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Nuclear Power: a Competitive Option?

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Economic competitiveness is the cornerstone for the successful deployment of any electricity generation source and technology. Decisions on technologies and energy mixes for electricity generation have to take into account a variety of non-economic issues, including social, environmental and health impacts, but utilities base their choices primarily on the costs of generating electricity from alternative energy sources and technologies available on the market.

The evolution of the policy making landscape, including economic deregulation and privatisation of the power sector, but also an increasing awareness of sustainable development goals, leads to changes in the framework of economic assessment. This evolution creates new challenges and opportunities for different generation technologies, including nuclear power.

Deregulation of the electricity market and privatisation of the sector are changing the criteria upon which assessments of competitiveness are based. Private investors tend to prefer low capital intensity technologies that offer a rapid return on investments. This poses challenges for capital intensive technologies, such as nuclear power, because the open competition for supplying electricity will introduce a higher uncertainty about the future level of sales by each producer.

In order to reduce financial risks, producers will tend to seek more flexible generation strategies that are based upon small power plants with relatively low investment costs and short pay-back times. Nuclear power will be challenged to establish its competitive position in such a market, owing to the fact that it is a relatively complex technology that requires sophisticated industrial and R&D infrastructures which might be difficult for the private sector to support. On the other hand, the reduction of barriers to bulk electricity exchange via extended networks offers new market opportunities for large units that have stable long-term generation costs, such as nuclear power plants.

The increasing awareness of environmental issues and the recognition of broad macroeconomic and social effects arising from technology choices are leading to new approaches and additional criteria in the comparative assessment of different generation options. Cost comparisons of generation technologies can be taken beyond the traditional approach of calculating the direct economic costs to the utility by internalising other costs to society, i.e. externalities, insofar as feasible. Internalising externalities might enhance the competitiveness of nuclear power versus coal and gas-fired power plants.
Owing to the early recognition of the need adequately to protect the public and environment from ionising radiation, the classic levelised cost

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assessment already takes into account most of the elements related to the health and environmental impacts of nuclear power generation, from mining through electricity generation to decommissioning of the facilities, waste management and disposal. Also, the costs related to the application of safety standards and regulations are embedded in the investment, operation and maintenance costs of nuclear power plants. On the other hand, the externalities arising from fossil fuel electricity generation, for example, the potential costs of greenhouse gas emissions, are not taken fully into account at present, and their inclusion would increase the costs of fossil fuel based generation relative to nuclear.

Since the future development of nuclear power will depend largely on its economic performance as compared with alternatives, the OECD Nuclear Energy Agency (NEA) investigates continuously economic aspects of nuclear power. The series of OECD studies on projected costs of generating electricity provides documented data and detailed analyses on the status and trends in generation costs. This paper is based upon key findings from those studies and other related NEA activities. It addresses the cost economics necessary for nuclear units to be competitive. The challenges and opportunities resulting from the new economic landscape, and the ways in which they might affect the competitiveness of nuclear power, are discussed.

Direct Levelised Cost Comparisons

The last OECD study on projected cost of generating electricity,[1] published in 1998, covers cost data for baseload power plants that could be commissioned by 2005-2010 in the nineteen countries which participated in the study. Although the energy sources and technologies considered vary from country to country, the main alternatives are coal-fired, gas-fired and nuclear power plants. The scope of the study excludes hydro power plants because their costs are highly site specific. As far as other renewable sources are concerned, cost information on their use for electricity generation was provided by three countries only.

The OECD method and results are not a substitute for economic studies that would be carried out by utilities based upon detailed cost elements corresponding to a given project and taking into account the overall context of electricity system expansion. However, the outcomes are indicative of the relative competitiveness of alternative options and point to the most economically attractive options in each country.

