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Electricity Market and Energy Policies Uncertainties for Investment in Life Time Operation of Nuclear Power Plants

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ABSTRACT

In the electricity sector, market participants must make decisions about capacity choice in a situation of radical uncertainty about future market conditions. Electricity sector is characterized by non-storability and periodic and stochastic demand fluctuations. Capacity determination is a decision for the long term, whereas production is adjusted in the short run. Today decisions pertaining to investment in new capacity or life time extension are surrounded by considerable uncertainties about the future economics of the projects. One reason is that in a deregulated market private investors typically have to bear a greater portion of the investment risk compared to a monopoly utility in a regulated market. This favours flexible investment alternatives with short-lead times and low capital requirements. Moreover, energy and climate policy – with feed-in tariffs for RES or green certificate system and the EU CO_2 ETS may add to investment uncertainties. From the economic point of view, the costs of LTO are usually lower than the construction of any other source of electricity. But in the aftermath of the Fukushima accident, policies towards nuclear energy in some countries were changed. Because of that economic life decisions are plant specific. In evaluating the future economic prospects of existing plant, the owners/utility focus on the unique circumstances of that plant and its cost and performance, and the future demand for electricity, and value of electricity. Nevertheless, quantification of the LTO costs is not an easy task. It is recognized that LTO costs are highly dependent on specific conditions related to each NPP, such as: design of the plant; NPP operating history including ageing conditions; regulatory requirements; full or partial replacement of components; refurbishment for LTO; accounting methodologies; etc. The risks that may have an impact on the economic case for the long term operation of NPP should be identified with pre mitigation impact and probability assessment.

Keywords: *Life Time Operation Nuclear Power Plant, Electricity Market, Energy Policies, Economic Analysis, Costs of Nuclear Power Plant.*

1 INTRODUCTION

NPP operating costs, capital investment costs in addition to decommissioning costs may decrease "profitability" of the NPP eventually to the extent that it could prove to be above projected wholesale electricity price on accessible markets. Therefore there are the following major tasks for economic assessment for LTO of NPPs: Evaluate the facts and circumstances that define the boundary conditions for the economics and long-term operation of NPP; ultimately marginal cost of electricity from NPP shall be determined to represent the justification of investments in all strategic upgrades required to continue operation in extended lifetime; identify scenarios that might lead to loss of competitiveness of NPP power generation; assess the risk of early closure i.e. not to continue operation after year the original lifetime of NPP; perform sensitivity analyses for the contributing parameters with the highest identified risk.

All, including additional capital expenditure necessary to meet regulatory requirements, have significant impact on the cost of nuclear power generation to the extent that is prudent to reconfirm/check the continuity of economic sustainability of NPP continues operation. The economic assessments of NPP operation for long term operation are necessary due to: required capital investment into upgrading the safety level of the plant, potential increase of operation & maintenance (O&M) costs, limited existing capacities for storage of low level and intermediate waste and spent nuclear fuel, regulation framework that may require additional capital investments, Potential increase of annual charges into national decommissioning funds, volatility of electricity market prices.

Each nuclear power plant has its own unique history of costs and performance. Large year-to-year fluctuations in costs are common for most NPPs as capital additions are undertaken and completed. Plant availability also varies from year to year as the plants undergo refuelling and planned maintenance during refuelling cycles. Also, unplanned repair outages contribute to cost and performance fluctuations.

Three types of nuclear power plant costs can have important and distinct roles in determining the economic life of individual units: historical capital costs, future capital additions (for regular operating time and for LTO), annual O&M and fuel costs.

It is important to stress that the economic evaluation of LTO measures is complicated and depends on the concrete circumstances for each plant.

Deregulation of electricity market is increasing competition and eliminating monopolies and guaranteed sales at fixed rates defined usually by government. Therefore, nuclear power plant owners endeavour to reduce the cost of plant life management.

The choice between LTO and building a new power plant, fossil-fuelled or nuclear or renewable, is influenced also by the size of the investment which is smaller for refurbishment than for a new construction.

To support the business case for extending the operating life of NPP (and delaying the start of decommissioning activities) it is need to undertake an independent economic assessment of the life extension.

Indeed, extending the operating lives of existing plants provides clear advantages. High capacity factors and low operating costs make nuclear plants some of the most economical power generators. And even when major plant components must be upgraded to extend operating life, these plants represent a cost effective, carbon-free asset that is critical to energy future. Extending the life of a major generating asset avoids the need for immediate investment in new generating capacity. The capital costs of plant life management for LTO will be smaller than investment in any type of replacement capacity, although there might be a need for additional investment in plant upgrading and safety improvements. Combining the plant upgrading and safety improvements with power uprating made lifetime extension even more cost effective. In addition, the kWh costs for waste management and decommissioning can be reduced.

In a deregulated electricity market power plant lifetime extension and upgrading are driven by cost and revenue consideration. Decision to continue operating an existing plant is based on its marginal generation cost, i.e., operation & maintenance, fuel cycle cost, taxes and capital cost compared to generation costs of other options. The marginal cost is lower for existing nuclear power plants than for most alternatives, therefore LTO is a lucrative option.

