Proceedings of the ASME 2011 Small Modular Reactors Symposium
SMR2011
September 28-30, 2011, Washington, DC, USA

SMR2011-6591

ARE SMR A REASONABLE CHOICE FOR SWITZERLAND?

AN APPLICATION OF THE INCAS MODEL

Eng. Sara Boarin
Politecnico di Milano
Energy Department
Milan, Italy
saraboarin@gmail.com

Eng. Giorgio Locatelli Ph.D.
Department of Management, Economics &
Industrial Engineering
Milan, Italy
giorgio.locatelli@polim.it

Prof. Mauro Mancini Ph.D.
Department of Management, Economics &
Industrial Engineering
Milan, Italy
Mauro.mancini@polimi.it

Prof.Marco E. Ricotti Ph.D.
Politecnico di Milano
Energy Department
Milan, Italy
Marco.ricotti@polimi.it

ABSTRACT

Small countries can represent a suitable market for Small Medium Reactors (SMR). Among them Switzerland is one the more interesting since already hosts five commercial nuclear reactors; three of them are SMR (about 370 MWe) and two are large units (985 and 1165 MWe). Since the oldest units are about 40 year- old the Swiss utilities wereplanning to replace them while adding new nuclear power capacity to the portfolio mix. . Most recently, a radical re-thinking of the country energy policy is taking place as a Fukushima accident's aftermath. Debate is about abandoning nuclear power and replacing it with renewable new capacity and import.

"Economiesuisse, the umbrella organisation for Swiss business, considers a premature abandonment of atomic energy <irresponsible>. Without valid alternatives, Economiesuisse warns, abandoning the nuclear option will have serious consequences for Swiss industry". Also "the environmental organisationsrecognise that the discussion on energy policy – which will really heat up with the parliamentary debate in June – is not solely an ideological one. Financial and economic considerations are likely to make all the difference" (L.Jorio, "What price a future without nuclear energy?",www.swissinfo.ch, May 17, 2011).An objective and unbiased estimation of the cost of new nuclear power is essential to Policy Makers and a focus on SMR economic potential is a further contribution to the debate. SMR advanced passive safety features may cope with public concerns about safety, which has become a priority. Polimi's INCAS model has been developed to compare the investment in SMR respect to LR and is able to assess the financial/economic indicators arising from these two alternative investment options. In particular the INCAS model provides the value of IRR (Internal Rate of Return), NPV (Net Present Value), Upfront investment, etc. A stochastic approach to the data elaboration and the implementation of a Montecarlo analysis provide the evaluation of the investment risk profile.

Results show that investment returns are comparable for LR and SMR; however SMR require a lower upfront investment, thus representing lower sunk costs and more affordable and scalable investment option than monolithic LR.

INTRODUCTION: NUCLEAR POWER IN SWITZERLAND

1.1 Switzerland and Nuclear Power in Switzerland

Switzerland has an Area of 41,285 sq km and e Population 7,807,000abitants . The Capitals are Bern (administrative), Lausanne (judicial) Switzerland is divided into three regions: the meadow-covered Jura Mountains; the central Mittelland, a rich agricultural and urbanized area; and the lofty crags of the

Alps. It is one of the world's major financial centres; its economy is based largely on international trade and banking, as well as light and heavy industries. It is a federal state with two legislative houses; its head of state and government is the president of the Federal Council. [1]. Electricity consumption in Switzerland has been growing at about 2% per year since 1980. In 2007 electricity production was 68 billion kWh gross, mostly from nuclear and hydro, requiring 2.5 TWh net import to match demand – less than previous years. A lot of electricity is imported from France and Germany and up to 26 TWh/yr exported to Italy. Per capita consumption is 7650 kWh/yr. In 2007 nuclear power contributed 26.5 TWh net, 43% of Swiss demand.

Switzerland's electricity supply is secured by approximately 850 companies. Many of the electricity works in towns and cities are also responsible for supplying water and gas. In some cantons and towns, a single vertically integrated company is responsible for the entire supply chain, while in other cantons a variety of companies share this responsibility. Approximately 80 percent of the electricity supply company capital totaling around 5.6 billion Swiss francs is held by the public sector, while the remaining 20 percent is held by private companies (in Switzerland and abroad).Approximately 83 percent of the electricity supply company capital totaling around 5.2 billion Swiss francs is held by the public sector, while the remaining 17 percent is held by private companies (in Switzerland and abroad).

In 2009, end-user electricity consumption totaled 57.5 billion kWh, and domestic producers generated a total of 66.5 billion kWh. Cross-border electricity trading is of major significance for Switzerland, both economically and in terms of supply security. In 2009, 52.0 billion kWh were imported and 54.2 billion kWh were exported. The electricity trading balance for 2009 was around 1.5 billion Swiss francs.

Private households, industry and the services sector each account for one-third of Switzerland's electricity consumption. The proportion of electricity to overall energy demand is approximately 23 percent. [2]

Hydropower plants account for around 55 percent of domestic production, followed by nuclear power plants (40 percent) and conventional thermal energy / renewable energy plants (approximately 5 percent).

