COMPARATIVE COSTS OF GENERATING ELECTRICITY

Evelyne Bertel, Geoffrey H. Stevens
OECD Nuclear Energy Agency, France

ABSTRACT

The paper presents comparative costs of generating base-load electricity by state-of-the-art power plants expected to be commercially available by 2005 or shortly after. In order to assess the competitiveness of alternative sources within an harmonised framework, lifetime constant-money levelised costs calculated using a common set of economic assumptions are compared. A detailed analysis of the different elements of nuclear electricity generation costs is provided. Beyond direct costs, the paper investigates external costs and benefits of alternative options. For example, the extent to which carbon taxes, or other policy measures for alleviating the risk of global climate change, could modify the relative costs of carbon-free electricity generation sources (such as nuclear power) as compared to fossil fuels is assessed. Finally, the relevance of including policy issues (such as long term security of supply and generation cost stability) and environmental issues (such as global climate change threat) together with direct cost comparisons, in the assessment of alternative options is discussed.

INTRODUCTION

While choices for new technologies and decisions on energy mixes for electricity generation are based upon a number of factors including social, environmental and health impacts of the different options available, economic competitiveness remains a key factor for the deployment of alternative sources and technologies. However, the policy-making landscape and, thereby, the framework of economic assessment and comparison are evolving, creating new challenges and offering new opportunities for alternative generation technologies. Therefore, when undertaking a comparative assessment of different sources for electricity generation, it is important to adopt a methodology that reflects in so far as feasible current criteria and priorities of economic actors in the sector.

Deregulation of the electricity market and privatisation of the sector are changing criteria upon which competitiveness is assessed. In markets where generation becomes open to competition, decisions on generating capacity will no longer incorporate non-economic requirements unless they are made explicit by regulation or other policy measures and all potential competitors are subject to them. Also, private investors will tend to prefer low capital intensive technologies with rapid return on investments.

Market liberalisation is challenging for capital intensive technologies, such as nuclear power, because deregulated competitive markets will reduce long term guarantees of sales for each producer. This will lead producers to seek flexible expansion strategies based upon small size power plants with relatively low investment costs and short pay-back times. Also, nuclear power is a highly demanding technology that requires sophisticated industrial infrastructures and R&D programmes and facilities that the private sector might have difficulties in supporting. On the other side, the reduction of barriers to electricity exchange on extended networks offers opportunities for investing in large units with stable long term generation costs such as current generation nuclear power plants.

The increasing awareness of environmental issues and the recognition of broad macroeconomic and social effects arising from technology choices, lead to new approaches in cost assessment going beyond the traditional direct cost calculations and aiming at internalising external costs insofar as feasible. Two main issues have to be addressed for implementing this approach: valuing external costs corresponding, for example, to impacts on biodiversity, social preferences and aversion of risk; and integrating those costs in the economic comparison of alternative options.

Internalising externalities might enhance the competitiveness of nuclear power and renewable energy sources versus coal- and gas-fired power plants. Owing to the early recognition of liabilities arising from the generation of nuclear electricity, the classic levelised cost assessment already takes into account most of the elements related to health and environmental impacts of the nuclear fuel chain, 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 and operation and maintenance costs of nuclear power plants.

DIRECT COST COMPARISONS

Methodology

The adoption of a standardised methodology for estimating costs of electricity generation allows a fair comparison between different options. The levelised life time cost calculation method, which discounts expenditures and incomes to their present value by applying a discount rate that reflects the time value of money, provides total present-worth costs and revenues during the lifetime of a power plant. The levelised lifetime cost per kWh of electricity generated is the ratio of total lifetime expenses versus total expected outputs, expressed in terms of present value equivalent. This cost is equivalent to the average price that would have to be paid by consumers to repay exactly for the capital, operation and maintenance and fuel expenses, with a rate of return equal to the discount rate.

The economic merits of different candidate power plants are derived from the comparison of their respective average lifetime levelised costs. Technical and economic assumptions underlying the results are transparent and the method allows for sensitivity analysis showing the impact of different parameter variations on the relative competitiveness of the alternative technologies considered. The levelised costs are calculated on the basis of net power supplied to the station bus-bar, where electricity is fed to the grid, and expressed in constant money terms. For comparison purposes, OECD studies (IEA and NEA, 1993) present the results in a common monetary unit, generally United States dollars.