In case of Europe lifetime extension and uprating of NPPs are going hand in hand together with safety improvements. The cost for lifetime extension and consequently necessary safety upgrading are in the average €400 million per unit despite of the size.

For the purpose of economic analysis, can be identified two NPP operational life scenarios:
Scenario 1 – NPP operation to planned operating life and
Scenario 2 – Full life extension up to 20 years.

To make decision at least should be assessed the cost of each of these two scenarios to determine the most economically viable scenario. It is also need to understand the risks associated with these scenarios and the alternate power options that may be included in scenarios 1 and 2.

In addition to ranking the different NPP scenarios and alternate power options based on their LCOE, analysis of the risks associated with each option should be undertaken. This analysis should be considered along with the LCOE ranking of the options considered.

Future revenue and expenses can be determined by based on actual historic data, known future plans and the experience of NPP. Investment plan data is based, where possible, on indicative quotations that NPP has obtained for the major capital works.

2 ECONOMIC ANALYSIS FOR DECISON ON LTO OF NPP

2.1 Introduction

Responsibility for the economic performance of existing nuclear power plants and decision on life time extension lies with the utilities owning and operating them.

The objectives in nuclear plant life operation (LTO) decisions stem from broader electricity power system objectives, including the following:

- assuring adequate supplies to meet demand; minimizing the costs of electricity (including, increasingly, environmental costs);
- equitably treating both electricity consumers and plant owners in the recovery of costs; and increasingly, responding to intensifying market forces in the electric power industry.

The nuclear power plants represent a technical and financial asset with strategic significance for both the utility/corporation and the country.

Decision on life time extension includes many of the tasks associated with LTO that includes input to the corporate strategy and interaction with many corporate elements not directly associated with plant operations. These activities include economic evaluations of alternatives for major refurbishment or replacement projects as well as strategic decisions regarding use and disposition of the plant.

Today, elements for decision for LTO also depend of electricity market structure: regulated or deregulated market.

To assess the economic benefits of life time extension the following factors should be considered at regulated market:

- LTO economic dependence on a many ‘power system-level’ characteristics, including alternatives options for replacement capacity, short-term replacement energy costs during nuclear plant outages, corporate financial situation, and accounting policies
- LTO uncertainties: the long planning horizon determined by the licensing lead time, the lead time for possible replacement capacity and the period of actual operation. Furthermore the lack of industry large experience with LTO creates uncertainty about capital and operating costs, regulatory requirements and long-term plant performance.
- LTO should present interest for both customers and investors. From the viewpoint of investors and owners, the operating life of a nuclear unit will be determined primarily by its profitability rates relative to other available generation options. With respect to the customers, their major interest will be the minimisation of electricity rates.

It is not enough just to assess independently NPP and comprehensive approach in assessing the economic viability of actual operational lifetime should include a power system analysis. This means that in order to decide on economic viability of extended nuclear power generation, it should be compared the costs (or rather the present value) of this generation with the costs of replacement power. As replacement power alternatives can be generation on conventional or innovative power sources, power purchases from power exchange, contracts with independent power producers or demand side management. Based on the power system analysis, utility selects the adequate grid development scenario for the next period (usually the time interval considered is 10-20 years) to meet the demand for electricity at the minimum cost, subject to a set of financial, resource, technical, environmental and political constraints.

2.2 Cost in existing nuclear power plant

Each nuclear power plant has its own unique history of costs and performance. Large year-to-year fluctuations in costs are common for most nuclear plants as capital additions are undertaken and completed. Plant availability also varies from year to year as the plants undergo refuelling and planned maintenance during 12, 18 or 24-month refuelling cycles. Also, unplanned repair outages contribute to cost and performance fluctuations.

Because of that economic life decisions are plant specific. In evaluating the future economic prospects of existing plant, the owners/utility focus on the unique circumstances of that plant and its cost and performance, and the future demand for electricity, and value of electricity in the country.

Three types of nuclear power plant costs can have important and distinct roles in determining the economic life of individual units:

1. historical capital costs,
2. future capital additions (for regular operating time and for LTO)
3. annual O&M and fuel costs.

It is important to stress that the economic evaluation of LTO measures is complicated and depends on the concrete circumstances for each plant.

2.3 Methodology for LTO economic analysis

Nuclear power plant lifetimes are, for the most part, driven by cost and revenue consideration. In most cases, the decision to continue operating an existing plant is based upon its marginal generation cost, i.e., operation, maintenance and fuel cycle cost, and amortisation of the investment required for lifetime extension if applicable, as compared with the marginal generation costs of other options. The marginal cost is lower for existing nuclear power plants than for most alternatives. Therefore, lifetime extension generally is an attractive option from an economic viewpoint.

Deregulation of electricity market is increasing competition and eliminating monopolies and guaranteed sales at fixed rates defined usually by government. Therefore, nuclear power plant owners endeavour to reduce the cost of plant life management.

The choice between LTO and building a new power plant, fossil-fuelled or nuclear or renewable, is influenced also by the size of the investment which is smaller for refurbishment than for a new construction. The refurbishment cost of major components are in the order of tens to a few hundred million US dollars per net GWe capacity [1] but these costs are relatively smaller compared to new plant investment, but still can be significant from financing point of view.