Switzerland has 5 nuclear reactors. Two large new units are planned. [3]

Reactors	Operator	Type	Net MWe	First power	Expected closure (approx)
Beznau 1	NOK	PWR	365	1969	2019
Beznau 2	NOK	PWR	365	1971	2021
Gösgen	KKG/Alpiq	PWR	985	1979	2029
Mühleberg	BKW	BWR	372	1971	2022
Leibstadt	NOK/Alpiq	BWR	1165	1984	2034

Table1Swiss NPP

1.2 Scenarios in the pre- Fukushima events

Replacement of the nuclear units was part of an energy policy announced by the country's government in 2007 to avoid predicted energy shortfalls by 2020 as reactors close and an electricity import agreement with France is phased out. Switzerland's other operating nuclear power plant, the 1165 MWe Leibstadt BWR, is not scheduled for closure until 2034. [4]

In late 2007 three Swiss energy companies have announced a joint venture called Resun with the purpose of replacing the Beznau and Muhleberg nuclear power plants in 2020. Resunwas formed by NordostschweizerischeKraftwerk (NOK, owned by Axpo Group), CentralschweizerischeKraftwerk (CFC) and BKM FMB Energie. Those companies own 57.75%, 11% and 31.25% respectively of the new company, to be based in Aarau, but reserve the right to allow new members to join. In a statement, the companies said that Resun would submit paperwork at the end of 2008 towards permits to build nuclear power units of up to 1600 MWe at the Muhleberg and Beznau sites. Axpo and BKW said that they are convinced the Swiss population would support nuclear power alongside renewables and energy conservation in upcoming referendums on energy policy. [5]

In 2008 Switzerland's President, Pascal Couchepin, said, "The issue of energy poses a huge challenge to our country. Nuclear power is not the only solution, but it is an important part of the solution." He said: "We must now conduct a rational public debate with all stakeholders." Bruno Pellaud, chairman of the Swiss Nuclear Forum expressed confidence that the Swiss people are aware of the advantages of nuclear energy for the security of energy supplies and the preservation of the environment and climate. [6]

In late 2008 Axpo Group and BKW FMB Energy have filed framework permit applications to build **two identical latest-generation power plants should, up to 1600 MWe, and that only one manufacturer of a globally recognized technology should be considered**. Furthermore, the companies say, the plants will use modern hybrid cooling towers that does not affect river water temperatures and are less visually obtrusive than conventional towers. At Niederamt, adjacent to but independent of the existing Gösgen nuclear power plant, the application was filed by Atel in June, meaning that applications for three new plants was under review. [7]

In November 2010 the permit application process three new nuclear plants in Switzerland has taken a step forward with an in-principle decision from the federal safety regulator that the Niederamt, Beznau and Müheleberg sites are suitable for the purpose. The utilities are working to address the requirements and recommendations brought up in ENSI's extensive reports on their applications. All three applications are for 1100 to 1600 MWe advanced reactors of as-yet unspecified design using hybrid cooling systems to minimize water consumption. [4]

In late 2010 Axpo and BKW have been joined by Alpiq to "join forces in further pursuing the planning and construction of two new nuclear power stations." This will replace old reactors and "compensate for long-term import agreements with France

which are due to expire." The concept of building new reactors at all three sites was approved by the Swiss Federal Nuclear Safety Inspectorate (ENSI) in November. [8]
In early 2011 Residents of the Swiss canton of Bern have expressed their support for the construction of a new nuclear power plant at Mühleberg in a local referendum, but Nidwalden residents registered their opposition to a nuclear waste repository [9]

1.3 Post – Fukushima event

March 11 - Fukushima I nuclear accidents (further information in [10])
March 15 - Doris Leuthard, the Swiss energy minister, said Switzerland would suspend plans to build and replace nuclear plants. She said no new ones would be permitted until experts had reviewed safety standards and reported back. Their conclusions will apply to existing plants as well as planned sites. [11]
April 11 – The President Micheline Calmy-Rey said "We are examining several scenarios, including exit scenarios". [12]
April 24 - Switzerland's economy minister said on Sunday it would be decades before the country could give up nuclear power completely but that in the meantime no new nuclear power plants should be built. [13]
Late April - The obligatory insurance is being raised from 1 to 1.8 billion Swiss francs ($2 billion), but a government agency estimates that a Chernobyl-style disaster might cost more than 4 trillion francs -- or about eight times the country's annual economic output. [14]
Early May - Operators of Swiss nuclear power plants will have to improve instrumentation as well as earthquake and flooding resistance after a safety review. The changes may be made during operation, said the safety authority, as there is no immediate danger. Plant operators now have until 31 August to submit details of the measures they propose to take to address these issues. [15]

On the basis of the previous information it is possible to summarize the Swiss scenario in the following bullet points:

- Nuclear Energy have a primary role in the Electricity production in Switzerland
- Before the Fukushima event the government, utilities and population supported the nuclear energy and the replacement of aging NPP with new Large Reactor.
- The plan was to replicate the same large design concepts for 3 reactors in 3 sites
- The Fukushima accident dramatically changed the prospective and, because of safety concerns, set a radical re-thinking of the country’s energy strategy.

