Economics of Nuclear Power Plant and the development of nuclear power in Viet Nam

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1. Introduction

The purpose of this report is to give a general picture to consider the cost of nuclear power. It includes all the costs for building a nuclear power plant like total capital investment costs, production costs, external costs in which the capital investment costs is the largest component of the kWh cost.

There are many factors affecting the capital costs like: increased plant size, multiple unit construction, improved construct methods, increase the lifetime of plant and so on, and beside is technical to enhancing the safety for NPPs.

For the question that whether building a NPP is really economic than other energy resources or not, we will find the answer by comparing the USD per kWh of different energy sources as: nuclear power, coal, oil, hydro natural energy sources.

The situation of energy in Vietnam was also mentioned in this paper. Vietnam has an abundant natural resources likes: coal, gas, hydro power etc, but from year 2013 to now Vietnam facing of electricity shortage and to solve the problem, Vietnam Government has chosen nuclear power energy to achieve energy balance between the rate of energy consumption and the ability to energy supply. Eight units will be built in Vietnam and in October 2014 Vietnamese officials have chosen Rosatom's AES-2006 design with VVER-1200/v-491 reactors for country's first nuclear power plant at Ninh Thuan and a second plant should follow based on a partnership with Japan.

2. Assessing the costs of nuclear power

In this section some of the several aspects were considered to assess the cost of nuclear power.

2.1 *Capital Investment Costs*

The capital costs for a complete NPP are the overall cost of constructing a power plant from initial site investigation to commercial operation. In addition to the base costs, which consist of direct and indirect costs, other costs such as supplementary costs, financial costs and owner's costs are also includes. Direct costs include those related to equipment, structures, installation and materials and labor. It was the largest portion of the total capital cost, which represented between 60-80% of the total capital cost (from the NEA report in 1990) in which the breakdown of direct equipment, labor and materials costs as percentage of the total direct costs is shown in Fig.1. The data from the Fig.1 indicate that the equipment and material costs account for approximately 74% of the total direct costs, and labor related cost represent 26% of it.

Indirect costs encompass design, engineering and project management services; supplementary costs include as insurance, transportation, decommissioning cost etc;

Financial costs include escalation and interest during construction, and the owner's cost (land, cooling infrastructure, administration and associated buildings, site works, switchyards, projected management, licenses, etc.)[1].

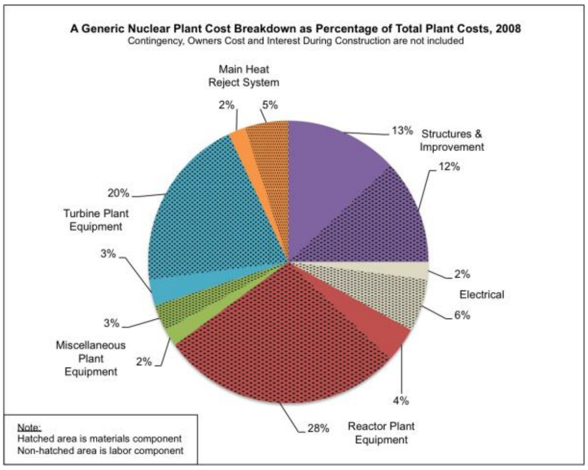


Fig.1: Breakdown of Nuclear Power Plant Costs by major components (from EPRI) [?]

Capital costs may be calculated with the financing costs included or excluded. Financing costs will depend on the rate of interest on debt, the debt equity ratio, and if it is regulated, how the capital costs are recovered. There must also be an allowance for a rate of return on equity, which is risk capital. If financing costs are included then the capital costs change in proportion to the length of time it take to build. It is normally termed the "investment cost". And the "overnight cost" if the financing costs are excluded from the calculation the capital costs, because it imagines that the plant appeared fully built overnight.

The term "overnight capital cost" is often used to identify the total costs of construction and for determining the effects of construction delays. In general the construct costs of nuclear power plants are significantly higher than for coal- or gas-fired plants because of the need to use the special materials, and to incorporate sophisticated safety features and buck-up control equipment. These contribute much of the nuclear generation costs, but once the plant is built the distribution of other costs are minor.

