Economic Analysis of Nuclear Power Generation

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Abstract

Nuclear power is an important option for energy demand mitigation without emitting carbon di-oxide, methane which are largely responsible for greenhouse effect. Nuclear power needs high cost for constructing the plant and relatively low cost to run. Nuclear energy is competitive with fossil fuels as a means of electricity generation. If the social, health and environmental costs of fossil fuels are taken into account, the economics of nuclear power is outstanding.

Capital cost which is required for the construction of a nuclear power plant represents almost 60% of the total cost of nuclear electricity. Moreover operating cost helps to know the costing during operation of a nuclear power plant. Waste disposal and decommissioning cost should be taken into account to make proper management after the life of a power plant.

The Net Present Value (NPV) analysis of nuclear plant is very important because it gives us the current value of money that is invested in long-term projects. The positive NPV of a power plant is always desired. A positive NPV means that the return on an investment is higher than the required rate of return.

The analysis of levelized cost gives per unit electricity cost of nuclear power plant. This cost is equivalent to the average price that consumers will have to pay for the plant operators and investors to offset the expenditure and to repay a proper amount of return. Annuity analysis provides income from a nuclear power plant over a year.

The sensitivity analysis of nuclear economics includes the factors that influences the costing of the nuclear power plant. The cost of a nuclear power plant is sensitive to different factors such as investment cost, emission pricing, interest rate, lifetime etc.

Moreover large capital costs for nuclear power, and the relatively long construction period, leading to a substantial period of uncertainty before the power plant is able to begin generating revenue. On the other hand competent project management can reduce costs through more efficient work sequences, higher productivity, shorter activity durations and the parallel reduction of accumulated interest during construction of nuclear power plants.

New nuclear power plants should now be regarded as good long-term investment prospects. Once the initial significant capital cost is overcome, nuclear power plants can offer electricity at reasonably low costs for 60 years of operating life. Investment in nuclear power plant should therefore be attractive to industrial companies who require significant base-load amounts of low cost power for their operations in the long run.

This paper reports the economic aspects of nuclear power generation in the present context.

KEYWORDS: ***Nuclear Power, Levelized Cost, Net Present Value, Annuity Analysis***

INTRODUCTION

In recent year nuclear power has become one of the main sources for the energy satisfaction. Nuclear energy occurs through the fission process of atoms (when atoms split), which creates energy in the form of heat. Moreover it is considered the most carbon free source of energy and so it is considered as the most environmental friendly electricity production process.

According to World Nuclear Association (WNA) (2005) in most industrialized countries today, new nuclear power plants (NPPs) offer the most economical way to generate electricity, even without consideration of the geopolitical and environmental advantages.

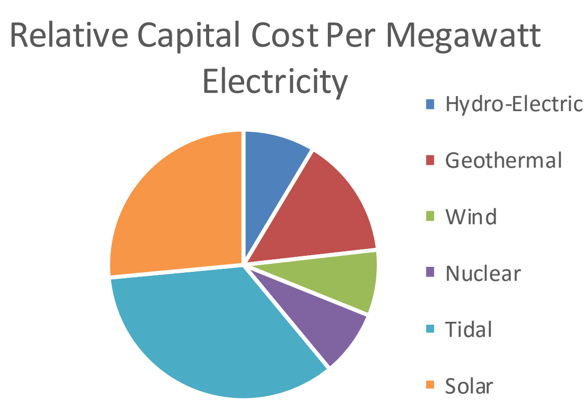
According to International Atomic Energy Agency (IAEA) 30 countries worldwide are operating 438 nuclear reactors for electricity generation and 67 new nuclear plants are under construction in 15 countries. Moreover 96 more reactors are reported to IAEA as planned.

OBJECTIVE

The objectives of this paper is to study about the cost analysis and the economics of nuclear power plant. Moreover this paper gives one the clear concept on the costing of nuclear power generation.