Since safety and economics confirm as the major concerns in the public debate, SMR may represent a viable option even to new GEN-III large plants: small size allows for enhanced design robustness and intrinsic safety than LR . The contribution of this paper is about the economic competitiveness of an SMR option against planned LR, which is not evident due to a relevant loss of economy of scale in capital costs..Finally, the issue investigated in this paper is:
From the economic and financial point of view are the SMR viable and competitive with LR in the Swiss scenario?

THE INCAS MODEL

Polimi’s nuclear economics research group is developing the INCAS model as the founding theoric and simulation framework able to quantify the most meaningful financial, economical and strategic indicators of .
INCAS (INtegrated model for the Competitiveness Assessment of SMR) is a unique model able to account for “economy of multiples” benefits that characterize SMR investment paradigm.
For the purpose of this analysis , INCAS consider a given total power generation capacity, installed either through multiple SMR or single/few LR. A comparative methodology to evaluate the differential economic and financial advantages/disadvantages, offered by the two different plant configurations and technologies, is adopted. The so called “Investment Model” brings up all the main elements of an economic and financial analysis (revenues, operating and capital costs, financial costs) and relies upon a cash flow analysis over the plant lifetime. The output of the Investment Model is a set of indexes measuring the financial performances of the investment from the investor point of view: profitability for a private investor or economic soundness for a public stakeholder. The previous monetary factors must be merged with other strategic factors generally much more difficult to be translated in economic performance (e.g. social acceptability) but highly influencing the profitability of the investment. This factors have been analysed in the external factors model of INCAS, aiming to assess the project attractiveness for a private investor or for a public body (at governmental, ministry, public administration level) once that the decision to invest in NPP has been taken.
This paper deals only with the investment model.

The “Investment Model” is based on a Discounted Cash Flow model and provides the indicators of the investment’s financial performances (e.g. IRR, NPV, cash flow profile). It includes the following modules:

- Generation costs (construction costs and operating costs, operation & maintenance, fuel cycle and decontamination & decommissioning);
- Revenues (plant’s availability factor, electricity sale price);
- Financial (sources of financing, cost of capital, debt amortization period).

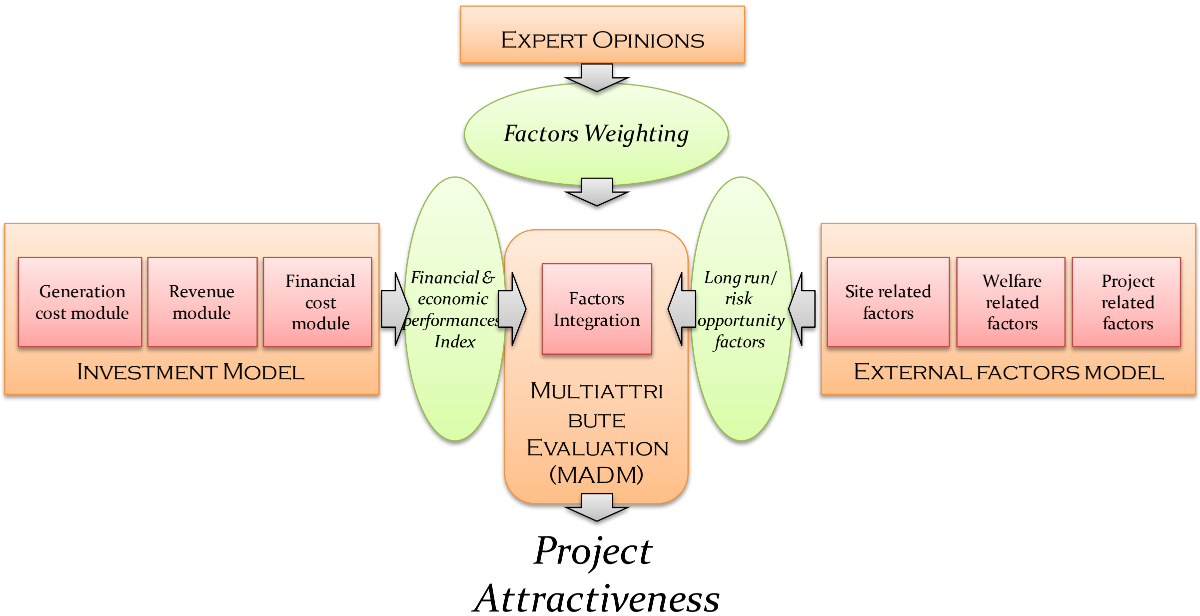

Figure 1The INCAS model

Unlike other simulation codes, INCAS' Generation costs model is not a mere input section of the code: an original calculation routine allows to derive the construction costs of each successive NPP unit on the basis of its output size, design technology and learning accumulation. INCAS' premise is that the cost of "n" NPP units is not equal to "n" times the cost of one NPP. Starting from a reference construction cost for a given design technology and a given reactor size, INCAS is able to calculate the construction cost for each of the successive NPP units of the same design technology, through a top-down estimation approach and on the basis of a given construction strategy in terms of schedule and site location. In particular the code takes into account:

- economies of scale;
- co-siting economies, due to fixed costs sharing by NPP built and operated on the same site;
- construction cost savings, due to modularization effects, that are size-dependent;
- learning economies, both at single site level and worldwide, with two different learning accumulation and decay laws;
- effect of delay in the construction period;
- cost of financing during construction period.