Nuclear LTO brings additional benefits in term of electricity cost, and price, stability since fuel cycle costs represent only a small share (typically around 15-20%) of total generation costs, and are not as volatile as gas prices for example.

2.3.1 Concept of Cost

Cost is a difficult concept, as there is a whole variety of different types of costs, each meaningful and applicable in a certain context. It is important to distinguish between bookkeeping cost, opportunity cost, average cost, marginal cost, sunk cost, investment cost, variable and operational O&M costs, fuel cost, operational cost, decommissioning cost, resource cost, fuel-cycle cost, refurbishment costs, private cost, social cost, external cost, etc.

Also there is requirement that for costs should be always identified the year of the currency quoted, or mention whether the quotation is in nominal or real currency, and what the reference year is in case of the real currency.

As a second important element in the discussion on nuclear costs, it must be recognized the difference between the cost of existing plants as seen today (only marginal cost and fixed O&M costs, since the investment cost is a repaid) and a new plant (whereby the investment cost must be taken into account). It means that the cost of nuclear electricity should be compared to the cost of other generation types, like coal, gas and renewables. Theoretically speaking, economic cost is reflected by the *opportunity cost* which is the value of the best alternative good or service foregone, or still differently, a measure of what has been given up when we make a decision. [2][3].

To cover full range of the cost for nuclear electricity generation, it must be calculated total cost - the *social cost*; which is equal to the sum of private and external cost.

- *Private costs*: costs that show up in the profit-and-loss statement at the end of the year
- *External costs*: or externalities, "are costs that arise when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated, for by the first group" [4]

Cost is somewhat untouchable: it varies in time, it is geographically different (e.g., the OECD versus the non-OECD countries) [5], it furthermore depends on the viewpoint of the investor because the opportunity cost may be different - a private versus a public investor, versus a (private) concession holder in a regulated market.

The fact that investors expect a return on investment (whereby this investment competes with other possible investment choices) and that interest is to be paid on loans means that money has a *time value*, usually expressed by a *discount rate*. The discount rate, usually considered as the opportunity cost of capital.

2.3.2 Cost Elements of Nuclear Generation

The cost elements constituting a "full" cost of electricity (i.e., EUR or USD per MWh) for nuclear power plants consist of following:

a. Private costs
   i. Investment cost
   ii. Decommissioning cost
   iii. Operation & Maintenance (O&M cost)
   iv. Fuel-cycle (including the back-end) cost
b. External Costs

When looking at external costs in the nuclear area it is important to recognize that a considerable fraction of the costs linked to the harmful nature of radioactive substances basically has already been internalized, and should thus no longer be considered as an externality. Typical examples are levies that have been and are being charged both for radioactive-waste management and final disposal, and for decommissioning, for the purpose of feeding long-term funds.

A few remaining externalities (where depending on the situation they may still be part of the externalities; in other cases they should be deleted from the list).

(1) Radioactive emissions
(2) Long-term waste disposal (sometimes part of fuel cycle; often already internalized)
(3) Accidents – liability
(4) Proliferation
(5) Avoided CO_2 emissions – a positive externality?
(6) System effects

2.4 Overview

Originally, NPP was designed to operate until original planed operating life (POL). Power generation would cease in year and decommissioning would immediately commence.

Owner is considering the economic case for extending the generating life of NPP beyond its POL. NPP must, with the nuclear regulator, undertaken a technical review of NPP and determined that significant engineering works are required to support the safety case, the safety case upgrades needed to the plant to operate to planned operating life (following the post Fukashima recommendations and stress test in EU) and to meet the regulators requirements for a life extension of up to 20 years. This may require significant investment.

To support the business case for extending the operating life of NPP (and delaying the start of decommissioning activities) it is need to undertake an independent economic assessment of the life extension.

3 NPP'S REVENUE AND EXPENSES

For the purposes of economic analysis, the costs for NPP, which are required to be covered by the price that is charged for electricity, should be divided into the following categories:

1. **Nuclear fuel:** This is expected to include the cost for uranium and enrichment under the existing contract with supplier.
2. **Water tax:** Tax for use of water, including river water for cooling, by NPP.
3. **Materials and Services:** This cost line covers all the costs associated with services carried out at the NPP and materials used at the NPP. This is expected to cover the cost of spare parts, maintenance (planned and unplanned) of fixed assets, other material, services in the production process and other miscellaneous services. Salaries and related costs, as well as fuel and depreciation charges are excluded.
4. **Depreciation charge/investment costs**: The cost line covers major investment in NPP. It is identified in the NPP accounts as the depreciation charge. The depreciation charges are not calculated on the basis of amortisation rates and asset values. The depreciation charge represents the sum of the amount of investment expected to be made in a specific year (as stated in the long term investment plan) and the amount relating to repayment of the principal outstanding for the long term bank loan facility (if any). This charge also includes an amount for small scale investments relating to investment in small assets like furniture, re-roofing etc.
5. **Insurance:** This includes all insurance costs (both nuclear and non-nuclear) associated with the ongoing operation of NPP.
6. **Salaries and related costs (labour costs):** This covers basic salaries of the NPP employees along with social contributions, taxes attributable to the employees and paid by NPP, and pensions insurance.
7. **Compensation to Local Communities (CLC) paid directly by NPP (Contributions to LC)**: This represents the contribution that NPP makes directly towards the local communities for restricted use of the land, in line with government legislative requirements.
8. **All other expenses:** Includes expenses of supplementary activities; financial expenses; revaluation/withdrawals; and other expenses as included in the NPP management accounts.