The overnight cost for nuclear power plant built in the Europe is about US$1,900-7200/kWe, in Asia it is $1,600/kW – 4365$/kW, in North America it is $2400/kW-$7000/kW and in the Middle East it is $3240/kW-$5300/kW[3]

There is also significant variation of capital costs by country, particularly between the industrial economies of East Asia and the markets of Europe and North America. (The IEA-NEA Nuclear Energy Road Map 2015 estimates China's average overnight costs of approximately USD 3,500/kW are more than third less than that in EU of USD 5,500/kW. Cost in US are about 10% lower than EU, but still 30% higher than in China and India, and 25% above South Korea)[2], and if the unit is first-of-a-kind technology then can add as much as 30% to the overnight capital cost of a project, Nadira Barkatullah, director of economic regulation at the Regulation and Supervision Bureau of the United Arab Emirates said.

Table 1 has shown the typical breakdown of levelized cost of electricity. The actual distribution between the four major elements depends on all kinds of variables, but the capital investment cost is the most dominant. The degree of dominance depends on many parameters of which the most important ones is overnight construction costs, discount rate, construction time, and the load factor.

Table 1: Structure of nuclear electricity generation cost (based on IEA/NEA, 2010).

	5% real discount rate	10% real discount rate
Total investment cost	58.6%	75.6%
Operation and maintenance	25.2%	14.9%
Fuel costs*	16.0%	9.5%
Carbon costs	0.0%	0.0%
Decommissioning	0.3%	0.0%

The period of construction is distribute of capital investment, long construction periods will cause increase the financing costs, in Asia construction time for plants today is typically 48 to 54 months.

The Table.2 showed the risk in construction costs (per kilowatt of capacity), much of it due to financing cost incurred by delays.

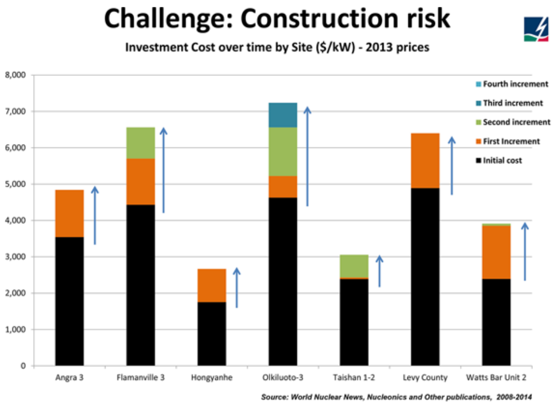


Fig. 2: The risk in construction costs
[Source: The presentation by Dr. N. Barkatullah, UAE Regulation & Supervision Bureau, at the World Nuclear Association 2014 Symposium]

2.2 Production Costs

Nuclear cycles costs and O&M costs which is called production costs is shown in Fig. 3. The nuclear fuel cycle costs include the costs of uranium supply, conversion and enrichment, fuel fabrication, waste fund etc.

The 'back end' of the fuel cycle, including treating and disposing of used fuel and wastes, contributes up to 15% of overall cost per kWh. But even with these included, the total fuel costs of nuclear power plant in the OECD are typically about a third of coal-fired plant and between a quarter and fifth of those for gas combined cycle plant.

For a typical 1,000 MWe BWR or PWR, the approximate cost of fuel for one reload (replacing one third of the core) is about $40 million, based on an 18-month refueling cycle. The average fuel cost at a nuclear power plant in 2012 was 0.75 cents/kWh.

Because nuclear plants refuel every 18-24 months, they are not subject to fuel price volatility like nature gas and oil power plants.

The O&M costs include all non-fuel costs, such as plant staffing costs, equipment, repair, replacements, purchased services, nuclear insurance etc. O&M costs are generally divided into 'fixed costs' those are incurred whether or not the plant is generating electricity and 'variable costs' which vary in relation to the output.

To calculate the production cost of a plant over its whole life (including the costs of decommissioning and used fuel and waste management), we must estimate the 'levelised' cost at present value. It represents the price the electricity must fetch if the project is to break even (after taking account of the opportunity cost of capital through the application of the discount rate).

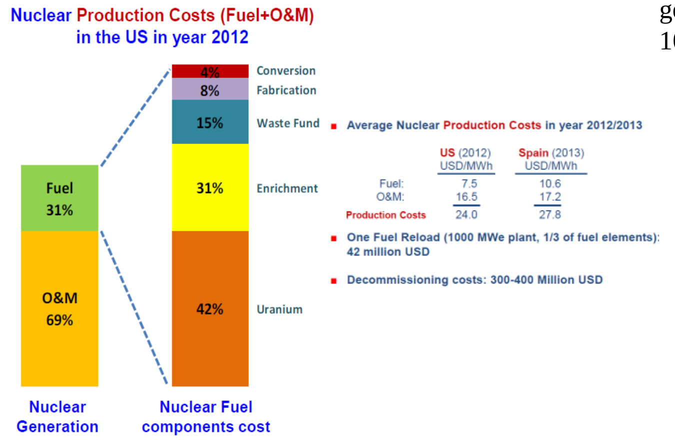


Fig.3: The Nuclear cost reference in US in year 2012 [4]

