduction from fixed costs sharing.

Tab.6: Unit construction cost for each NPP, Case MAX

	€/kWe
EPR1	4851
EPR2	4509
EPR3	4056
EPR4	3141
EPR5	3477
EPR6	3232
IRIS1	5241
IRIS2	4872
IRIS3	4749
IRIS4	4687
IRIS5	3265
IRIS6	3248
IRIS7	3116
IRIS8	3107
IRIS9	3835
IRIS10	3565
IRIS11	3187
IRIS12	3146
IRIS13	2993
IRIS14	2977
IRIS15	2966
IRIS16	2957

Overnight cost of EPR1 and EPR2 bear 2 year construction delay as compared to the expected construction period for the n^{th} EPR unit; the delay is 1 year for the 3rd EPR.

Construction costs decrease until EPR4 on account of learning accumulation. EPR 4 benefit from meeting its construction schedule (5 years) and from fixed costs sharing with EPR 3, on the same site.

EPR5 costs are higher than previous EPR4 due to a site change that prevents EPR5 from sharing site-related costs with previous NPP units and due to a stop in the learning accumulation: construction schedule shows that EPR5 and 6 are built before that 1/3 completion of previous NPP, which is a condition for INCAS to account for learning accumulation.

Construction costs of EPR 5 then benefit from a "worldwide" learning experience, built through the construction of 4 EPR units outside of the current site.

Construction of IRIS11 meets its 3 year schedule, thus decreasing significantly construction costs as compared to previous 4 units.

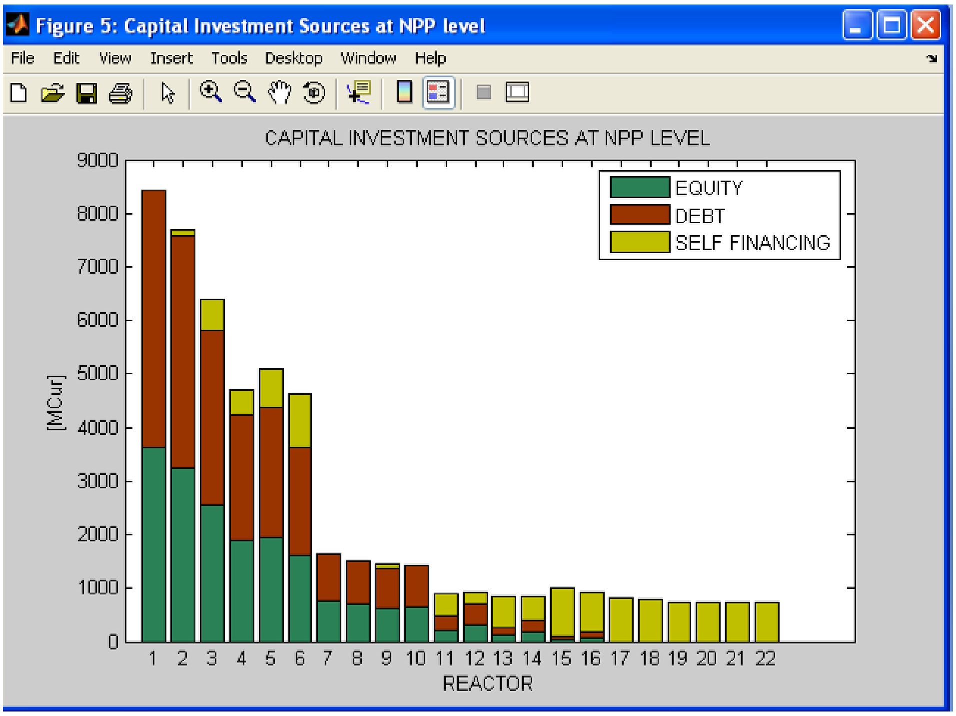


Fig.13: Capital Investment Sources at NPP level, Case MAX

IRIS15 shows a discontinuity due to a site change: this unit has to bear all the site-related fixed costs and is not able to benefit from any on-site learning accumulation. Successive IRIS unit from 16 to 22, will benefit from on-site learning effect and site-related fixed costs sharing, showing a constant, regular cost decrease.