4 ECONOMIC ANALYSIS BY COMPARING LTO OF NPP WITH ALTERNATE POWER GENERATION OR IMPORT OF ELECTRICITY

When considering the economics of nuclear power, it is instructive not only to focus on new build, but to reflect on the desirability, from an economics point of view, to consider *long-term operation* of existing plants, likely after appropriate refurbishment to keep the safety level of the plants in line with current expectations. Electricity generation system is currently going through almost revolutionary changes on its path towards a zero CO_2 emission target which is expected to cost considerably, it may be an interesting option to extend the operational life of NPPs beyond their originally 'estimated' design life, so as to keep a dispatchable and firm CO_2-free electricity generation technology on line at reasonably low cost. This would give the electric power sector more time to thoroughly analyse the transitional aspects of system integration with ample intermittent, decentralized and centralized, generation, with substantial non-dispatchable overcapacity. In addition, it gives reactor developers some breathing space to reflect on design changes that meet the challenges of future electricity systems, such as load-following participation, whilst still guaranteeing sufficient rotational inertia into the system to support grid stability.

Different aspects of prolonged operation of nuclear power plants is discussed in several sources in the literature ([6], [7], [8], [9], [10]), but the most updated, timely and comprehensive document on the economics of LTO has been published late 2012, by the Nuclear Energy Agency of the OECD. [11].

5 INVESTMENT COST FOR MAJOR REFURBISHMENTS FOR LTO

Plants that have been built in the past, whether or not depreciated in a bookkeeping sense, are characterized by a "sunk" investment cost. Such plants will keep operating as long as the marginal operational cost (consisting of the O&M cost and the fuel cost) is lower than the electricity market prices.

If operational costs are too high in comparison with other generation means and the market price, then it may be that owners/operators decide to shut down plants for pure economic reasons, regardless of the technical end/or safety related status of the plant. Such early retirement has taken place on May 07 2013 in the state of Wisconsin, USA, where the Kewaunee nuclear plant was shut down, even though it had received a regulatory operational extension by the NRC until 2033, because of low market prices mostly driven by cheap shale-gas electricity generation.

In other markets and circumstances, especially in Europe, where a possible shale-gas breakthrough is not obvious, it certainly makes economic sense to continue operation of existing plants. Even if safety concerns become an issue so that major refurbishment investments are necessary, it may still be advantageous in several markets to consider prolonged operation. A precondition for operational extension after refurbishment, however, is a stable political decision climate. When substantial investments are made to refurbish a plant, then an expected operational period must be part of the regulatory operational license (clearly always subject to the future safety status of the plant). The possibility for changes in future standpoints of the authorities must be foreseen in the LTO-related agreement with government authorities, with possible (contractual) compensation when a premature shutdown would be enforced.

The crucially important parameter for prolonged operation is the investment cost for refurbishment. This investment is to a large extent determined by the overnight refurbishment cost (ORC).

A set of specific overnight refurbishment costs has recently been obtained for a variety of countries by the NEA, as shown in Table 1. [11] As shown in the table post-Fukushima upgrades have been included in the numbers given.

Table 1: Cost summary of specific ‘overnight refurbishment investment cost’ in some OECD countries [11]

Country	Specific investment in LTO	Comment
Belgium	USD2010 650/kWe	Including ~11% increase due to post-Fukushima measures.
France	USD2010 1 090/kWe	Including all investments from 2011 to 2025: maintenance, refurbishment, safety upgrades, performance improvement; and ~10% increase due to post-Fukushima measures.
Hungary	USD2010 740-792/kWe	Including 10-17% increase due to post-Fukushima measures.
Korea, Republic of	USD 500/kWe	Including ~10% increase due to post-Fukushima measures.
Switzerland	USD2010 490-650/kWe	Specific future investment in NPP refurbishment and maintenance (approximately the double of the specific LTO investment) is USD2010 980-1 300/kWe.
United States	About USD2010 750/kWe	Electric Power Research Institute (EPRI) survey data and current spending on capital improvement.
Russian Federation	About USD2010 485/kWe	Data for Novovoronezh 5 unit (first series of VVER-1000: V-187).
Ukraine	About USD 300-500/kWe	Public statements by Energoatom and Ukrainian prime minister.

5.1 Economics in the decision between LTO versus new building replacement

Indeed, extending the operating lives of existing plants provides clear advantages. High capacity factors and low operating costs make nuclear plants some of the most economical power generators. And even when major plant components must be upgraded to extend operating life, these plants represent a cost effective, carbon-free asset that is critical to energy future.