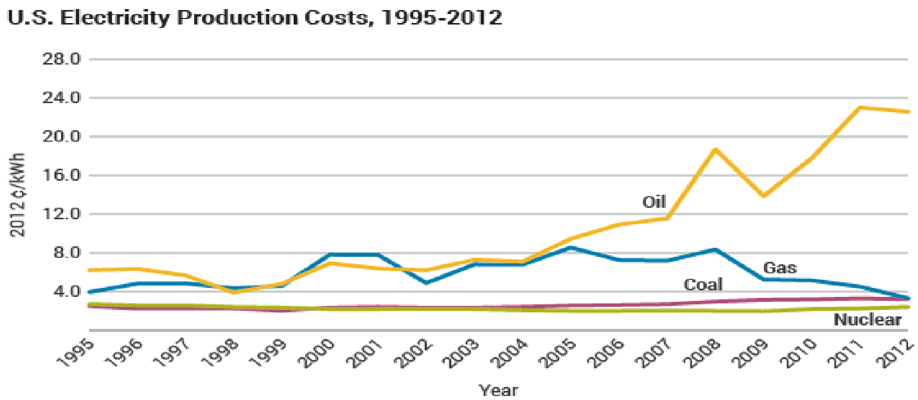
CAPITAL COST

Capital cost is one of the most important costing for the establishment of a nuclear power plant. It also include the cost of site preparation, construction, manufacture, commissioning and financing a nuclear power plant. Capital cost is the costing mainly required for the construction and financing of nuclear power plants. It takes huge percentage of the cost of nuclear electricity. In 2014, the US Energy Information Administration estimated that for new nuclear plants going online in 2019, capital costs will make up 74% of the levelized cost of electricity; higher than the capital percentages for fossil-fuel power plants (63% for coal, 22% for natural gas), and lower than the capital percentages for some other non-fossil fuel sources (80% for wind, 88% for solar PV). Many plants were also completed at a time of high general inflation, which dramatically exacerbated the impact of delays. With relatively few new nuclear plants constructed in the past decade, the amount of information on the costs of building modern nuclear plants is inevitably somewhat limited.
The pi-chart of relative capital cost of electricity generation from different sources is given in the next page

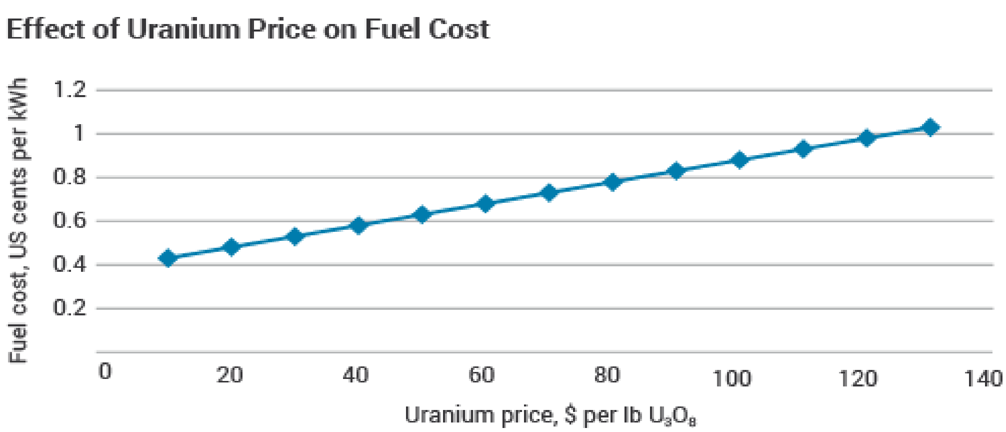


OPERATING COST

The operating cost of a nuclear power plant includes cost for the operation, maintenance and fuel cost of a nuclear power plant. Fuel costs account for about 28% of a nuclear plant's operating expenses. Uranium is the main fuel for the operation of a nuclear power plant. Uranium, however, has to be processed, enriched and fabricated into fuel elements, and about half of the cost is due to enrichment and fabrication. In some cases operating cost can considered as production cost by including maintenance cost and fuel cost of the nuclear power plant. US figures for 2012 published by NEI show the general picture, with nuclear generating power at 2.40 c/kWh, compared with coal at 3.27 cents and gas at 3.40 cents. Moreover in the graph below the production cost in nuclear power at different years is shown.



In most cases fuel used in nuclear power plant is Uranium (U_3O_8). So the costing for Uranium will influences the production cost of nuclear power plant. Doubling the uranium price (say from \$25 to \$50 per lb U_3O_8) takes the fuel cost up from 0.50 to 0.62 US cents per kWh, an increase of one quarter, and the expected cost of generation of the best US plants from 1.3 US cents per kWh to 1.42 cents per kWh (an increase of almost 10%). So while there is some impact, it is comparatively minor, especially by comparison with the impact of gas prices on the economics of gas generating plants. Now from the above discussion it known with increment of fuel cost the cost for electricity generation increases but it is too much small for the nuclear power plant electricity generation and relatively large for the other power generation plant. The impact of varying the uranium price in isolation is shown below in a worked example of a typical US plant, assuming no alteration in the tails assay at the enrichment plant.