INCAS results show that high capital costs and high cost of debt in the Case MAX account for higher LCOE as compared to Case MIN.

With an electricity price of 70 €/MWh NPV is negative in Case MAX, that means that the investment cannot reach 15% of remuneration rate for shareholders (IRR is actually 13.4%).

Either the electricity price must be higher than LCOE (i.e. higher than 80 €/MWh) to grant such a profitability, or the capital remuneration required must be lower than IRR to generate positive NPV.

4.1 LOW VARIANT – CASE MIN

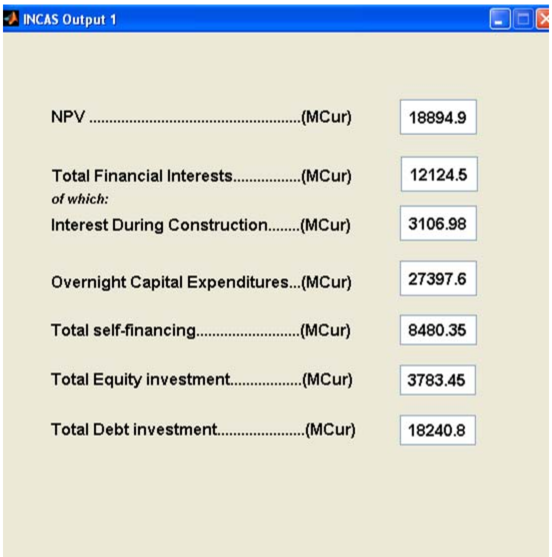


Fig.14: Key financial indicators 1

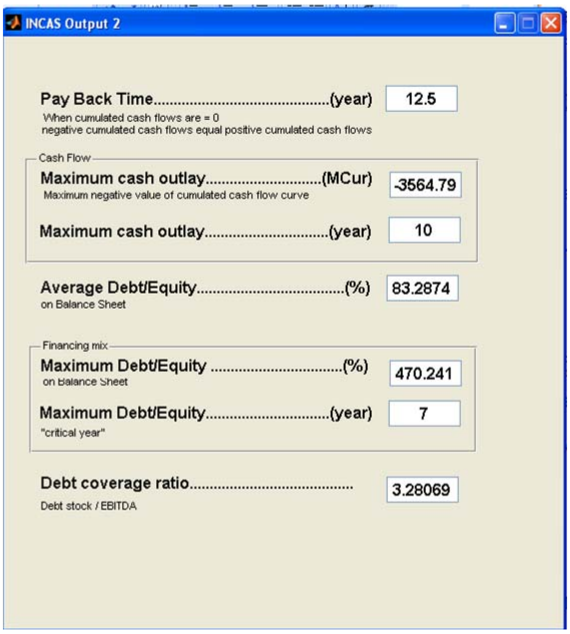


Fig.15: Key financial indicators 2

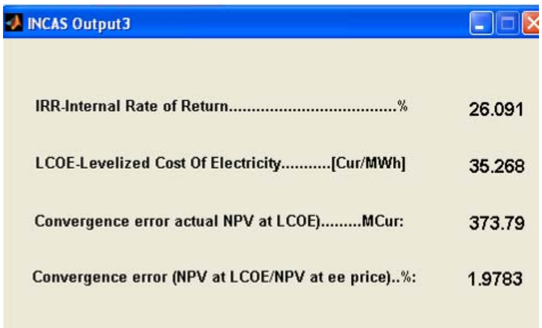


Fig.16: Key financial indicators 3

In 12 year and ½ the investment start generating positive net cash flows (Pay Back Time).

The investment remuneration in excess of the cost of equity capital (10%) is nearly 19€ billion, corresponding to a 26% IRR. The unit generating cost is 35€/MWh, very competitive with any other alternative power technology.