Extending the life of a major generating asset avoids the need for immediate investment in new generating capacity. The capital costs of plant life management for LTO will be smaller than investment in any type of replacement capacity, although there might be a need for additional investment in plant upgrading and safety improvements. Combining the plant upgrading and safety improvements with power uprating made lifetime extension even more cost effective. In addition, the kWh costs for waste management and decommissioning can be reduced.

Nevertheless, quantification of the LTO costs is not an easy task. It is recognized that LTO costs are highly dependent on specific conditions related to each NPP, such as: design of the plant; NPP operating history including ageing conditions; condition of the critical SSCs; regulatory requirements; full or partial replacement of components; refurbishment for PLIM versus refurbishment for LTO; accounting methodologies; etc.

5.2 Economics of lifetime extension and safety improvements

In a deregulated electricity market power plant lifetime extension and upgrading are driven by cost and revenue consideration. Decision to continue operating an existing plant is based on its marginal generation cost, i.e., operation & maintenance, fuel cycle cost, taxes and capital cost compared to generation costs of other options. The marginal cost is lower for existing nuclear power plants than for most alternatives, therefore LTO is a lucrative option.

In case of Europe lifetime extension and uprating of NPPs are going hand in hand together with safety improvements. The cost for lifetime extension and consequently necessary safety upgrading are in the average €400 million per unit despite of the size. These large costs increase the generation cost during the amortisation period by 0.2 – 0.6 eurocent/kWh [8].

6 EXAMPLE OF SCENARIOS FOR ECONOMIC ANALYSIS FOR LTO

For the purpose of economic analysis, can be identified two NPP operational life scenarios:

Scenario 1 – NPP operation to planned operating life:

- NPP is partially refurbished to provide for ongoing operation to planned operating life (e.g. implementation of safety upgrade work that the regulator requires).
- Decommissioning of the NPP will commence in year after planned operating life.
- Alternate power source(s) that could be available from the start of in year after planned operating life.

Scenario 2 – Full life extension up to 20 years:

- An investment programme is implemented that allows NPP subject to ongoing regulatory requirements, to extend operational life for up to 20 years.
- Decommissioning of NPP will commence in year after extended life.
- Alternate power sources that could be available after year of extended life have not been considered as these are outside the scope of this economic analysis.

To make decision at least should be assessed the cost of each of these two scenarios to determine the most economically viable scenario. It is also need to understand the risks associated with these scenarios and the alternate power options that may be included in scenarios 1 and 2.

As a baseline to the two scenarios mentioned above, is assessed the expenses associated with NPP ongoing generating activities. The expenses include NPP's operating expenses together with remaining contributions that will need to be paid into the decommissioning fund.

The contributions that need to be paid into the decommissioning fund will vary depending on the operating lifetime of NPP in each scenario and in terms of a Levelized Cost of Electricity (LCOE) will be significantly higher in the scenarios where NPP has a shorter remaining operating life.

In order to assess the two scenarios on an equalised basis, the LCOE generation can be used to compare the cost of electricity generation (in $/MWh terms) across the different scenarios. The LCOE approach is established and widely used across the electricity industry, to compare the economics of different generating options, particularly where alternate power generation options have differing operational lives.

Once the costs of NPP's ongoing generating activities (including the payments into the decommissioning funds) for scenarios 1 and 2 is established, it should be considered the alternative power sources that may be available in the market and the costs of implementing the alternative power sources (excluding grid and infrastructure associated with the power source outside of the plant itself). For scenarios 1 and 2, a long list of alternate power options can be determined. Alternate power options SHOULD BE determined on the basis of their suitability for use as base load electricity supply from the date that NPP is assumed to cease generation. Suitability should be determined on the basis of the alternate power generation technology being in use, on a commercial basis for base load generation, at any other site in the world.

In addition to ranking the different NPP scenarios and alternate power options based on their LCOE, analysis of the risks associated with each option should be undertaken. This analysis should be considered along with the LCOE ranking of the options considered.

Future revenue and expenses can be determined by based on actual historic data, known future plans and the experience of NPP. Investment plan data is based, where possible, on indicative quotations that NPP has obtained for the major capital works.

The inputs for the decommissioning fund are based on data sources that have been previously defined by the regulator or government.

6.1 Alternate power options

When considering alternate power options, it should be noted that a replacement scheme would be likely to include a mix of alternate power generation technologies, rather than a single replacement option. For the purposes of the economic analysis, however, each alternate power option should be considered on its own, recognising that the combined impact on the LCOE would result in an LCOE for the combined alternate power generation that would be higher than the LCOE for the more economically viable alternate power source if it were to be installed on its own. Therefore, by looking at the economic viability of the alternate power options when installed independently of one another, their economic viability may be compared with the NPP life extension case.

Where alternate power could be installed, the LCOE has been determined over the stated useful economic life of that alternative power option. For example, where an alternate power option has a useful operating life of 20 years then the economic analysis has been determined over the combined duration of NPP operation in the scenario and the 20 years operational life of the alternate power option. The use of LCOE equalises this difference as for each case being considered the full useful operating life of the alternate power plant is considered.