Twelve countries provided cost information for at least one nuclear unit and one alternative. The cost estimates presented below are based upon that information. The levelised generation costs were calculated using cost elements provided by participating countries, a commonly agreed methodological framework, and generic assumptions for some key parameters. Generic assumptions include a 40 year lifetime and a 75% load factor for all power plants considered. For gas-fired power plants, the costs of replacing major equipment at the end of their technical lifetime, around 20 years, are included in the investment costs.

The discount rate adopted to estimate levelised generation costs is a key parameter. The last OECD study used two real discount rates as reference, 5% and 10% per annum, that are considered representative of the range of values used by electricity producers in most countries. Fuel cost assumptions were provided by participating countries and, therefore, fuel costs in the commissioning year and fuel price escalation rates are country specific.

Cost elements were provided by each country in its national currency of 1 July 1996, but for the sake of consistency those costs were converted into United States dollars of the same date using official exchange rates prevailing at that date. Levelised costs, calculated in a unique currency, can be presented and compared in a consistent manner. Most countries provided data for several coal-fired, gas-fired or nuclear power plants, only the cheapest plant for each alternative is shown in Table 1, which summarises the main results of the last study.

The ranges of generation costs for each technology/energy source are quite broad (see Table 1), showing that competitiveness should be assessed on a case by case basis at the country or utility level, taking into account the specific technical and economic conditions applicable in each case. Nevertheless, average generation costs for each technology/source are indicative, and the cost ratios in each country illustrate the ranking of alternative options.

On average, projected generation costs for coal-fired power plants are around 38 mill/kWh (1 mill = US$0.001) at 5% discount rate and around 48 mill/kWh at 10%. Those costs are based upon coal prices ranging from US$1.0/GJ to US$2.8/GJ in 2005 (the year of commissioning of the plant) and increasing at an average escalation rate of 0.3% per annum. For gas-fired power plants, the average projected generating costs are 40 mill/kWh and 44 mill/kWh at 5% and 10% discount rate, respectively. The gas prices assumed vary between US$1.6/GJ and US$5.4/GJ in 2005 with a 0.8% per annum average escalation rate. The average generation costs for nuclear power plants are 34 mill/kWh and 51 mill/kWh respectively at 5% and 10% discount rate. This shows that nuclear power has the potential to compete favourably at 5% discount rate but loses most of its competitive margin at 10% discount rate.

In the twelve countries where coal and nuclear options are considered, the ratios between projected costs of nuclear and coal generated electricity range from 0.58 to 1.33 at 5% discount rate and from 0.73 to 1.43 at 10% discount rate (see Figure 1). In the ten countries where gas and nuclear options are considered, the ratios between projected costs of nuclear and gas generated electricity range from 0.68 to 1.43 at 5% discount rate and from 0.92 to 1.96 at 10% discount rate. In the same countries, the ratios between projected costs of coal and gas generated electricity range from 0.71 and 1.31 at 5% discount rate and from 0.9 and 1.47 at 10% discount rate. The analysis of key results from the study shows that nuclear can be the cheapest option in countries where capital costs of nuclear power plants can be kept low, and where gas and/or coal prices are rather high and are projected to increase during the economic lifetime of the plants.

Owing to uncertainties on projected cost elements and to the conceptual level of detail inherent in international studies based upon generic assumptions, small differences in generation costs may not be significant. But differences higher than 10% may be considered as indicative of the relative competitiveness of alternative options in each country. Within the twelve countries that provided data for nuclear power and at least one other option, at 5% discount rate, nuclear is the cheapest by a margin of at least 10% in five countries, coal is the cheapest by a margin of at least 10% in one country and gas is the cheapest by a margin of at least 10% in one country. At 10% discount rate, nuclear is the cheapest option by a margin of at least 10% in no country, coal is cheapest option by a margin of at least 10% in no country and gas is the cheapest option by a margin of at least 10% in five countries. This confirms the difficulties for nuclear power to compete at high discount rates.