The total capital investment is 30.5€ billion (IDC+overnight cost); cash flow generated by the operation of early plants and re-invested in the project (self-financing) contributes to 28% of this value. Figures 2 and 5 show that self-financing contribution is relevant to the construction of later units (yellow bars).

In this case we have set the step for LCOE calculation at 10 Cur/MWe to sweep the tentative range.

This produces an error of nearly 2% in the LCOE calculation.

To obtain more refined estimation of LCOE, a thinner step should be set (i.e. 2 Cur/MWe).

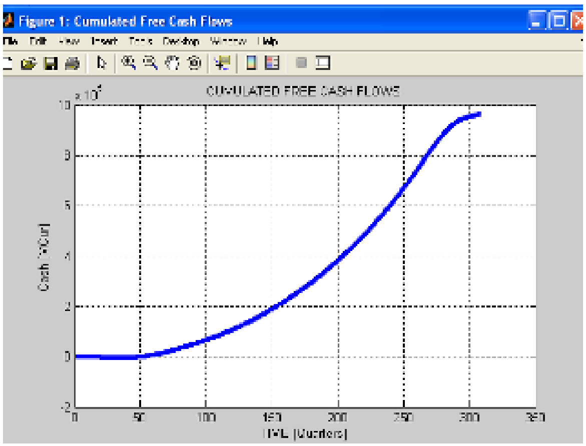


Fig.17: Cumulated free cash flows, Case MIN

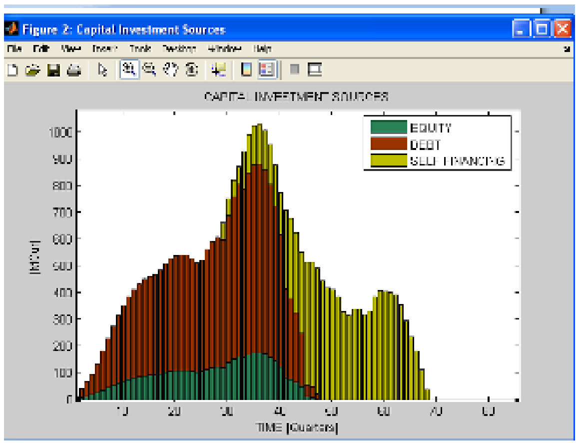


Fig.18: Capital investment sources, Case MIN

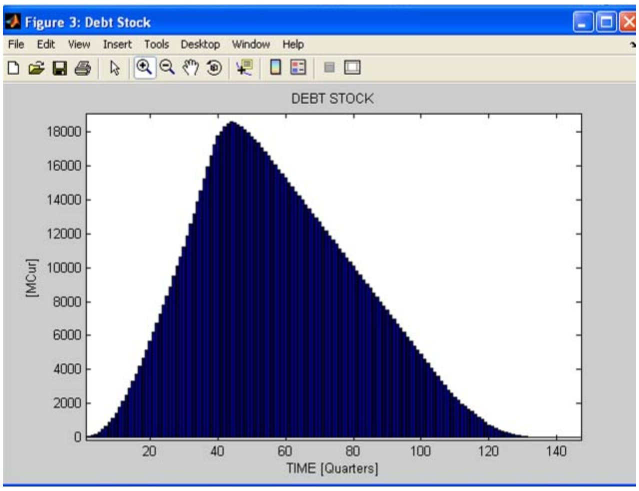


Fig.19: Cumulated free cash flows, Case MIN

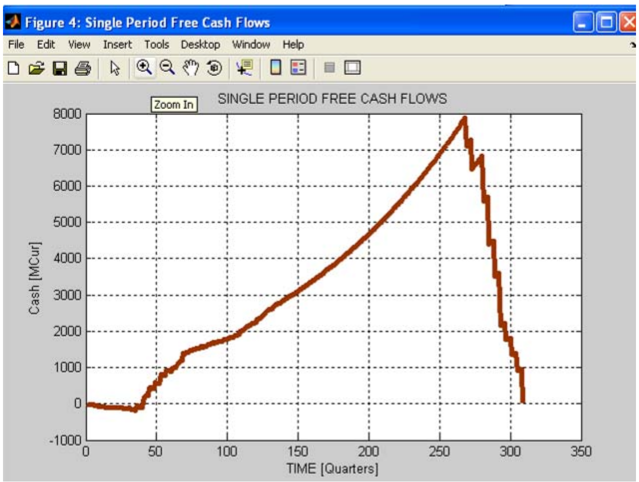


Fig.20: Capital investment sources, Case MIN

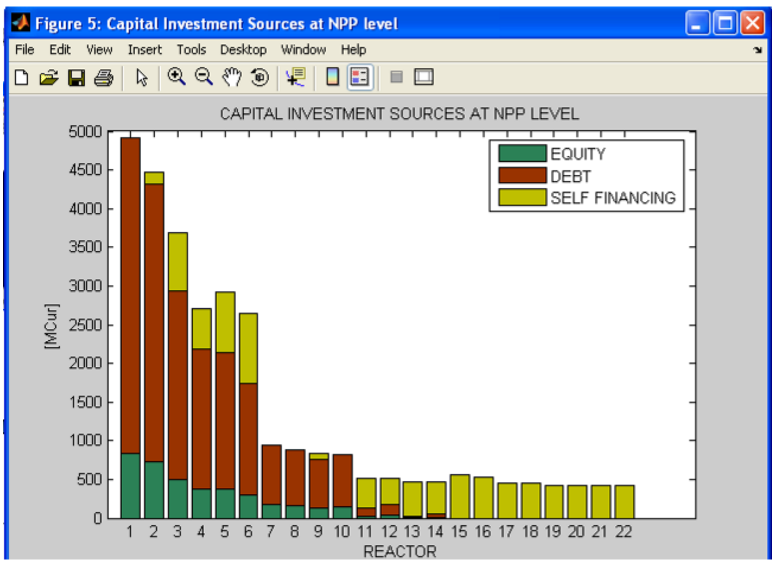


Fig.20: Capital investment sources at NPP level, Case MIN

Self-financing gives a significant contribution to the investment funding and is able to cover the capital costs of later IRIS NPP units.

4.2 LOW VARIANT – CASE MAX

NPV is negative: it means that the investment project cannot grant a remuneration of 15% (cost of Equity). Investment profitability, represented by the IRR, is actually 13.4%, lower than the cost of Equity. In this scenario the project starts repaying positive net cash flows after more than 17 years.

Fig.21: Key financial indicators 1

Fig.22: Key financial indicators 2

Total capital expenditure is much higher than Case MAX: 53€ billion, with self-financing contributing for 20%.

IDC are only 9% on total capital expenditures (22% in Case MIN) on the back of a lower debt-to-equity ratio in the financing mix.

The unit generating cost is around 80€/MWh, more than double as compared to Case MIN.