In the case of import of electricity, the LCOE can be calculated over a period to planned operating life (POL) so that it aligns with the NPP life extension scenario (Scenario 2). In the case of import of power there are many influences that may result in changes to the real cost of imported electricity over the duration being considered in the analysis. Review of historic baseload energy prices from the surrounding region should be undertaken to identify and confirm correlating regional electricity markets that may be used as a source of traded futures price data.

For each alternate power generation option, the development period has to be stated, along with the overnight investment cost per MW of installed capacity.

For the purpose of this economic analysis, alternate power options should be sized to deliver similar baseload electricity. Based on the future assumed capacity factor for NPP the equivalent annual electricity production should be, Which has been used as the required total useful energy production from alternate power options. The required installed plant size (or combined plant size where multiple plant is required) should be determined so that an annual amount of electricity that is equivalent to NPP is achieved. Import of electricity should be assessed on the same basis.

Where alternate power generation capacity of the required size is not available, i.e. in the case of new nuclear power plant, then it is assumed that additional capacity may be installed and that the spare capacity may be sold to other buyers for the same price.

The costs that are included in the LCOE calculation shall include all costs associated with generation of electricity, but shall not include costs associated with electricity grid infrastructure, supporting infrastructure and transmission charges. For all alternate power options there is likely to be a varying degree of additional grid infrastructure and associated infrastructure costs, and for certain options there will be ongoing costs for the grid operator as a result of incorporation of the alternate power option into the grid.

LCOE is not a complete and single method of assessing the economic benefit of an electricity source for the following reasons:

(a) The LCOE approach does not adequately reflect the market realities characterised by uncertainties and dynamic pricing.
(b) The LCOE approach provides generation costs at the plant level and does not include the network costs of a power system.
(c) The LCOE approach reveals little information on the contribution of a given technology to addressing energy.
(d) The LCOE does not indicate the relative likely stability of production costs over a plant's lifetime, and therefore the potential contribution to cost and possibly price stability.

6.2 Imported baseload electricity

Historic power price data should be used, with caution, as a general indicator of possible future prices. Where liquid power exchanges exist, and futures prices are available, this provides the best indication of short term future trends. Analysis of recent historic data may also be used to identify correlated markets.

It should be taken into account when considering cases that assume the use of imported electricity that the generating capacity of countries with ability to supply base load electricity on a long term basis should be assessed.

7 REPLACEMENT POWER GENERATION

Potential replacement power generation options should be considered. A long list of alternate power generation options should be determined, that may provide direct replacement of NPP for the purposes of baseload electricity generation. An equivalent annual electricity production requirement should be also assumed.

In the first instance, the long list of alternate power options can be prepared, along with an initial qualitative assessment of each alternate power option against a set of criteria that are considered likely to influence the successful implementation of that power option from a non-economic perspective.

Source for Replacement Power: New Solar, New Wind, Biomass, New CCGT, New Hydro, New Coal, New nuclear Power Plant.

Needed Characteristic for Replacement Power: required energy output (GWh/y); capacity factor assessment; required installed power (in MW); construction duration (initial decision to commercial operation).

It should be developed criteria for qualitative assessment of alternate power options: For example some criteria can be: is alternate power suitable for base load electricity (is it dispatchable), alignment with policy on CO_2 emissions, including national targets, aligned with other environmental policy, technically feasible within country, alignment with policy around high reliance on imported fuel, aligned with policy on diversity of supply.

The carbon cost, per tonne of CO_2 produced as a result of generation, for relevant generation technologies, should be stated and be on a consistent basis for all applicable energy sources.

Incentive payments are not included in the current LCOE calculations and should not be included unless there is long term contractual certainty regarding their payment.

Transmission costs, grid infrastructure and other external costs associated with grid enhancement works or ongoing grid stability operations may be included in the scope of analysis. There may also be additional costs associated with achieving a similar level of grid stability to that achieved currently, with NPP operational on the grid. These costs would be incurred under certain alternate power options and it is likely that the grid operators would look to recover these costs through grid connection charges. These costs should be taken into account as additional costs, when considering decisions related to alternate power sources.

National policy should be considered, with a particular focus on areas of policy which are considered likely to have an influence on the economic and risk analysis project.

Before any formal investment decision on alternate options is taken, a full review of the prevailing policy and regulatory framework should be undertaken to confirm that the policy and regulation has not been updated or superseded.

The decline in the demand for energy generally causes the price for energy to drop. As the recession, technologies with improved energy efficiency, energy efficiency policies lift the demand for energy and electricity it is likely to decrease the price of electricity.

For the purpose of analysis, it should be performed detailed analysis on the impact of different sensitivities on the LCOE for each scenario.

7.1 New nuclear plant to replace NPP

As it may not be possible to build a power plant that is smaller than 1,000 MW in today's market, there would be a surplus generating capacity at beginning of operation. This spare generating capacity will need to be sold to a third party. The LCOE calculation in this case assumes that the additional capex and the operating costs associated with the spare capacity will be covered by long term power purchase agreements with third parties.

There is a risk however that it may not be possible to obtain long term power purchase agreements for this additional capacity. If this is the case, then the additional investment cost and O&M costs associated with the spare capacity would have to be included in the LCOE calculation and would significantly increase the LCOE further.

The availability of finance to support the significant investment associated with new nuclear power plant construction, and the impact on the sponsors balance sheet and credit rating should be considered in this analysis.