THE DESIGN ROBUSTNESS OF SMR

A high level of safety is the result of a complex interaction between good design, operational safety and human performances, but design features are able to impact on all of these three dimensions. Design robustness encompasses three key strategic performance areas: reactor safety, radiation safety (public and occupational) and safeguards, according to Reactor Oversight Process (ROP) of NRC [16]. From these key areas, we define Design Robustness the reactor's capability to assure the core's integrity, the protection and the integrity of all the other components of the nuclear island, in order to guarantee the radiation safety of personnel, population and environment in every condition. It's possible to evaluate the size effecton design robustness considering the three areas separately.
A complete picture of SMR design and implication on the safety features is provided by [17].
Reactor safety considers accidents leading to significant, unmitigated releases from containment. Core Damage Frequency (CDF) and Large Early Release Frequency (LERF) are the most important indicators for this dimension. Lower plant size allows for higher degree of passive safety features and design simplification as respect to LR. Such enhancements drive to the elimination of several classical event initiators and guarantee higher efficiency of mitigating systems. As an example, advanced SMR have integrated primary circuit in the reactor vessel with the absence of large penetrations and pipes in and out the reactor vessel: this eliminates the LOCA accident type. With internal CRDM there's no ejection driving force. Large water inventory in reactor pressure vessel above the core permits passive core cooling through natural water convection.

As a result, safety-by-design approach of Westinghouse's IRIS permits a reduction of CDF from 5.1x10-7 of a GENIII+ AP1000 to 10-8 [18]. IRIS LERF is around five orders of magnitude less than large PWRs and the other GEN III+ SMR designs have a three orders lower one [19]. Occupational Radiation Safety refers to operators' overexposure risk. Plant workers can be exposed to a high-level radiation during the maintenance of reactor coolant pumps, pressurizers, water chambers of steam generators and during refueling. Operators exposure is then related to planned outages frequency for refueling and maintenance. SMR core is designed for extended life-cycle, reducing the frequency of operators activity in the nuclear island.

IRIS had been designed to extend the need for scheduled outages to at least 48 months [18]. On the other side, outages are planned for each of multiple SMR units, considering the same installed power as LR.

Total exposure depends on overall number and duration of outages, on single outage exposure for operator and on number of operators involved in activities. If utilities follow best common practices during outages, occupational exposure will not penalize SMRs. Public Radiation Safety considers collective radiation exposure to liquid and gaseous effluents from routine nuclear reactor operations. Each SMR has lower source term as compared to a LR. This is not true when we consider multiple the same total output at site level. On account of the higher safety performances estimated, studies have been done about the opportunity for the Regulator to reduce IRIS' EPZ to the boundaries of the plant. Safeguards refer to physical protection of the facility and proliferation resistance. Charlton [20] produces a report that can be considered the most relevant for this theme, synthesizing the parameter in a likelihood scale from 0 to 1, where the highest is the value, the highest is the proliferation risk. For a typical PWR LR of GEN III this value is 0.07, while for a SMR case with a batch loading of the fuel the parameter becomes 0.06.

Moreover, portion of SMRs' containment can be located under the ground, as for IRIS, mPower, etc.: the cost would be prohibitive for LRs. This potential low SMRs' profile makes them an extremely difficult target for aircraft flying terrorists.

Design robustness is strictly design-specific but simplification, standardization and compactness of SMRs permit to obtain certain improvement on reactor safety and physical protection.

COST OF NUCLEAR POWER IN SWITZERLAND: scenarios definition

The most recent studies about the economics of nuclear power in Switzerland are summarized in Table 2and Table 6. However value in Table 2 are 5-year older than in Table 6, therefore the following analysis is based on the most recent values of Table 6. Exchange rates are [21]:

CHF/Euro 1.3
CHF/USD 0.896
USD/EUR 1.4

Considering the economics of NPP the main drivers are:

- Size, because of the Economy of scale application. Otherwise, INCAS assumes that the lower the size, the higher is the plant modularization and related construction cost savings.
- Construction strategy in terms of : site co-location of units, deployment time-schedule.

These factors determine the degree of learning, co-siting economies and interest capitalization over the construction period. Other country-specific input being equal (e.g. financial costs, EE price etc..) four different plant sizes are considered (1,565MWe, 1,200MWe, 300MWe and 150MWe) and 2 different amount of total power installed.

Table 4presents the siting configuration considering a total power of about 4700 MWe on three sites.

Table 5 considers a more conservative scenario of about 3100 MW on two sites.

In both the scenarios one site can host either a Large stand stand-alone reactor or a number of SMR with equivalent power.