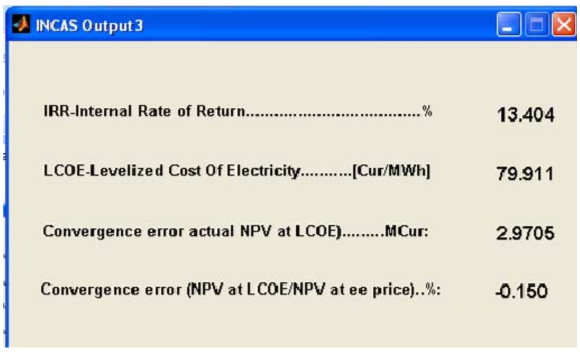


Fig.23: Key financial indicators 3

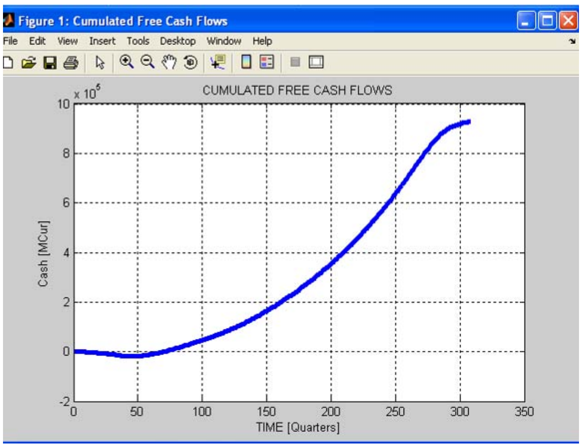


Fig.24: Cumulated Free Cash Flows, Case MAX

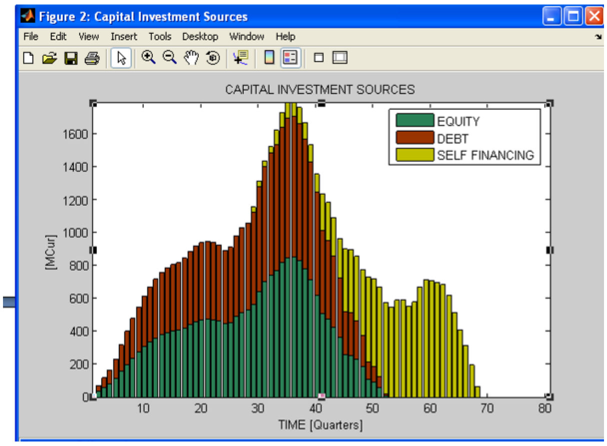


Fig.25: Capital investment sources, Case MAX

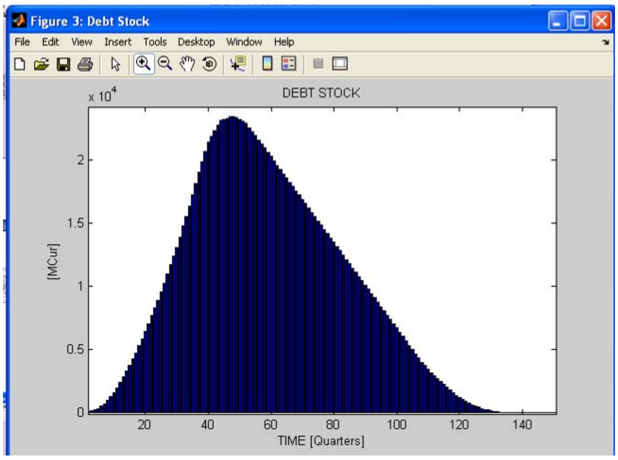


Fig.26: Debt stock, Case MAX

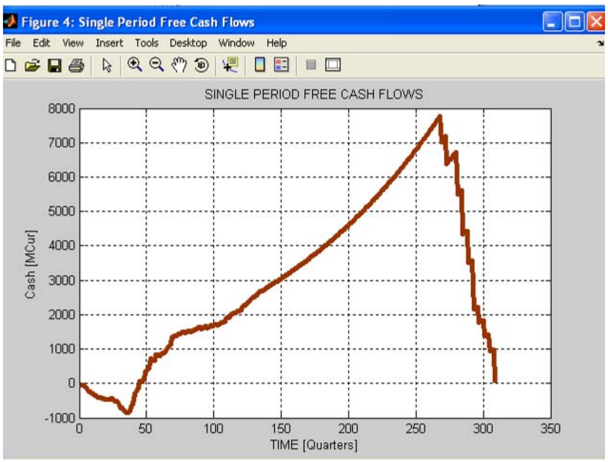


Fig.27: Single period free cash flows, Case MAX

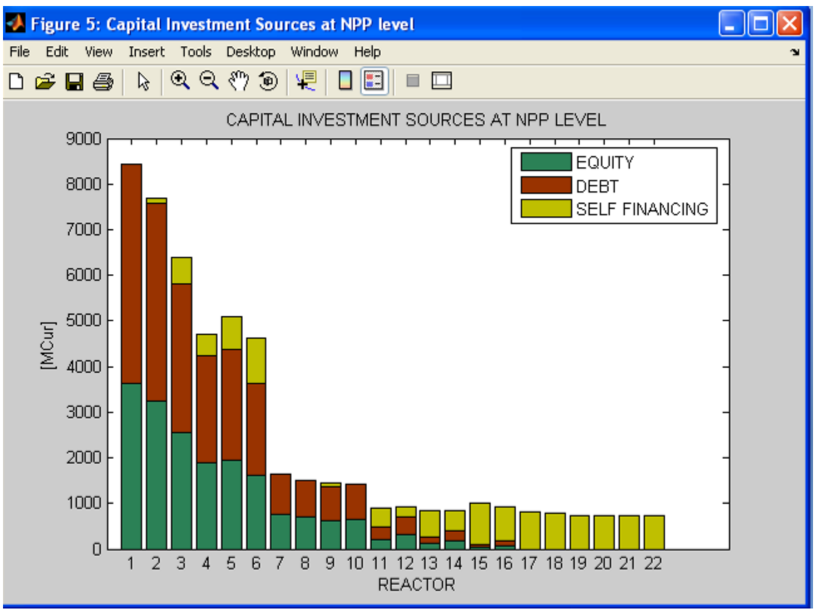


Fig.28: Capital investment sources at NPP level, Case MAX

5 CONCLUSIONS AND FURTHER DEVELOPMENTS

In this study we have simulated the deployment of a mixed, large and medium sized NPP fleet countrywide. We measured the economic performance of such investment project by mean of INCAS, a proprietary computer code developed by Polimi in 2009.

A preliminary analysis has been conducted on a single-site case study, where the economic performance of alternative investments in a single LR or 4 equivalent SMR in terms of power capacity. This analysis has shown the chance for SMR to recover on the loss of economy of scale that affects construction costs, granting the same cost-effectiveness and investment profitability as LR project.

In multiple NPP deployment, learning accumulation on the fabrication/assembling activities generates significant cost savings; site-related, fixed costs sharing and modularization cost savings in the fabrication phase further relieve construction costs.

In particular, this case study highlights a higher capability of SMR to manage the financial debt obligation, by limiting their escalation: shorter Pay Back Time account for lower debt capitalization during the construction phase, while LR is characterized by a tighter capital structure and exposure to financial default risk.

In the country-level case study, different scenario conditions are applied to appreciate the extent of their impact on the economic performance of the investment project.