8 DECOMMISSIONING COSTS

The different costs associated with decommissioning of the NPP and the disposal of low and intermediate level waste (LILW) and spent fuel should be considered. It can be assumed that all decommissioning and waste management costs will be funded by decommissioning fund.

For the purposes of the economic analysis, two scenarios can be considered:

1. Shutdown as envisaged in original licence (Scenario 1)
2. Changes to the quantum and the timing of decommissioning costs if the life extension works are completed and the NPP shuts down is posponed (Scenario 2).

Definitions for the sub categories that make up the total decommissioning cost:

1. NPP dismantling (or NPP Decommissioning): This is assumed to reflect the costs associated with the onsite transportation, storage, decontamination and removal of the main components and the reactor vessel, demolishing of the buildings and complete restoration of the site.
2. Spent Fuel (SF) disposal: This is assumed to include the construction costs associated with building the SF repository (and/or the deep geological repository for High Level Waste (HLW)).
3. SF Storage and transport to disposal site: This is assumed to reflect costs for construction of the dry storage facility if needed, procurement of any containers and the transportation of spent fuel from the spent fuel pit to the dry storage facility at generic site.

9 RISK ANALYSIS

The risks that may have an impact on the economic case for the long term operation of NPP should be identified. A list of risks has to be prepared. The list of risks has to be prepared with pre mitigation impact and probability assessment. Mitigating actions has also to be proposed where considered appropriate.

1. **Political and policy risks*:*** These risks cover the impact of changes in policy relating to the use of nuclear power plants to operate. Other policy changes may include changes to the national radioactive waste and used fuel management/ decommissioning. There is also a risk that NPP may be required to pay additional taxes as a result of changes to the tax regime that adversely impact nuclear power compared to other sources making NPP a more expensive source of electricity.
2. **Business and economic risks*:*** These risks broadly relate to unexpected adverse changes in the national economy, risks with regards to the projections data/assumptions that have been provided by for the purposes of this economic analysis and also risks relating to the base decommissioning costs for NPP. Another key risk is the impact that fluctuating inflation.
3. **Social risks:** These risks relate to impact of stakeholders on the NPP life extension option. There is a risk that the general public and other stakeholders may set requirements for NPP that are difficult to meet due to the perceived radiological risks.
4. **Technical risks:** These risks relate to the safety status of the power generation technology, ability of the plant to operate at high availability and capacity factors, duration for construction and commercial operation given the programme requirement, extreme weather conditions etc. i.e., any risks resulting in mechanical or safety issues which affect the operation of the plant.
5. **Legal and regulatory risks:** These risks relate to the impact of changes in national or other international laws and regulations with respect to use of nuclear energy or the impact that implementation of additional safety upgrade requirements will have on the life extension of NPP.

The majority of the risks identified in the list of risks, under the above categories, may have an impact on the costs for NPP. The key risks are:

1. NPP's capacity factor will decline over NPP's extended life.
2. Base decommissioning cost assumptions that were originally agreed may have changed significantly.
3. NPP's projected operating cost uncertainty.
4. NPP's projected investment costs may vary over the next 30 years.

Once ranked by LCOE, a qualitative assessment of risks associated with each option should be undertaken. This assessment has to consider a series of risks, including the following:

- Political and policy risks
    - Whether the alternate power option would have an impact on national commitments to climate change
    - Whether the alternate power option is aligned with security of supply and diversity of supply policy for the Ultimate Owners and the European Union
    - Long term availability of subsidies or incentives
    - Future environmental charges, such as carbon charges
- Economic risks
    - Inflation of costs
    - Discount rates
    - Electricity prices in neighbouring countries or attainable markets as well as price of services and materials
- Technical risks
    - Availability of suitable/ technically feasible sites

- Availability of sites for building a (or multiple) power plant(s) to match the scale required to replace NPP.
- The likely amount of additional grid investment required to incorporate the alternate power option
- Whether the alternate power option can be constructed in the time available prior to NPP stopping generation for the given scenario

- Legal and legislative
  - Existing contract durations and contract replacement
  - Legislative changes
  - Risk associated with expiry of nuclear fuel contracts.

10 CONCLUSION

Capacity determination is a decision for the long term, whereas production is adjusted in the short run. Paper looks on the main contributions in investment planning under uncertainty, in particular in the electricity market for capital intensive investments like NPP. The relationship between market and non-market factors in determining investment signals in competitive electricity markets is analysed. Paper analyse the ability of competitive electricity markets to deliver the desired quantity and type of generation capacity and also investigates the variety of market imperfections operating in electricity generation and their impact on long-term dynamics for generation capacity.

Today decisions pertaining to investment in new capacity or life time extension are surrounded by considerable uncertainties about the future economics of the projects. One reason is that in a deregulated market private investors typically have to bear a greater portion of the investment risk compared to a monopoly utility in a regulated market. This favours flexible investment alternatives with short-lead times and low capital requirements. Moreover, energy and climate policy – with feed-in tariffs for RES or green certificate system and the European emission trading systems for CO_2 (EU ETS) - may add to investment uncertainties. Delayed and uncertain permitting processes also increase investors' risks.