All the components of the costs falling on the utility that would, therefore, influence its choice of generation options are taken into account. Tax on income and profit charged to the utility and any other overheads that do not influence the choice of technology are excluded. External costs that are not borne by the utility, such as costs associated with health and environmental impacts of residual emissions, are not included either. On the other hand, station specific overheads, insurance premiums and R&D expenditures borne by producers are included, as well as the costs associated with environmental protection measures and standards, e.g., implementation of abatement technologies and emission permits.

Generating costs and their relative magnitudes are highly sensitive to the discount rates used. Recent OECD studies present generating costs calculated using two discount rates, 5% and 10% per annum, which are considered representative of the range of values used by electricity producers in most countries.

Main Generation Options

The energy sources and technologies considered for base-load electricity generation vary from country to country, according to resource availability, policy and a number of other factors. However, in most countries, the main alternatives are coal-fired, gas-fired, hydro and nuclear power plants. Hydro power plants are not discussed in this paper since their costs are highly country/site specific. In spite of the drop of oil prices in the mid eighties, oil-fired power plants are not considered for base-load generation in most countries owing to concerns on oil price volatility and long term security of supply.

The economics of renewable sources for electricity generation are highly variable and site dependent. However, in most cases the levelised cost of electricity generated by renewable sources is significantly higher than the cost of electricity generated by fossil-fuelled or nuclear power plants. Furthermore, with the exception of hydro power, renewable energy power plants are essentially intermittent in their operation and, therefore, are often regarded as possible fuel saving plants rather than base-load contributors.

Cost Comparisons

The results of a series of OECD studies on projected costs of generating electricity, published every third year since 1983, illustrate the trends in costs and relative competitiveness of coal, gas and nuclear power plants. For those three options, projected generation costs have decreased continuously since 1986 owing to technology progress and lower fuel prices.

Until the 1989 study, gas was seldom considered as a competitive option for base-load electricity generation. Since the 1989 study, for power plants to be commissioned by 2000 or after, gas-fired power plants were considered, together with nuclear and coal-fired power plants, among the main options for base-load generation. The competitiveness of gas for base-load generation is a new trend resulting from technological progress as well as low gas prices. In particular, combined cycle power plants have high efficiency (50% or more) and low investment costs. However, the cost of gas generated electricity is very sensitive to the price of gas and, therefore, an increase in gas prices in response to rising demand would reduce the competitive margin of gas-fired power plants.

The cost structure of alternative options for electricity generation has a significant impact on their relative competitiveness. Fuel is the main component of fossil-fired electricity generation costs. As a consequence, fossil generation costs are more sensitive than nuclear generation costs to fuel price trends and less sensitive to discount rates which have an impact mainly on investment costs.

For nuclear power plants, investments account for some 65% of generation costs while operation, maintenance and fuel costs together represent some 35%. This highly capital intensive cost structure results in a long-term stability of nuclear generation costs that is attractive at the country macroeconomic level. On the other side, it implies long times for return of invested capital, that might not be compatible with the short-term objectives and financing capabilities of private producers.

At the other extreme of the range, gas-fired power plants have low capital intensity with investment costs representing around 15% of generation costs and fuel costs contributing some 75%. It makes gas-fired power plants attractive from the view point of private investors seeking short investment pay-back times but may raise concerns about the sensitivity of generation costs to gas prices.

While present low fossil fuel prices are challenging the competitiveness of nuclear reactors and renewable sources, long-term energy policies have to take into account uncertainties on future fossil fuel prices. Whether coal and gas price will remain low as demand grows is questionable. Therefore, the assessment of economic competitiveness in the power sector should include sensitivity to different assumptions on fuel price escalation.

In countries where the three main options are considered, the ratio between projected costs of nuclear, coal and gas generated electricity is typically between 0.7 and 1.4. Nuclear electricity is the cheapest in countries where large nuclear power programmes have been implemented. In countries having access to low cost fossil fuels, fossil-fired power plants are the cheapest options with an advantage to gas in many cases. In most countries the direct costs of generating electricity from coal-fired, gas-fired and nuclear power plants are sufficiently close for their ranking to be very sensitive to discount rate and fossil fuel price assumptions. This generally leads countries and utilities to include in their systems a mix of different sources, taking into account economics, security of supply and other national or global concerns and objectives such as environmental protection.

NUCLEAR ELECTRICITY COST COMPONENTS

The information provided for the studies on projected generation costs includes three reactor types: pressurised water reactors (PWR), boiling water reactors (BWR) and pressurised heavy water reactors (PHWR).