Size	MWe	1600	
Life	Year	60	
Interest Rate	%	5	8
Construction cost included IDC	Milion of CHF	3.7	4.2
Specific construction cost	Cent CHF /KWe	2400	2600
Capital cost	Cent CHF /KWe	2.0	2.7
O&M	Cent CHF /KWe	0.8	1.0
Fuel	Cent CHF /KWe	1.3	1.5
LCOE Total	Cent CHF /KWe	4.1	5.2

Table 2 Costs according to [22]

Cost Of Equity [Ke, %]	10%
Financing Mix [E/(E+D), %]	20%
Debt Amortization Period [Y]	15
Cost Of Debt [Kd, %]	5%
Escalation Constr. Costs [%/Y]	2%
Inflation [%/Y]	1.50%
EE Price [CHF Per Mwh]	80
EE Increase [%/Y]	1.5%
Depreciation Fixed Assets [Y]	12.5
Tax Rate [%]	25%
Risk Free Rate	2.5%

Table 3Financial parameters.[23]for general value,[24] for inflation and [25] for EE price

	site 1	site 2	site 3	Total
1565	1565	1565	1565	4695
num. of NPP	1	1	1	3
1200	2400	1200	1200	4800
num. of NPP	2	1	1	4
300	1800	1800	1200	4800
num. of NPP	6	6	4	16
150	1800	1500	1500	4800
num. of NPP	12	10	10	32

Table 4Siting scenario 1 (3 LR)

	site 1	site 2	site 3	total
1565	1565	1565	0	3130
num. of NPP	1	1	0	2
1050	2100	1050	0	3150
num. of NPP	2	1	0	3
300	1800	1200	0	3000
num. of NPP	6	4	0	10
150	1650	1500	0	3150
num. of NPP	11	10	0	21

Table 5Siting scenario 2 (2 LR)

Country	Net Capacity [MWe]	Overnight Cost [USD/kWe]	Decommissioning cost [USD/MWh]		Fuel Cycle costs Decommissioning cost [USD/MWh]	O&M costs [USD/MWh]	LCOE [USD/MWh]	
			5%	10%			5%	10%
Switzerland	1600	5863	0.29	0.03	9.33	19.84	78.24	136.50
	1530	4043	0.16	0.01	9.33	15.40	57.83	96.74

Table 6 Costs according to [26]

REACTOR-SPECIFIC INPUT					
	V.LARGE	LARGE	LARGE	MEDIUM	SMALL
Power [MWe]	1565	1200	1050	300	150
Availability [%]	90%	93%	93%	95%	95%
O&M [CHF/MWh]	15.727612	15.7	15.7	18.9	18.87313
Fuel[CHF/MWh]	8.327958	8.327958	8.327958	8.327958	8.327958
D&D [CHF/MWh]	0.200835	0.20	0.20	0.40	0.4
Construction time [Year]	6	5	5	3	3
Plantlifetime [Year]	60	60	60	60	60
Overnightcost[CHF/KWe]	4421	INCAS	INCAS	INCAS	INCAS
DESIGN SAVING FACTOR	100%	100%	100%	90%	88%
MODULARIZATION SAVING FACTOR	100%	100%	100%	85%	73.72%

Table 7Main assumptions for the model

RESULTS

The main results of this analysis are summarized in Table 8 and Table 9by key economic and financial indicators.
From these tables it is possible to point out:

- capital remuneration (IRR) for an investment in new nuclear capacity is in the range of 12%-14%.
- Profitability of SMR is only slightly lower than LR: the gap is about 0.5-0.7%. This is reflected in 3-3.6€/MWh higher LUEC.
- When 1565MWe NPP are considered stronger cost efficiency emerges as the result of EOS: LUEC is 7-7.6€/MWh higher for SMR.
- When 6-year construction schedule is assumed for 1565MWh plant, which seems more realistic than vendor 5-year estimation, this gap is reduced to 6-6.5€/MWh, but is still relevant
- The IRR value is higher for 150 MWe than 300 MWe. The economy of replication (learning and site sharing) partially compensate the EOS; design modularization and simplification definitely fill the gap.

The case of two sites determines worsen performance in LR and SMR due to reduced economy of replication.In countries with very scarce resource, multiple SMR may deployedon a longer timeframe. While allowing gradual new capacity increase to the grid,first units can finance the construction of the later deployed NPP, reducing and diluting the upfront investment.. However, in the Swiss scenario due to higher O&M and fuel costs as compared to the OCSE average and due to conservative assumptions on construction costs, self-financing is almost negligible (not more than 5%). Nevertheless IDC are much lower for SMR due to better control over interest capitalization. TCIC is the sum of overnight construction costs and IDC: thanks to lower IDC, it has to be remarked that 300MWe plants program and "Large Reactors" (i.e. 1200MWe or 1050MWe) have the same TCIC. On the contrary, 150MWe's TCIC is 22-28% higher than 1565MWe, even if TCIC is only 17-23% higher than 1565MWe, due to small plants' lower IDC.

Figure 2 and Figure 3show self-financing capability of the SMR projects on later deployed units.