2.3 External costs

The external costs are defined as those incurred in relative to health and the environment, and it paid by the community generally. The report of a major European study of the external costs of various fuel cycles, focusing on coal and nuclear, was released in 2001 shown that the nuclear energy averages 0.4 cents/kWh, much the same as the hydro, coal is over 4.0 cents (4.17-7.3), gas ranges 1.3-2.3 cents and only wind shown up better than nuclear, at 0.1-0.2 cents/kWh average [3].

2.4 Comparing the economics of different forms of energy source

There are many studies carried out examining the economics of further generation options, and the following are the most important and also focus on the nuclear element.

The 2010 OECD study comprised data for 190 power plants from 170 OECD countries as well as some data from Brazil, China, Russia and South Africa. It used levelised costs with carbon price internalized (OECD only) and discounted cash flow at 5% and 10%, as previously. And the competitiveness of different energy source depended very much on local circumstances and the cost of financing and fuels.

The overnight capital costs in OECD ranged from \$1556/kW for APR-1400 in South Korea through \$3009 for ABWR in Japan, \$3382/kW for Gem II$^+$ in USA, \$3860 for EPR in France, \$5863/kW for EPR in Switzerland. Belgium, Netherlands, Czech Rep. and Hungary were all over \$5000/kW. In China overnight costs were \$1748/kW for CPR-1000 and \$2302/kW for AP1000, in Russia \$2933/kW for VVER-1150. OECD black coal plants were costs at \$807-2719/kW, those with carbon capture and compression (tabulated as CCS, but the cost not including the storage) at \$3223-5811/kW, brown coal \$1802-3485/kW, gas plants \$635-1747/kW (overnight costs were defined here as EPC)[3] and Table. 3 and 4 have shown the OECD electricity generating cost projections for year 2010 on -5% and 10% discount rate.

Table 3: OECD electricity generating cost projections for year 2010 on -5% discount rate, c/kWh

country	nuclear	coal	coal with CCS	Gas CCGT	Onshore wind
Belgium	6.1	8.2	-	9.0	9.6
Czech R	7.0	8.5-9.4	8.8-9.3	9.2	14.6
France	5.6	-	-	-	9.0
Germany	5.0	7.0-7.9	6.8-8.5	8.5	10.6
Hungary	8.2	-	-	-	-
Japan	5.0	8.8	-	10.5	-
Korea	2.9-3.3	6.6-6.8	-	9.1	-
Netherlands	6.3	8.2	-	7.8	8.6
Slovakia	6.3	12.0	-	-	-
Switzerland	5.5-7.8	-	-	9.4	16.3
USA	4.9	7.2-7.5	6.8	7.7	4.8
China*	3.0-3.6	5.5	-	4.9	5.1-8.9
Russia*	4.3	7.5	8.7	7.1	6.3
EPRI (USA)	4.8	7.2	-	7.9	6.2
Eurelectric	6.0	6.3-7.4	7.5	8.6	11.3

* For China and Russia: 2.5c is added to coal and 1.3c to gas as carbon emission cost to enable sensible comparison with other data in those fuel/technology categories, though within those countries coal and gas will in fact be cheaper than the Table above suggests.
Source: OECD/IEA NEA 2010, table 4.1.

Table 4: OECD electricity generating cost projections for year 2010 on -10% discount rate, c/kWh

country	nuclear	coal	coal with CCS	Gas CCGT	Onshore wind
Belgium	10.9	10.0	-	9.3-9.9	13.6
Czech R	11.5	11.4-13.3	13.6-14.1	10.4	21.9
France	9.2	-	-	-	12.2
Germany	8.3	8.7-9.4	9.5-11.0	9.3	14.3
Hungary	12.2	-	-	-	-
Japan	7.6	10.7	-	12.0	-
Korea	4.2-4.8	7.1-7.4	-	9.5	-
Netherlands	10.5	10.0	-	8.2	12.2
Slovakia	9.8	14.2	-	-	-
Switzerland	9.0-13.6	-	-	10.5	23.4
USA	7.7	8.8-9.3	9.4	8.3	7.0
China*	4.4-5.5	5.8	-	5.2	7.2-12.6
Russia*	6.8	9.0	11.8	7.8	9.0
EPRI (USA)	7.3	8.8	-	8.3	9.1
Eurelectric	10.6	8.0-9.0	10.2	9.4	15.5

* For China and Russia: 2.5c is added to coal and 1.3c to gas as carbon emission cost to enable sensible comparison with other data in those fuel/technology categories, though within those countries coal and gas will in fact be cheaper than the Table above suggests.
Source: OECD/IEA NEA 2010, table 4.1.