The costs of generating electricity have decreased continuously during the last decade or so owing to technological progress, more efficient plant management and lower fuel prices. The results from the series of OECD studies on projected costs of generating electricity illustrate those trends for coal-fired, gas-fired and nuclear power plants. Similarly, renewable energy sources, although they remain expensive for electricity generation and are seldom competitive, have experienced drastic cost reductions recently. Regarding trends in cost ratios, one of the main findings from the last two studies in the series is the rapidly increasing competitiveness of gas for baseload generation. Modern gas-fired combined cycle power plants, having high efficiency, 50% or more, and low capital intensity, are challenging the competitiveness of coal and nuclear at present gas prices on international markets.

In spite of the relevance of economic comparisons, it is important to be aware of their limits. The input values for any evaluation of generation costs, whether they are tied specifically to a project or are generic in nature, are not known with absolute certainty. Fossil fuel prices, regulations, environmental standards, and other factors may change from what were originally expected. The uncertainty of input values generally leads decision makers to take into account potential variations in the values of some cost factors and they may also look beyond direct costs in their evaluations.

Nuclear Generation Cost Structure

For a nuclear unit, over half of the total generation cost is related to capital investment, while for coal and gas, fuel represents some 40 to 80% of the total generation cost. The high capital costs of nuclear power plants hamper their competitiveness, especially at high discount rates, and nuclear plant investors must accept long periods of time for return of their invested capital in order to achieve competitive generation costs. Therefore, reducing investment costs is a prerequisite for enhancing the competitiveness of nuclear power. A recent NEA study[2] analyses means to reduce the capital cost of nuclear power plants, identifying as the most significant: plant size, multiple unit sites, design improvement, standardisation, modularisation, and performance improvement.

The French and Korean experiences are of interest in this connection. France based its large nuclear power programme upon standardised units and large series orders, leading to competitive nuclear generation costs as compared with fossil fuels. The impacts of unit size and number of units constructed on the same site, according to French data, are illustrated in Table 2.

In the French case, the effect of series ordering is also estimated to have been significant. The “first-of-a-kind” initial cost may be between 15% and 55% higher than the cost of a series unit depending on the differences between a new design and previous reactors. When a series of reactors is ordered, additional cost reductions resulting from productivity effects are possible from the third unit on. With a 2% productivity gain for each new unit after the second one, the capital cost of the eighth unit in the series is 10% lower than the capital cost of the first unit.

The capital costs of the Korea Standard Nuclear Power Plant (KSNP), a 1000 MWe PWR, show a similar trends. Today, one KSNP unit is in operation and five more units are under construction. Table 3 illustrates expected capital cost reductions of subsequent KSNPs, based on contract prices.

Following the KSNP, Korea has started a programme for the development of the Korea Next Generation Reactor (KNGR), a 1300 MWe PWR. The key objective of the KNGR development programme is to enhance safety and economics. The cost reductions as compared with the existing KSNP are shown in Table 4, which indicates the main factors leading to those reductions. Globally, the new generation of plants is designed to be around 17% cheaper than previous nuclear units.

The bottom line is, however, that past experience and recent evaluations point to a maximum potential reduction of capital costs for nuclear units by 25%, which will probably not be enough to secure economic competitiveness with fossil-fuelled power plants.

Operations and maintenance (O&M) costs represent a relatively small component of the total generation cost for nuclear power plants, although in some countries they exceed fuel costs. At 10% discount rate they represent some 15% of the total cost of nuclear generated electricity in most countries, and at 5% discount rate the share of O&M cost generally reaches or exceeds 20%.

The O&M costs are influenced by technical performance of the nuclear power plants and, moreover, by safety regulations and manpower costs prevailing in different countries. Therefore, they vary significantly both in absolute and relative value from country to country. The reasons for the wide disparity in O&M costs in different countries have been analysed in an NEA study,[3] which concluded that international cost comparisons are difficult owing to the major role of country specific factors in these costs and to the lack of harmonised methodology for calculating O&M costs.