The scenario conditions that characterize “Case MIN” have a strong benefit on the project profitability (IRR, NPV) and cost-effectiveness (LCOE). Should contractual agreement and public support allow an effective risk-allocation scheme, investors might set a lower target remuneration for their invested capital. Along with this condition, if costs of construction meet the lower bound forecast, a disruptive benefit may be recorded on the project economics: LCOE in Case MIN is only 35€/MWh LCOE and the economic competitiveness of nuclear technology as compared to alternative technologies becomes unquestionable.

Another benefit of a modular investment in multiple NPP is the “self-financing” contribution to the total capital investment cost: the cash flow generated by the operation of early units is invested in the construction financing of later NPP modules. This contribution is more relevant, the more staggered is the construction of the NPP fleet and the more fractioned is the power output of the single independent NPP unit.

This means that the presence of SMR in the NPP fleet to be deployed countrywide introduces a higher degree of “modularity” in the investment project. This grants lower financial distress on the key capital structure indicators and lower up-front investment requirement on account of the self-financing contribution; overall investment PBT is shortened and project profitability is not undermined by the loss of economy of scale in the construction costs.

The sensitivity analysis of results may give a first understanding of the impact of input uncertainty on the model results, but a real stochastic approach supporting a Montecarlo simulation may give information on the statistics of output parameters and therefore on the project financial risk. Further development of Polimi’s research include the introduction of parameters’ uncertainty and the analysis of variances in the INCAs code.