	V.LARGE	V.LARGE	LARGE	MEDIUM	SMALL
SIZE [MWe]	1565	1565	1200	300	150
financing mix	20%	20%	20%	20%	20%
constr. Duration	5y	6y	5y	3y	3y
IRR	**14.37%**	**13.98%**	**13.02%**	**12.34%**	**12.53%**
LUEC[CHF/MWh]	**63.329**	**64.418**	**67.31**	**70.92**	**70.29**
OVERNIGHT [Milion of CHF]	19626	19675	22882	24287	23916
IDC [Milion of CHF]	1881	2328	2198	1356	1331
TCIC [Milion of CHF]	21507	22003	25080	25643	25247
SELF-FIN [Milion of CHF]	1069	932	1035	234	281
EQUITY[Milion of CHF]	3711	3749	4369	4811	4727
DEBT [Milion of CHF]	16726	17323	19675	20599	20238

Table 8Results scenario 1 – Power Installed equivalent to 3 Large Reactors

	V.LARGE	V.LARGE	LARGE	MEDIUM	SMALL
SIZE [MWe]	1565	1565	1050	300	150
constr. Duration	5y	6y	5y	3y	3y
IRR	**14.72%**	**14.13%**	**12.54%**	**12.04%**	**11.82%**
LUEC[CHF/MWh]	**63.183**	**64.29**	**69.514**	**72.057**	**72.74**
OVERNIGHT[Milion of CHF]	13045	13078	15594	15674	16689
IDC[Milion of CHF]	1271	1566	1540	879	935
TCIC[Milion of CHF]	14316	14644	17133	16553	17624
SELF-FIN[Milion of CHF]	321	270	80	14	81
EQUITY[Milion of CHF]	2545	2562	3103	3132	3321
DEBT[Milion of CHF]	11450	11812	13951	13407	14220

Table 9Results scenario 2 - – Power Installed equivalent to 2 Large Reactors

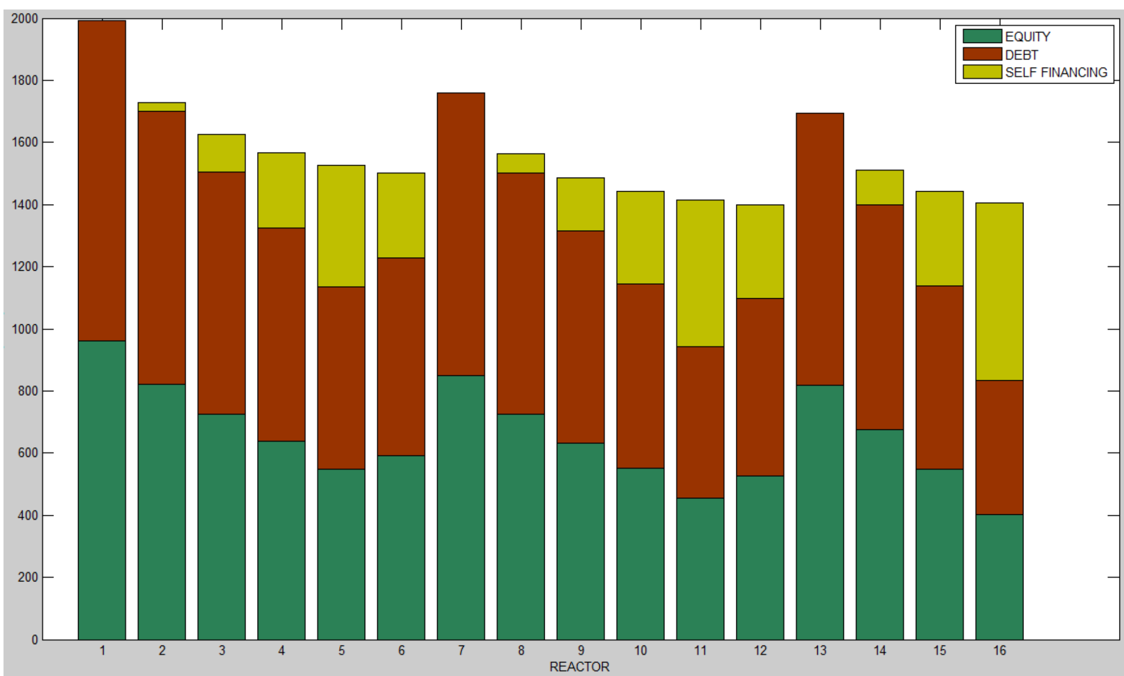

Figure 2 Scenario 1- Medium reactor 50% Equity. Incas calculated for each reactor the exact amount of Equity, debt and self-financing for each reactor