In the past, escalation in O&M costs has been mainly due to regulatory factors and, to a lesser extent, to the increasing cost of manpower. Lowering or at least stabilisation of O&M costs has been achieved recently through learning from increased experience in operating a growing number of nuclear power plants and reaching stable regulatory procedures. Also, in countries where the electricity sector has been deregulated already, more efficient management methods have been introduced that lead to lower O&M costs. Moreover, as well as enhancing overall performance, advanced reactor designs have simplified O&M processes, leading to an overall reduction of O&M costs.

Nuclear fuel accounts for less than one quarter of total generation cost. In contrast, fuel can account for one half of coal-fired generation cost and three quarters of gas-fired generation cost. In light of the small proportion of the total generating cost taken up by the nuclear fuel cycle component, nuclear generation costs are relatively insensitive to uranium and fuel cycle service price volatility. However, decreases in fuel cycle costs experienced during

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recent years have contributed significantly to the overall decreasing trend in nuclear electricity generation cost.

In the recent years, fuel cycle costs have decreased significantly for all types of nuclear power plants in all countries. Technical improvements leading to efficiency gains have led to a reduction in the costs and prices of most nuclear fuel services. According to the NEA studies on economics of the fuel cycle,[4] a 40% reduction in estimated lifetime levelised nuclear fuel cycle costs has occurred since 1985 in real terms. This reduction is due to improved reactor and fuel performance and lower prices for uranium and some fuel cycle services. Improved fuel and reactor performance factors contributed some 20% of the total reduction in nuclear fuel cycle costs. Major decreases in the prices of uranium and enrichment services, and reduction in back-end service prices, contributed 80% of this reduction.

The most important technical factors that have an impact on nuclear fuel cycle costs are the level of fuel burnup in reactors and the tails assay of enrichment plants. The discount rate has little influence on the total fuel cycle costs. While the levelised costs of front-end steps increase with increases in discount rate, for the back-end steps, in particular spent fuel or high level waste disposal, increasing the discount rate decreases levelised costs, since these operations occur after electricity generation.

The downward trend in uranium prices that has occurred since the late 1970s has contributed significantly to the reduction in fuel cycle costs. Drastic uranium price escalation does not appear very likely in the short term owing to existing excess inventories of fissile materials. In the long term, even if uranium prices were to rise either through market mechanisms or increased production costs, the effect on total nuclear fuel cycle and electricity generation costs would be limited. A doubling of the uranium price would lead to only some 20% increase in the nuclear fuel cycle cost.

Enrichment prices decreased by some 30% between 1985 and 1990. This trend is expected to continue owing to market forces and to efficiency improvements in the existing enrichment facilities, as long as supply capabilities remain in excess of demand. In the longer term, the enhancement of existing technologies and the possible market entry of new processes should lead to cost and price reductions for enrichment services.

Reprocessing costs are expected to decrease through learning from experience and efficiency gains as new industrial facilities are commissioned and the overall process reaches commercial maturity. The same is applicable to direct disposal of spent fuel.

Concluding Remarks

At the present time a new nuclear power plant is seldom the cheapest option. With the power sector undergoing deregulation and privatisation, highly capital intensive technologies such as nuclear power are not the most attractive in the market. In the present and expected future business environment, risks will be greater for investors embarking on nuclear projects, while technologies with lower capital cost will have an advantage.

In a free deregulated market, economic competitiveness is a key factor, if not the only one, in selecting an option. Existing nuclear units, where they are well operated and managed, generally have a clear economic advantage owing to their low marginal cost. New reactor projects, on the other hand, will find it difficult to be competitive. They must achieve significantly lower capital costs per unit of installed capacity, and total generation costs lower than the alternatives, to be successfully deployed. This may be difficult to accomplish as nuclear technologies seem inherently capital intensive, and fossil fuel prices are currently low and are projected to rise only modestly.