Investment costs

The base construction costs reported for nuclear power plants vary from country to country between 1000 and 2500 US$/kWe, the average being around 1500 US$/kWe. There are a number of factors explaining the broad range of construction costs reported. The exchange rate values and the relative cost of labour, services and goods are a major cause for differences in investment costs reported by various countries. Those explains largely the high costs reported by Japan not only for nuclear but for all types of power plants. Besides those, the major parameters having an impact on the base construction costs of nuclear power plants are the size and series effects. Significant cost reductions are obtained by building several plants at a site, which can then benefit from common infrastructure and services, and ordering a series of units which reduces R&D and design costs per unit. It can also help by amortising testing costs over a larger number of similar units and enhancing the productivity of qualified manpower. The relatively low construction cost of French nuclear units, for example, illustrates this point.

The typical construction times for a nuclear unit (5 to 9 years) are longer than for coal-fired units (4 to 7 years) or combined cycle gas-fired units (3 to 6 years). This has an impact on the total construction cost, especially when high discount rates are applied. At 10% discount rate the interest during construction represent some 25 to 30% of the total construction cost of a nuclear unit. Advanced reactors with simplified designs are expected to require shorter construction times and, therefore, to have lower construction costs.

Decommissioning cost estimates for large size nuclear power plants are based upon technical experience gained through similar tasks already carried out for decommissioning of research reactors and for the replacement of major components of large power plants (NEA, 1991). Although these cost estimates vary significantly according to national regulatory frameworks and policies regarding the timing of dismantling operations, they fall within a fairly narrow range when expressed relative to the total investment cost and represent in any case less than 1% of total nuclear electricity generation costs. Decommissioning costs amount to some 10 to 20% of the total investment cost, if not discounted. With 10% discount rate, decommissioning represents less than 2% of the total investment cost.

Operation and Maintenance Costs

Operation 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. 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 (NEA, 1995) 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 a harmonised methodology for calculating O&M costs.

The past trend of escalation in O&M costs has been mainly due to regulatory factors and, to a lesser extent, to the increasing cost of manpower. More recently, O&M costs have decreased significantly in several countries, e.g., Germany and the United States, owing to learning from experience and enhanced management. This trend is expected to continue as experience will accumulate and as competition on the market will put pressure on utilities to reduce costs.

Nuclear Fuel Cycle Costs

In light of the small share of fuel cost in the total generating cost, nuclear generation costs are relatively insensitive to changes in uranium and fuel cycle service prices. For light water reactors (PWR and BWR), nuclear fuel costs represent typically some 20% of the total levelised generation cost at 5% discount rate, and less than 15% at 10% discount rate. For heavy water reactors, the fuel cycle costs are even lower, representing some 5% of total electricity generation costs.

Front-end of the fuel cycle costs include uranium mining and milling, conversion, enrichment (for light water reactors) and fuel fabrication. Back-end of the fuel cycle costs include, depending on the option adopted, storage, conditioning and disposal of spent fuel or reprocessing and disposal of high level waste. In the case of the closed cycle, credits for recycled uranium and plutonium are deduced from the overall fuel cycle costs. Uranium, enrichment and, in the case of closed cycle, reprocessing are the major cost elements in the total.

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

In recent years, nuclear fuel cycle costs have decreased significantly for all types of nuclear plants in all countries. A 40% real term reduction in estimated lifetime levelised nuclear fuel cycle costs has occurred since 1985 in NEA countries (NEA, 1994) This reduction is due to improved fuel performance and lower prices of uranium and some fuel cycle services.

The downward trend in uranium prices that occurred since the late seventies has contributed significantly to the reduction of fuel cycle costs. Drastic uranium price increase does not appear very likely in the short term owing to the existing excess inventories of fissile materials. In the long term, even if uranium prices were to rise either by market mechanisms or by increase in the production costs, the effect on the 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 nuclear fuel cycle costs, i.e., a few percent increase in total generation costs.

Technical improvements leading to efficiency gains have led to a reduction in the costs, and prices, of most nuclear fuel cycle services. Enrichment prices decreased by some 30% between 1985 and 1990. This trend is expected to continue owing to efficiency improvement in the existing enrichment facilities and to market forces as long as supply capabilities will exceed demand. In the longer term, the enhancement of presently used technologies and the possible entry on the market of new processes should lead to cost and price reduction for enrichment services. For the back-end of the fuel cycle, costs are being decreased through efficiency improvements leading to, for example, lower volumes of waste to be handled. In the future, feedback from experience and technology progress should reduce costs of services to be provided by new facilities.