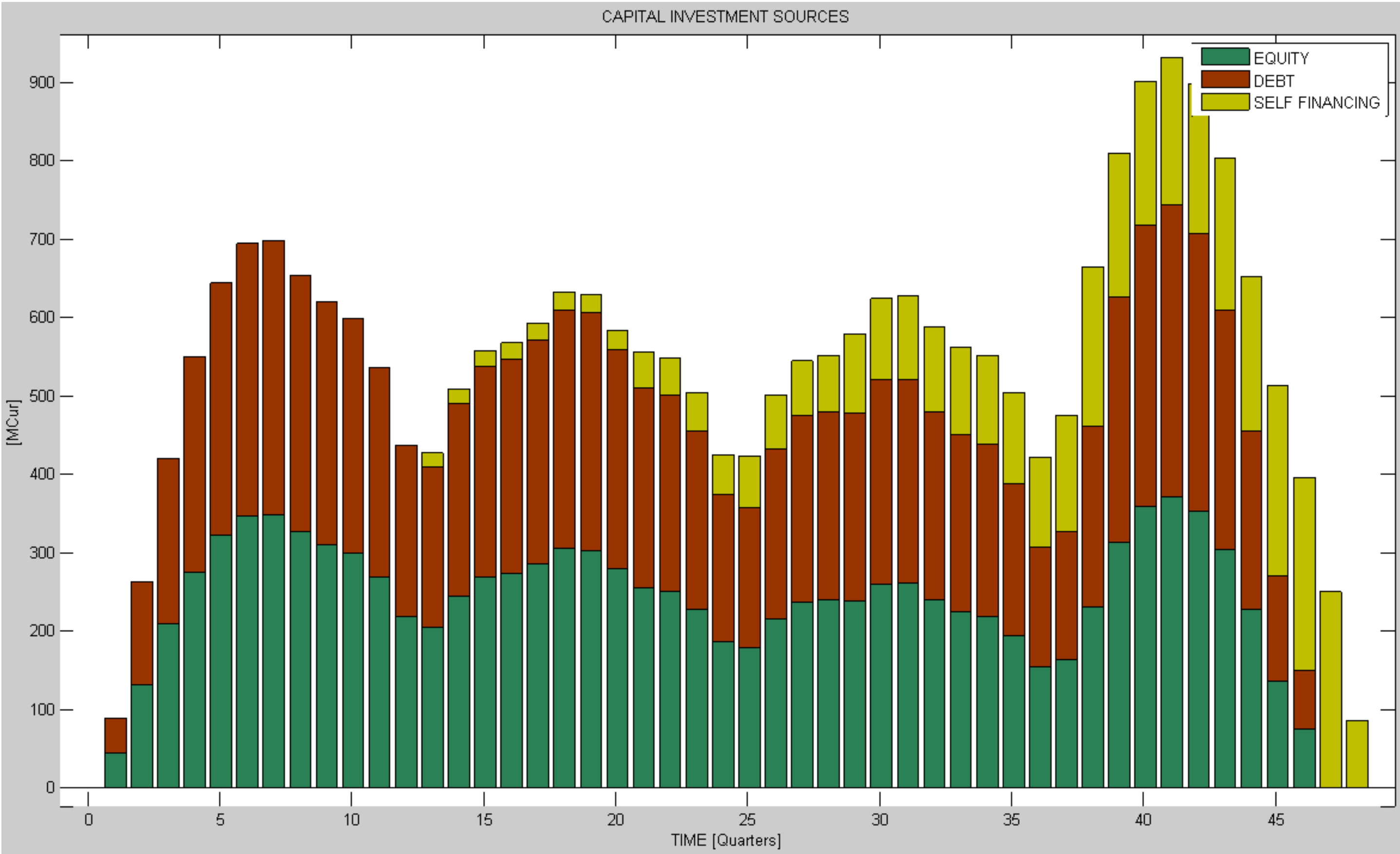

Figure 3 - Scenario 1- Medium reactor 50% Equity. Incas calculated for each reactor the exact amount of Equity, debt and self-financing each quarter in the construction period

CONCLUSIONS

One of the greatest challenges in the construction of NPP is the public acceptability. The Fukushima accident renewed the fears against the nuclear energy and set plants' safety as a prior requirement.

SMR have improved safety standard and higher seismic robustness due to lower size of containment. Results of this analysis show that SMR loose some cost-efficiency against very large NPP (i.e. 1565MWe) on account of EOS, but also that very large plants economics are very sensitive to construction schedule delays. Multiple SMR can exploit the economy of replication and offer design enhancements and modularization cost savings that bring they competitiveness in line with large plants (i.e. 1200-1050MWe). Moreover, SMR represent a scalable, flexible investment strategy for gradual new capacity installed. Shorter construction time and consequent shorter PBT for each SMR unit explains better IDC control over construction period, against considerable interest capitalization and TCIC escalation incurred by large plants' projects.

Should the Swiss government as the stakeholder of Swiss utilities, pursue the nuclear option by mean of SMR technology, it would have to promote an appropriate campaign to inform the citizens about superior safety features of SMR to amend the public concern and conviction that all NPP are as unsafe as the 40year old Fukushima reactors.

NOMENCLATURE

IDC = Interests During Construction
IRR = Internal Rate of Return (%)
K_e = cost of equity (%/y)
K_d= cost of debt (%/y)
LUEC = Levelised Unitary Electricity Cost
NPV = Net Present Value
OCC = Overnight Construction Cost
PBT = Pay Back Time (y)
TCIC = Total Capital Investment Cost

REFERENCES

1. **Encyclopædia Britannica.** Switzerland. [Online] 2011. http://www.britannica.com/EBchecked/topic/577225/Switzerland.

2. **Swiss Federal Office of Energy SFOE.** Electricity Supply. [Online] 20 04 2010. http://www.bfe.admin.ch/themen/00612/index.html?lang=en.