The above figure shows the variation of fuel cost with the variation of Uranium price.

External Cost

External cost, in case of nuclear power plant, are not included in the building and operation of any power plant, and are not paid by the electricity consumer, but by the community generally. The external cost is directly related to health and weather which are quantifiable but not related to the cost of electricity production. The external costs used to calculate this indicator are based upon the sum of three components: climate change damage costs associated with emissions of CO2; damage costs (such as impacts on health, crops etc.) associated with other air pollutants (NOx, SO_2, NMVOCs, PM10, NH_3), and other non-environmental social costs for non-fossil electricity-generating technologies.

Any other electricity production power plant, other than wind running power plant, causes more cost than nuclear power plant. Nuclear energy averages 0.4 euro cents/kWh, much the same as hydro, coal is over 4.0 cents (4.1-7.3), gas ranges 1.3-2.3 cents and only wind shows up better than nuclear, at 0.1-0.2 cents/kWh average. At the time of electricity production by nuclear power plant there will be radiative emission which is responsible for global warming. External cost is also needed for the reduction and filtration of radiative emission during electricity production by nuclear power plant.

Levelized Cost

Levelized cost of electricity also known as levelized energy cost is the net present value of the unit-cost of electricity over the lifetime of a generating asset. Levelized cost includes three factors such as capital cost, operation & maintenance costs and the fuel costs. Levelized cost is equivalent to the average price that would have to be paid by consumers to repay exactly for capital cost, operation & maintenance costs and the fuel costs with a proper discount rate. Typically the levelized cost is calculated over the design lifetime of a plant, which is usually 20 to 40 years, and given in the units of currency per kilowatt-hour or megawatt-day.

The levelized cost is that value for which an equal-valued fixed revenue delivered over the life of the asset's generating profile would cause the project to break even. This can be roughly calculated as the net present value of all costs over the lifetime of the asset divided by the total electrical energy output of the asset.

The levelized cost of electricity is given by: [1]

$$Levelized\ Cost = \frac{Sum\ of\ Costs\ Over\ The\ Lifetime}{Sum\ of\ Electrical\ Energy\ Produced\ in\ The\ Lifetime}$$

$$= \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where ---

I_t : Investment expenditures in the year *t*

M_t : Operations and maintenance expenditures in the year *t*

F_t : Fuel expenditures in the year *t*

E_t : Electrical energy generated in the year *t*

r: Discount rate

t : Expected lifetime of system or power station

NET PRESENT VALUE

Net Present Value (NPV) is a measurement of the profitability of an undertaking that is calculated by subtracting the present values (PV) of cash outflows (including initial cost) from the present values of cash inflows over a period of time.

The difference between incomes and expenses produces the net benefit. During the construction period there is no net income, and the investment produces a negative benefit, after start-up a positive profit is produced during the plant's lifetime. This will produce a time dependent profit or net income that could be levelized using a discount rate. This levelized net income is also called Net Present Value (NPV). If the electricity price is constant and is equal to the levelized lifetime cost, the NPV is zero because at that discount rate, levelized income exactly equals the levelized expenses. Projects with NPV > 0 increases investors return and projects with NPV < 0 decreases investors return.

Given the (period, cash flow) pairs (t, R_t), the net present value (NPV) is given by ---

$$NPV\ (i, N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

Where ---

N: Total number of periods
t: The time of the cash flow
i: The discount rate
R_t: R_t: The net cash flow i.e. (cash inflow – cash outflow) at time *t*

INTERNAL RATE OF RETURN

The internal rate of return (*IRR)* is one of the most frequently-used method for assessing investment opportunities. It is an iterative procedure that determines the unknown discount rate that is needed to balance the stream of expenditures and income. The *IRR* is defined as the discount rate for which the *NPV* of a project is zero. The discount rate is sometimes taken at a somewhat higher value than IRR, with the argument presented that the rate of return must be above the cost of the funds or there would be no interest in the investment. In that case it needs to be taken as a necessary condition, but not as a sufficient one.

$$\sum_{t=0}^{N} \frac{R_t}{(1+IRR)^t} = 0$$

By solving this equation numerically we can find the IRR. For the IRR, the decision rules are as follows :

If IRR > hurdle rate, accept the project

If IRR< hurdle rate, reject the project

Annuity Analysis

An annuity is a series of equal payments at regular intervals. It is a financial instrument designed to provide a more secure financial future. If the number of payments is known in advance, the annuity is an annuity certain or guaranteed annuity. Valuation of annuities certain may be calculated using formulas depending on the timing of payments.