Competitive wholesale markets for electricity and energy often fail to provide adequate net revenues to attract investment in generation to meet reliability criteria. In addition, it is also argued that short-term price volatility is more extreme and frequent than in other commodity markets, because storage for electricity is too costly for commercial application. The liberalization of electricity markets shows that the fate of nuclear is strongly affected by energy market structure. In liberalized markets investments are profit motivated, with the choice of technology left to the market. The redistribution of risk among the different stakeholders is likely to make nuclear generation unattractive for an investor, even when its levelized costs are similar to the levelized costs of the dominant technology, for several reasons.

Current electricity price on EU Power Exchanges and CO2 allowances are so low that no new power plant even life time extension of NPP can be competitive on electricity market and that almost all investment will be in renewable energy sources because of support schemes.

From the economic point of view, the costs of LTO are usually lower than the construction of any other source of electricity. But in the aftermath of the Fukushima accident, policies towards nuclear energy in some countries were changed.

All, including additional capital expenditure necessary to meet regulatory requirements, have significant impact on the cost of nuclear power generation to the extent that is prudent to reconfirm/check the continuity of economic sustainability of NPP continues operation. The economic assessments of NPP operation for long term operation are necessary due to: Required capital investment into upgrading the safety level of the plant, Potential increase of operation & maintenance (O&M) costs, Limited existing capacities for storage of low level and intermediate waste and spent nuclear fuel, Regulation framework that may require additional capital investments, Potential increase of annual charges into national decommissioning funds, Volatility of electricity market prices.

Each nuclear power plant has its own unique history of costs and performance. Large year-to-year fluctuations in costs are common for most NPPs as capital additions are undertaken and completed. Plant availability also varies from year to year as the plants undergo refuelling and planned maintenance during refuelling cycles. Also, unplanned repair outages contribute to cost and performance fluctuations.

Because of that economic life decisions are plant specific. In evaluating the future economic prospects of existing plant, the owners/utility focus on the unique circumstances of that plant and its cost and performance, and the future demand for electricity, and value of electricity in the country.

Three types of nuclear power plant costs can have important and distinct roles in determining the economic life of individual units: historical capital costs, future capital additions (for regular operating time and for LTO), annual O&M and fuel costs.

It is important to stress that the economic evaluation of LTO measures is complicated and depends on the concrete circumstances for each plant.

The choice between LTO and building a new power plant, fossil-fuelled or nuclear or renewable, is influenced also by the size of the investment which is smaller for refurbishment than for a new construction.

To support the business case for extending the operating life of NPP (and delaying the start of decommissioning activities) it is need to undertake an independent economic assessment of the life extension.

Indeed, extending the operating lives of existing plants provides clear advantages. High capacity factors and low operating costs make nuclear plants some of the most economical power generators. And even when major plant components must be upgraded to extend operating life, these plants represent a cost effective, carbon-free asset that is critical to energy future.

Extending the life of a major generating asset avoids the need for immediate investment in new generating capacity. The capital costs of plant life management for LTO will be smaller than investment in any type of replacement capacity, although there might be a need for additional investment in plant upgrading and safety improvements. Combining the plant upgrading and safety improvements with power uprating made lifetime extension even more cost effective. In addition, the kWh costs for waste management and decommissioning can be reduced.

Nevertheless, quantification of the LTO costs is not an easy task. It is recognized that LTO costs are highly dependent on specific conditions related to each NPP, such as: design of the plant; NPP operating history including ageing conditions; condition of the critical SSCs; regulatory requirements; full or partial replacement of components; refurbishment for PLIM versus refurbishment for LTO; accounting methodologies; etc.

In a deregulated electricity market power plant lifetime extension and upgrading are driven by cost and revenue consideration. Decision to continue operating an existing plant is based on its marginal generation cost, i.e., operation & maintenance, fuel cycle cost, taxes and capital cost compared to generation costs of other options. The marginal cost is lower for existing nuclear power plants than for most alternatives, therefore LTO is a lucrative option. Lifetime extension and uprating of NPPs are going hand in hand together with safety improvements.

For the purpose of economic analysis, can be identified two NPP operational life scenarios:

Scenario 1 – NPP operation to planned operating life and Scenario 2 – Full life extension up to 20 years.

To make decision at least should be assessed the cost of each of these two scenarios to determine the most economically viable scenario. It is also need to understand the risks associated with these scenarios and the alternate power options that may be included in scenarios 1 and 2.

In addition to ranking the different NPP scenarios and alternate power options based on their LCOE, analysis of the risks associated with each option should be undertaken. This analysis should be considered along with the LCOE ranking of the options considered.

Future revenue and expenses can be determined by based on actual historic data, known future plans and the experience of NPP. Investment plan data is based, where possible, on indicative quotations that NPP has obtained for the major capital works.

The risks that may have an impact on the economic case for the long term operation of NPP should be identified. A list of risks has to be prepared. The list of risks has to be prepared with pre mitigation impact and probability assessment: Political and policy risks; Business and economic risks; Social risks; Technical risks; Legal and regulatory risks, Mitigating actions has also to be proposed where considered appropriate.

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