At 5% discount rate comparative costs are as shown in Table 3, Nuclear energy is comfortably cheaper than coal and gas in all countries, and at 10% discount rate in Tab.4 nuclear still cheaper than coal in all but gas in three EU countries become still cheaper. Coal with carbon capture is mostly more expensive than nuclear (for paying CO2 emissions).

The levelised nuclear power cost with 24% of the overnight cost need to be added for the initial units of a first-of-a-kind advanced design such as AP1000, the overnight cost capital cost of \$1800/kW is assumed and power costs are projected beyond the range above. However, considering a series of four or eight units of the same kind and assuming the efficiency due to experience which lower overnight capital costs, the levelised cost drop 20% from the quoted above (eg the \$1500/kW case above), making them competitive at about 4.5 c/kWh for 4th unit and 3.4 c/kWh for 8th unit (Table.5).

Table 5: Nuclear plant: projected electricity costs (c/kWh)

Overnight capital cost \$/kW		1200	1500	1800
First unit	7 yr build, 40 yr life	5.3	6.2	7.1
	5 yr build, 60 yr life	4.3	5.0	5.8
4th unit	7 yr build, 40 yr life	4.5	4.5	5.3
	5 yr build, 60 yr life *	3.7	3.7	4.3
8th unit	7 yr build, 40 yr life	4.2	4.2	4.9
	5 yr build, 60 yr life *	3.4	3.4	4.0

* calculated from above data

It is important to distinguish between the economics of nuclear power plant already in operation and those at the planning stage. Once capital investment costs are effectively "suck", existing plants operate at very low costs and are effectively "cash machines" [3], and their operation costs (including used fuel management) contribute to overall cost of the electricity produced is relatively small compare with the coal-fired plant and gas-fired plant.

2.5. The situation for Energy in Viet Nam

Viet Nam is a developing country with 93 million people. According to economic growth, the energy demand in Viet Nam is growing at a rapid rate. Between the years 1990 and 2007, the total primary energy demand increased annually 5%, from 24.3 MTOE in 1990 to 55.6 MTOE in 2007. In the supply side, Viet Nam is endowed with several energy resources including coal, oil, natural gas, hydro, and renewable energy with the growth rate of domestic energy production for the period 1990-2007 was 14% with coal production grew at the highest rate (15% per year), followed by oil and gas (13% per year). In 2007, total domestic energy production was 49.4 MTOE while the corresponding primary energy demand in that year was 31 MTOE, making a positive balance of 18.4 MTOE.
The rapid change which was is expected to increase annually by 5.5 percent up to year 2025, from 55.6 MTOE (2007) to 146 MTOE (2025) in primary energy demand , in order to support the projected 8 percent economic growth up to the year 2025 (JICA, 2008) (Table 6a and 6b). [6]

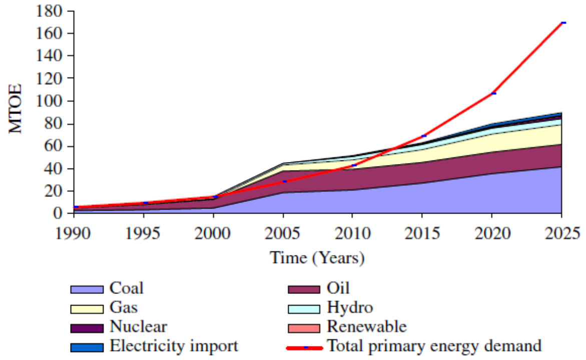
As predicted, the energy imbalance occurs around year 2013 or earlier. Electricity shortage is now a big problem in the power sector. Many industrial consumers have prepared themselves for power interruptions with stand-by self-generating units; in some cases, even independent power plants have been commissioned for industrial consumers such as centralized zones or export processing zones.

Table 6a: Primary energy balance: Vietnam (1990-2025)

Primary energy balance: Vietnam (1990–2025).
Sources: (IEA, 2007a, 2008b) and (JICA, 2008).