Annuity is calculated by the given method:

$AF\ (i, n) = \frac{i}{1-(1+i)^{-n}}$

$A = AF\ (i, n) \times I$

$A = \frac{i}{1-(1+i)^{-n}} \times I$

Where ---

I = Investment

A = Equal annual payment = Annuity

i = Interest rate

n = Economic lifetime of the investment

AF (i, n) = Annuity factor for period of *n* years and annual interest rate of *i*

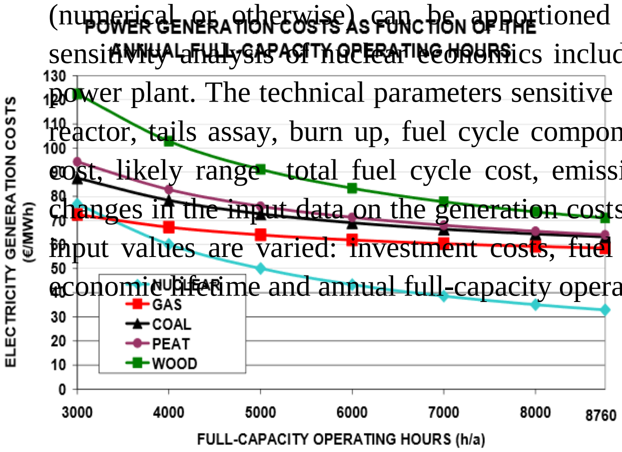
For an example, Investment *(I)* is 500 million, interest rate *(i) is 8 % and* economic life time of the investment is 40 years then,

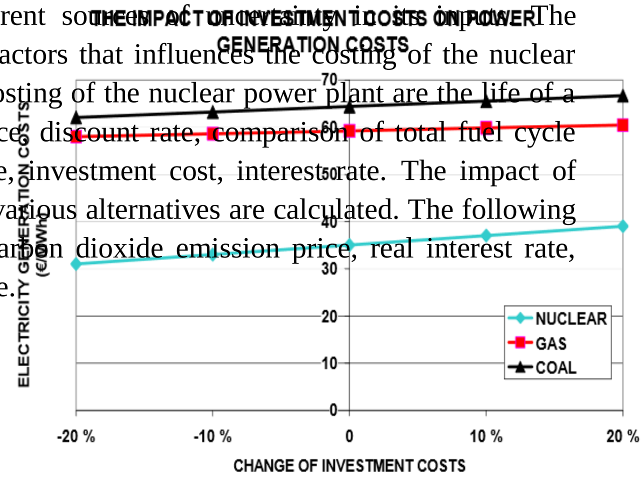
$AF\ (8\%, 40) = \frac{0.08}{1-(1+0.08)^{-40}} = 8.386\%$

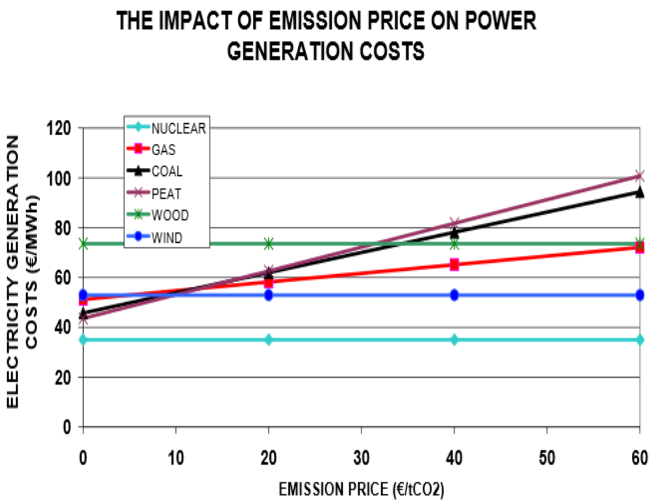
$A = AF\ (8\%, 40) \times 500 = 41.93$ million