3. **World Nuclear Association.** Nuclear Power in Switzerland. [Online] December 2010. http://www.world-nuclear.org/info/inf86.html.

4. **World Nuclear News.** Safety OK for new Swiss nuclear. [Online] 2010 November 2010. http://www.world-nuclear-news.org/NN-Safety_inspectorate_OKs_Swiss_new_build_sites-1611107.html.

5. —. Consortium formed to replace Swiss nuclear. [Online] 13 December 2007. http://www.world-nuclear-news.org/newsarticle.aspx?id=14560&LangType=2057.

6. —. Nuclear an 'important part' of Swiss energy solution. [Online] 02 June 2008. http://www.world-nuclear-news.org/IT-Swiss_president_Nuclear_important_part_of_energy_solution-0206085.html.

7. —. New Swiss plants under starter's orders. [Online] 04 December 2008. http://www.world-nuclear-news.org/NN-New_Swiss_plants_under_starters_orders-0412087.html.

8. —. Three become one for new nuclear in Switzerland. [Online] 23 December 2010. http://www.world-nuclear-news.org/NN_Three_become_one_for_new_nuclear_in_Switzerland_2312102.html.

9. —. Local voters in favour of new Swiss plant. [Online] 14 February 2011. http://www.world-nuclear-news.org/NP-Local_voters_in_favour_of_new_Swiss_plant-1402118.html.

10. **IAEA.** Fukushima Nuclear Accident. [Online] 15 05 2010. http://www.iaea.org/.

11. **The New York Times.** Nuclear Plants in Europe Are Delayed. [Online] 15 March 2011. http://www.nytimes.com/2011/03/15/business/global/15euronuke.html?_r=1&src=busln.

12. **Expatica.** Switzerland says considering nuclear shutdown. [Online] 11 April 2011. http://www.expatica.com/ch/news/swiss-news/switzerland-says-considering-nuclear-shutdown_141969.html.

13. **Thomson Reuters.** Swiss Econ Min against new Swiss nuclear plants. [Online] 24 April 2011. http://af.reuters.com/article/energyOilNews/idAFLDE73N06120110424.

14. **pittsburghlive.** Insurance cost vs. nuclear power risk. [Online] 1 May 2011. http://www.pittsburghlive.com/x/pittsburghtrib/business/s_734814.html.

15. **World Nuclear News.** Improvements required after Swiss review. [Online] 06 May 2011. http://www.world-nuclear-news.org/RS-Improvements_required_after_Swiss_review-0605114.html.

16. **Commission, U.S. Nuclear Regulatory.** *"Reactor Oversight Process", NUREG-1649.* U.S. NRC. Washington D.C., United States : s.n., 2000.

17. **IAEA.** *Design features to achieve defence in depth in small and medium sized reactors.* 2009. IAEA Nuclear Energy Series - No. NP-T-2.2.

18. *"The design and safety features of the IRIS reactor".* **Carelli, M.D., Conway, L.E., Oriani, L., Petrovic, B., Lombardi, C.V., Ricotti, M.E., Barroso, A.C.O., Collado, J.M., Cinotti, L., Todreas, N.E., Grgic, D., Moraes, M.M., Boroughs, R.D., Ninotaka, H., Ingersoll, D.T., Oriolo, F.** 2004, Nuclear Engineering and Design, Vol. 230, p. 151-167.

19. *"IRIS simplified LERF model".* **Maioli, A., Finnicum, D.J., Kumagai, Y.** Miami, Florida, United States : s.n., 2004. ANES 2004 Proceedings of International Conference October 2004.

20. **Charlton, W.S., Le Bouf, R.F., Gariazzo, C., Ford, D.G., Beard, C., Landsberger, S., Whitaker, M.** *"Proliferation resistence assessment methodology for nuclear fuel cycle".* Nuclear Engineering Department, Texas A&M University. Texas, United States : s.n., 2008.

21. **yahoo finance.** [Online] 2011. http://it.finance.yahoo.com.

22. **Hirschberg, Stefan, et al.** *Neue erneuerbare Energien und neue Nuklearanlagen: Potenziale und Kosten.* Villigen : Paul Scherrer Institut, 2005. PSI Bericht Nr. 05-04 - Mai 2005 - ISSN 1019-0643.

23. *Financial case studies on Small-Medium sized Modular Reactors.* **Boarin, Sara, et al.** 2011 in press, Nuclear Technology.

24. **FindTheBest.com.** World Economic Outlook . [Online] 2011. http://world-economic-outlook.findthebest.com/directory/d/Switzerland/Inflation,-average-consumer-prices.

25. **Swiss Federal Office of Energy SFOE.** Electricity Supply. [Online] 2011. http://www.bfe.admin.ch/themen/00612/index.html?lang=en.

26. **IEA - OECD.** *Projected Costs of Generating Electricity 2010 Edition.* Paris : Organisation for Economic Co-operation and Development/International Energy Agency/Nuclear Energy Agency, 2010.

27. **Operators, World Association of Nuclear.** *"2008 WANO Performance Indicators".* WANO. London, United Kingdom : s.n., 2009.

ANNEX A

CONSTRUCTION SCHEDULE