Type of energy	(MTOE)					
	1990		2007		2025	
	Demand	Supply	Demand	Supply	Demand	Supply
Commercial energy	**5.4**	**5.8**	**31.0**	**49.4**	**135.4**	**88.7**
Coal	2.2	2.6	9.9	24.3	64.2	45.0
Oil	2.7	2.7	13.0	16.5	43.7	19.9
Gas	0	0	5.5	5.9	16.3	16.2
Hydro	0.5	0.5	2.6	2.6	6.8	5.4
Nuclear	0	0	0	0	2	2
Renewable	0	0	0	0	1	0
Elec. Import	0	0	0	0	2	0
Non-commercial energy	**18.9**	**18.9**	**24.5**	**24.5**	**10.6**	**18.6**
Total	**24.3**	**24.7**	**55.6**	**73.9**	**146.0**	**107.3**

Table 6b: Primary energy balance: Vietnam (1990-2025)



Currently, Nuclear Energy Power is also considered as a solution to cope with the shortage of current energy. Following Nuclear Power Development Program, Viet Nam will be building eight Nuclear Power Plants (as the Table 1), with two reactors total 2000 MWe have been planned at Phuoc Dinh in the southern Ninh Thuan province. A further 2000 MWe was planned at Vinh Hai nearby, followed by a further 6000 MWe by 2030. Four more units would be added to the first two sites and then six more at three or four central sites in provinces of Quang Ngai (Duc Thang or Duc Chanh), Binh Dinh (Hoai My) and Phu Yen (Xuan Phuong).

Table 7: Planned and Proposed PPs to 2030

Location	Plant (province)	Type	MWe nominal	Start construction	Operation
Phuoc Dinh	Ninh Thuan 1-1	VVER-1200/V-491	1200	2019	2025
	Ninh Thuan 1-2	VVER-1200/V-491	1200	2020	2026
	Ninh Thuan 1-3	VVER-1200/V-491	1200		?
	Ninh Thuan 1-4	VVER-1200/V-491	1200		?
Vinh Hai	Ninh Thuan 2-1	AP1000 or Atmea1 ?	1100	Dec 2015, delayed	2024?
	Ninh Thuan 2-2	AP1000 or Atmea1 ?	1100	2016, delayed	2025?
	Ninh Thuan 2-3	AP1000 or Atmea1 ?	1100		?
	Ninh Thuan 2-4	AP1000 or Atmea1 ?	1100		?
Central		APR-1400?	1350		2028
Central		APR-1400?	1350		2029
Total planned (4)			**4800**		
Total proposed by 2030			7100		

*[Source: **www.world-nuclear-new.org**, **Nuclear Power in Vietnam (Updated February 2015)**]*

One of the major disadvantages of nuclear energy is the huge investment required to construction cost in the first period, in addition, the length of the construction period time (usually it take longer than the construction a traditional plant) and in Vietnam is need to import the modern nuclear technology is prohibitively expensive compared with the cost of procuring a traditional cost coal fired plant, even though the costs of operating a nuclear power plant are low, by comparison with other technologies. The cost of developed the first nuclear power plant in Vietnam is considered to be at least US$10 billion, and almost of funds was borrowed from abroad, so the costs to build a NPP is significantly more than the cost of developing a coal fired plant.

The second one is the security of fuel supply, Vietnam will need to import uranium to process into fuel assemblies for use in its nuclear power plants from the other countries at potentially considerable cost.

But thanks to an abundance of low wage labor**,** a multiply of units will be built at the same kind and with the Vietnam's ultimate goal is foster the expertise and experience to potentially develop its own technology and build its nuclear operating and fuel processing capability within Vietnam, to reduce of the cost is significantly in the long term.

3. Conclusions

In this paper, the breakdown of NPP costs is considered. All the costs for building a NPP includes: the investment costs are the largest components (about 60%), fuel costs (15%), O&M costs (25%) and external costs are lower than 1% of the kWh costs.

Comparing the economics of different forms of energy source also studies, the result shown that nuclear energy is comfortably cheaper than the coal- and gas-plant in all countries.

The situation for energy in Vietnam was mentioned with increase annually by 5.5 %, and now the shortage electricity is the big problem in power section. Nuclear energy Power was chosen to deal with situation of diminishing resources shortages. The nuclear safety is much focused to ensure safety for people and environment.

With the growing nuclear technology now the nuclear resource is the most competitive to other resources and it also contribute to the improvement of environment by minimizing the air pollution due to CO2 production.

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