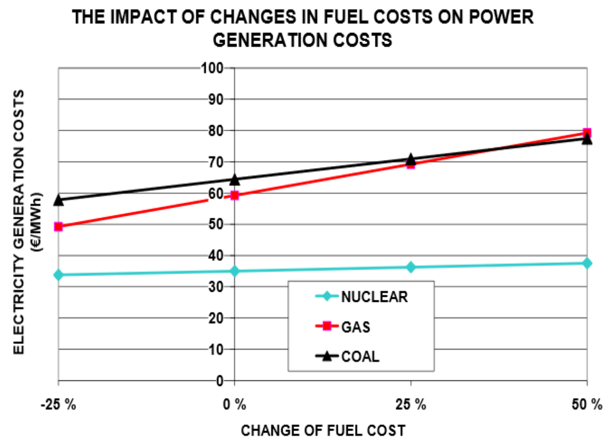
Sensitivity Analysis

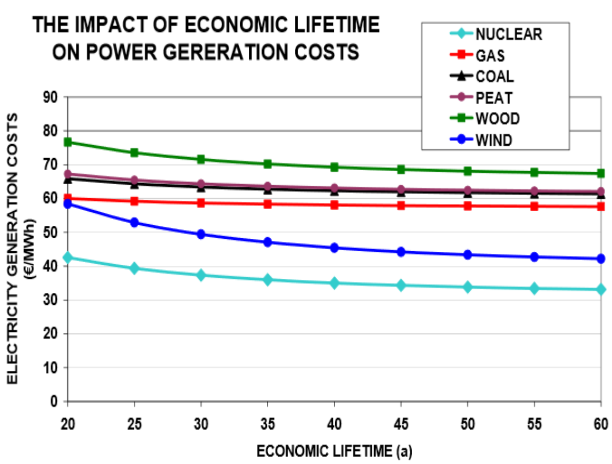
Sensitivity analysis is the study of how the uncertainty in the output of a mathematical model or system (numerical or otherwise) can be apportioned to different sources of uncertainty in its inputs. The sensitivity analysis of nuclear economics includes the factors that influences the costing of the nuclear power plant. The technical parameters sensitive to the costing of the nuclear power plant are the life of a reactor, tails assay, burn up, fuel cycle components prices, discount rate, comparison of total fuel cycle cost, likely range total fuel cycle cost, emission price, investment cost, interest rate. The impact of changes in the input data on the generation costs of the various alternatives are calculated. The following input values are varied: investment costs, fuel costs, carbon dioxide emission price, real interest rate, economic lifetime and annual full-capacity operating time.