BEYOND DIRECT COSTS

As long as the full costs to society of any given option are not entirely reflected in the direct costs as described above, there is a need to take into account other parameters and factors in the comparative assessment of alternative options. Costs and benefits to society that are generally not incorporated in direct costs of electricity generation include: macroeconomic impacts such as job creation and price stability; strategic factors such as security of supply and energy resource management; and externalities that are not borne directly by consumers but by society at large, such as health and environmental impacts of residual emissions. The increasing awareness of global impacts on the environment and the recognition of the concept of sustainability are leading analysts and decision makers to aim towards incorporating these parameters explicitly or implicitly in the comparative assessment process. A number of international studies carried out recently provide some results allowing an assessment of broad economic impacts (NEA, 1992) and externalities (EC, 1995) of different electricity generation sources.

Residual Emissions and Wastes from Normal Operation

Atmospheric emissions from fossil-fired power plants include sulphur dioxide, nitrogen oxides, carbon dioxide and particulate. The use of fossil fuels for electricity generation is also responsible for emissions arising from extraction, processing and transport of coal, gas or oil.

For nuclear power, radioactive emissions are subject to standards and limits set out by the International Commission on Radiological Protection (ICRP) are such as man, other species and the environment are not put at risk (ICRP, 1990). The potential health impacts of radioactive emissions from nuclear power plants and fuel cycle facilities are assessed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). According to UNSCEAR, measured or calculated exposures of workers and the public to routine radioactive emissions from nuclear power activities amount to less than 0.1% of the public's exposure to natural radiation arising from minerals, atmospheric radon and cosmic rays (UNSCEAR, 1994). It means that there is no measurable external cost associated with these emissions.

The adoption of emission standards and environmental protection regulations has led to the implementation of cleaner technologies and/or abatement devices reducing the emissions of electricity generation systems. Therefore, they are not yielding significant external cost to society, with the possible exception of global climate change induced by greenhouse gas emissions, in particular carbon dioxide. Electricity systems based on renewable energy sources and nuclear power are practically free from greenhouse gas emissions. Photovoltaic solar systems might generate carbon dioxide emissions indirectly when fossil energy is used in the process of fabricating solar cells (this applies also to nuclear power when fossil energy is used for uranium enrichment). Biomass might generate carbon dioxide if the energy system is not set up to be sustainable, i.e., compensating carbon dioxide emissions from burning biomass by its capture from growing biomass fuel.

The risk of global climate change cannot, at present, be evaluated with a reasonable level of certainty taking into account the status of scientific knowledge on climate mechanisms. The economic benefit from reducing carbon emissions is difficult to assess in the light of the uncertainties on economic consequences of global warming and on the specific impacts of global climate change in different regions of the world. Therefore, the values assigned to those emissions may vary widely from country to country depending upon policy choices and priorities of each government. This in turn makes it difficult to estimate the degree to which internalising global climate change risks might impact on the competitiveness of nuclear power and renewable energy sources as compared to coal- and gas-fired power plants.

Wastes arising from electricity generation are a concern mainly for coal fired and nuclear power systems. The costs associated with the management and disposal of these wastes are essentially (totally in the case of radioactive waste) captured by the levelised cost estimations. However, in the case of coal-fired power plants, the volumes of waste arising are very large and, although they contain hazardous heavy metals and radioactive elements, these wastes are disposed of at ground level and are not normally isolated from the biosphere. On the other hand, the total volumes of radioactive wastes arising from nuclear electricity generation are rather small and can be disposed of in repositories ensuring protection of human beings and the environment.

Abnormal Operation and Accident Risks

The potential risks of severe accidents, i.e., accidents with significant off-site risk to people and the environment, are recognised, and partly reflected in costs through insurance premiums, for all energy systems. However, data on the frequency and the health and environmental damages of severe accidents in the power sector are not systematically collected by a single national or international organisation. There are virtually no data on delayed health effects from severe accidents arising in non-nuclear electricity generation chains and their ultimate long term effects on the environment are difficult to establish owing to their rare occurrence. It should be pointed out that data and information on severe accidents and their consequence are based on two different approaches: actual historical occurrence for most electricity generation systems and probabilistic estimates of occurrence mainly for nuclear power. Therefore, their comparative assessment within an integrated framework might be somewhat misleading.