However, nuclear power may regain the competitive margin that it enjoyed in the mid 1970s. There are innovative reactor concepts, such as the modular high temperature gas cooled reactor or the new generation of Korean PWRs, that might eventually meet the objective of very low specific capital costs. Moreover, in some countries indigenous fossil fuel supplies are scarce and/or expensive, and in these areas nuclear power is likely to keep an economic advantage.

The experience already acquired in some countries has shown the potential to further decrease the costs of nuclear power generation through decreasing the costs of investment, operation and maintenance, and the fuel cycle. Nuclear power plant costs can be minimised if certain conditions exist at the outset. These conditions include design simplification and standardisation, clear and stable regulatory requirements, a high fraction of design completion before construction starts, use of multiple unit sites with phased construction, and the use of modular construction.

A factor that may influence the competitiveness of nuclear power in the future is external costs. National policy issues related to energy security and diversity of supply may modify the selection process from purely one of relative internal costs. In addition, the global environmental impacts of various power generation technologies are not completely internalised at present. Should this occur, nuclear power will likely have an improved economic ranking worldwide. It is not clear, however, if and when such recognition will take place.

The challenges for nuclear energy are: to secure and demonstrate the competitiveness of units currently in operation through efficient operation and management, and continued reduction of fuel cycle costs; and to develop a new generation of reactors that could successfully compete when existing units have to be replaced.

REFERENCES

1. *Projected costs of generating electricity.* International Energy Agency & Nuclear Energy Agency, OECD, Paris, 1998.
2. *Reduction of capital costs of nuclear power plants.* Nuclear Energy Agency, OECD, Paris, 1999.
3. *Methods of projecting operations and maintenance costs for nuclear power plants*. Nuclear Energy Agency, OECD, Paris, 1995.
4. *The economics of the nuclear fuel cycle.* Nuclear Energy Agency, OECD, Paris, 1994.

Table 1. Projected levelised generation costs (US mills of 1.7.1996 per kWh).

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Country	At 5% discount rate Coal	Gas	Nuclear	At 10% discount rate Coal	Gas	Nuclear
Canada	29.2	30.0	24.7	37.0	33.0	39.6
Finland	31.8	35.9	37.3	39.1	41.1	55.9
France	46.4	47.4	32.2	59.5	53.3	49.2
Japan	55.8	79.1	57.5	76.1	84.4	79.6
Korea	34.4	42.5	30.7	45.0	47.0	48.3
Spain	42.2	47.9	41.0	54.7	54.4	63.8
Turkey	39.8	30.7	32.8	48.7	33.9	51.8
United States	25.0	23.3	33.3	34.7	23.6	46.2
Brazil	35.4	28.5	33.1	43.2	32.7	46.7
China	31.8	n.a.	25.4	40.0	n.a.	39.0
India	33.0	n.a.	32.8	40.2	n.a.	51.0
Russia	46.3	35.4	26.9	55.3	39.0	46.5

Table 2. Relative overnight costs of nuclear power plants, normalised for a site with one 1000 MWe unit.

1 × 300*	2 × 300*	1 × 650*	2 × 650*	**1 × 1000***	2 × 1000	1 × 1350	2 × 1350*
1.82	1.44	1.22	1.0	**1.0**	0.84	0.87	0.75

* Reactor size in MWe

Table 3. Capital costs of subsequent Korea Standard Nuclear Plants (KSNPs), normalised for first and second units.

	1st & 2nd units	3rd & 4th units	5th & 6th units
Direct cost	1.0	0.9	0.9
Indirect cost	1.0	0.9	0.73
Contingency	1.0	0.9	0.85
Total capital cost	1.0	0.9	0.85

Table 4. Expected capital cost reductions and influencing factors for Korea Next Generation Reactor (KNGR) compared with KSNP.

Influencing factor	Expected cost reduction
Standardised design	4.9%
Simplified design	> 4%
Capacity upgrade	8%
Reduced construction period	4%
Total capital cost reduction	> 16.9%

Figure 1. Generation cost ratios for nuclear, coal and gas fired generation at discount rates of 5% and 10%.