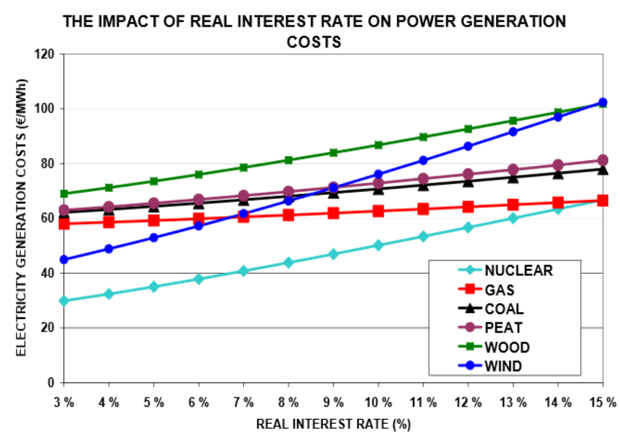










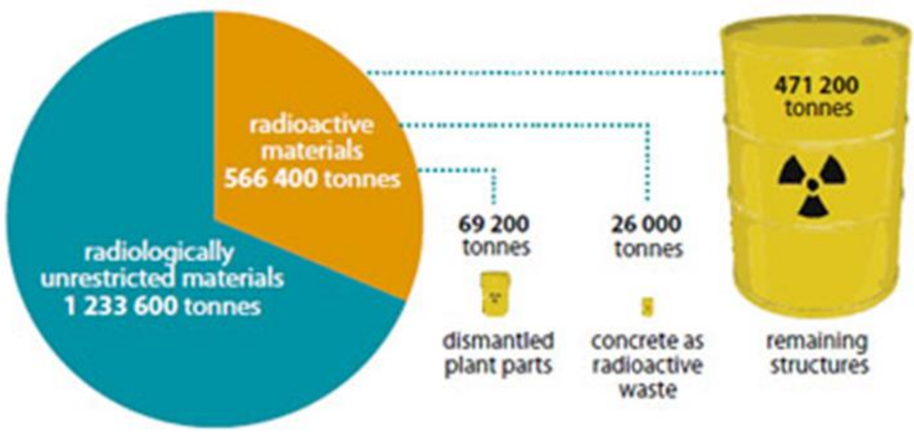


Waste Disposal Cost

All nuclear plants produce radioactive waste. The cost of storing, transporting and disposing these wastes in a permanent location is to be considered in the total waste disposal costing of nuclear power plant. Presently, waste is mainly stored at individual reactor sites and there are over 430 locations around the world where radioactive material continues to accumulate. A centralized underground repositories which are well-managed, guarded, and monitored, would be a vast improvement for the waste disposal of nuclear power plant. In the current statistics there are no commercial scale purpose built underground repositories in operation. The Waste Isolation Pilot Plant (WIPP) in New Mexico has been taking nuclear waste since 1999 from production reactors, but as the name suggests is a research and development facility. A radiation leak at WIPP in 2014 brought renewed attention to the need for R&D on disposal or radioactive waste and spent fuel.

DECOMMISSIONING

If nuclear power plant is longer economically viable, nuclear reactors and uranium enrichment facilities are generally decommissioned, returning the facility and its parts to a safe enough level to be entrusted for other uses, such as green-field status. After a cooling-off period that may last decades, reactor core materials are dismantled and cut into small pieces to be packed in containers for interim storage or transmutation experiments. The process is expensive, time-consuming, dangerous for workers and potentially hazardous to the natural environment as it presents opportunities for human error, accidents or sabotage, but it is too small in comparison with facilities of production of electricity in nuclear power plant. Decommissioning costs are about 9-15% of the initial capital cost of a nuclear power plant. But when discounted, they contribute only a few percent to the investment cost and even less to the generation cost. In the USA they account for 0.1-0.2 cent/kWh, which is no more than 5% of the cost of the electricity produced. As of January 2012, 138 civilian nuclear power reactors had been shut down in 19 countries, including 28 in Germany, 12 in France, 9 in Japan and 5 in Russian Federation. Decommissioning has only been completed for 17 of them, so far. Decommissioning of these nuclear power reactors are given below.



LOAD FACTOR

In electrical engineering the load factor is defined as the average load divided by the peak load in a specified time period.

$$f_{\text{load}} = \frac{Average\ load}{Maximum\ load\ in\ given\ time\ period}$$

It is usually derived from the load profile of the specific device or system of devices. Its value is always less than one because maximum demand is always higher than average demand, since facilities likely never operate at full capacity for the duration of an entire 24-hour day. A high load factor means power usage is relatively constant. Low load factor shows that occasionally a high demand is set. To service that peak, capacity is sitting idle for long periods, thereby imposing higher costs on the system.

Capacity Factor

A percent which indicates the utilized fraction of the plant's maximum capacity to produce electricity. The net capacity of a power plant is the ratio of its actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity continuously over the same period of time. In case of electricity production capacity factor is defined as the ratio of the total amount of electricity produced by the plant during a period of time and the amount of electricity would have produced at its full capacity.

$$\text{Capacity Factor} = \frac{electricity\ production\ over\ a\ period\ of\ time}{electricity\ production\ at\ full\ capacity}$$

Moreover capacity is mainly dependent of fuel which is used for electricity production and the design of the plant.

Conclusion

With an increasing appetite for the consumption of electricity, it is very important to implement Nuclear Power Plants for the generation of electricity. Electricity generation costs of the nuclear power are stable. The growth of the uranium price causes only a slight increase in the nuclear electricity cost, whereas the gas alternative is sensitive to the changes of the fuel price. The increasing use of gas in Europe causes a risk for considerable growth of the gas price which would lead to higher generation cost of the gas power. The impact of investment cost is greatest for the nuclear power. However, even quite big increase of the investment cost does not change the competitiveness.

The sensitivity analysis reveals that the nuclear power maintains well its competitiveness compared to the other electricity generation forms. Some changes in the input data, such as the growth of fuel prices and emission prices, make the competitiveness of the nuclear power even better. Emission trading will increase the electricity generation costs of gas, coal and peat-based power plants – perhaps even remarkably. Consequently, the advantages of nuclear power will still be improved.

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