Rough estimates, based upon available data, suggest that the human health risks from severe accident in nuclear, oil and gas chains are of the same order of magnitude, and two orders of magnitude smaller than those from the hydro power option. However, any direct comparison in this regard should be interpreted with great care owing, as mentioned above, to the lack of comprehensive harmonised databases (IAEA, 1991).

Although accident risks are partly incorporated in the direct costs borne by producers by means of insurance and wages that reflect the risk supported by exposed staff, residual external costs arising from low probability/high consequence accidents are difficult to assess. The summary report on the ExternE study (EC, 1995) states that: “At this time there has been no general consensus on a methodology to assess the external costs of severe accidents”.

A review of studies on financial risks associated with severe accidents in the power sector shows a wide range of estimations owing to the uncertainties prevailing and, moreover, to differences in the assumptions adopted in different countries with regard to the monetary value of health, in particular fatalities, and environmental damages resulting from accidents. In any case, risk aversion often entails, especially in OECD countries, individual willingness to pay more to avoid accidents than the estimated costs that would be calculated by the risk-based approach.

Other Environmental Impacts

Other environmental impacts, with the exception of land requirements which are already captured by direct costs of electricity generation, are of a more qualitative nature and difficult to express in term of costs. Visual intrusion and reduction of biodiversity, for example, cannot be measured easily by numeric indicators and their monetary valuation, which is essentially context dependent, remains highly subjective. In most cases, the value of these impacts is estimated by the willingness to pay for avoiding or reducing them. As an example, lower prices of properties in areas exposed to noise or where the initial environment has been (or might be) degraded reflect the economic impact/external cost of the activities creating such impacts. These impacts should to be evaluated on an “ad hoc” basis for each specific project, taking into account local conditions since they cannot be fully assessed by generic methodologies and frameworks.

However, published studies and analysis carried out so far seem to indicate that their economic impact on the total cost of electricity generation is not significant.

Other Externalities

Broader impacts from technology choices in the power sector that entail external costs or benefits include: secondary investment effects; stability of electricity costs and prices; balance of payment equilibrium; regional and national technological, industrial and socio-cultural development; security of supply; and natural resource management.

Most of these effects are inter-related and can be quantified only, if ever, in a country specific context. Macroeconomic models developed recently have improved significantly the capabilities for dealing with these various parameters in an integrated framework. However, there is no single model that would allow all these aspects to be tackled and provide an estimate of their integrated overall economic impact within the time frame implied by the long term effects of choices and policies in the power sector.

With regard to nuclear power, the analysis carried out by NEA (NEA, 1992) estimated that the non-environmental externalities fall within the range of uncertainty surrounding the standard projected levelised cost of electricity generation and concluded that external costs or benefits will have no significant impact on the competitiveness of nuclear versus other alternatives.

CONCLUDING REMARKS

In most countries, direct projected costs for base load electricity generation are fairly close for coal-fired, gas-fired and nuclear power plants. Renewable sources are generally not considered for base load electricity generation and, in most cases, would not be competitive.

Choices of generation sources and technologies would, therefore, differ from country to country depending mainly on the discount rates prevailing and on the expected prices of fossil fuels. In this context, policy issues, such as security of supply, and social and environmental concerns, such as public acceptance and the potential risks of global climate change, are likely to play an important role in the decision making process for the electricity sector.

REFERENCES

European Commission 1995. *Externalities of Energy*. EC/DGXII, ISBN 92-827-5310-0, Brussels.

International Atomic Energy Agency 1991. Senior Expert Symposium on Electricity and the Environment: Key Issues Papers. IAEA, STI/PUB/899, Vienna.

International Commission on Radiological Protection 1990. Recommendations of the International Commission on Radiological Protection Publication 60. Oxford/New York

International Energy Agency, Nuclear Energy Agency 1993. Projected Costs of Generating Electricity: Update 1992. OECD, Paris [and previous reports in the series published in 1983, 1986 and 1989].

Nuclear Energy Agency 1991. Decommissioning of Nuclear Facilities. OECD, Paris.

Nuclear Energy Agency 1994. Economics of the Nuclear Fuel Cycle. OECD, Paris.

Nuclear Energy Agency 1995. Methods of Projecting Operations and Maintenance Costs for Nuclear Power Plants. OECD, Paris.

United Nations Scientific Committee on the Effects of Atomic Radiation 1994. Ionising radiation: Sources and biological Effects. UNSCEAR, New York.