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Carbon Pricing, Power Markets and the Competitiveness of Nuclear Power

Executive Summary

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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Executive summary

The pricing of greenhouse gas emissions has increasingly become a reality in industrialised countries trying to attain their emission reduction targets defined under the 1997 Kyoto Protocol. Given that carbon dioxide (CO_2) emissions, also referred to as "carbon emissions", constitute the largest and most easily measurable share of greenhouse gas emissions (76% of the global total), it is no surprise that emission reduction efforts are concentrated in this area. Roughly 80% of CO_2 emissions are due to the burning of fossil fuels and of these roughly 40% are due to the generation of electricity and heat in the power sector, where the burning of coal contributes about three quarters of all carbon emissions. The question is what will be the role of nuclear energy once efforts to reduce these emissions have begun in earnest.

The accident at the Fukushima Daiichi nuclear power plant in Japan in March 2011 has of course questioned a number of assumptions in the nuclear power industry and in the energy industry at large. Nevertheless, the reality of climate change and of measures to reduce greenhouse gas emissions, among which carbon pricing is the most prominent and likely to be the most efficient, will not go away (see Box ES.1). In addition, the powerful trend in OECD countries towards more liberalised power markets that is driven by long-term developments in information technology, network management, regulatory and managerial progress, and increased consumer awareness will continue.

Box ES.1: How realistic is the NEA's carbon price analysis after Fukushima?

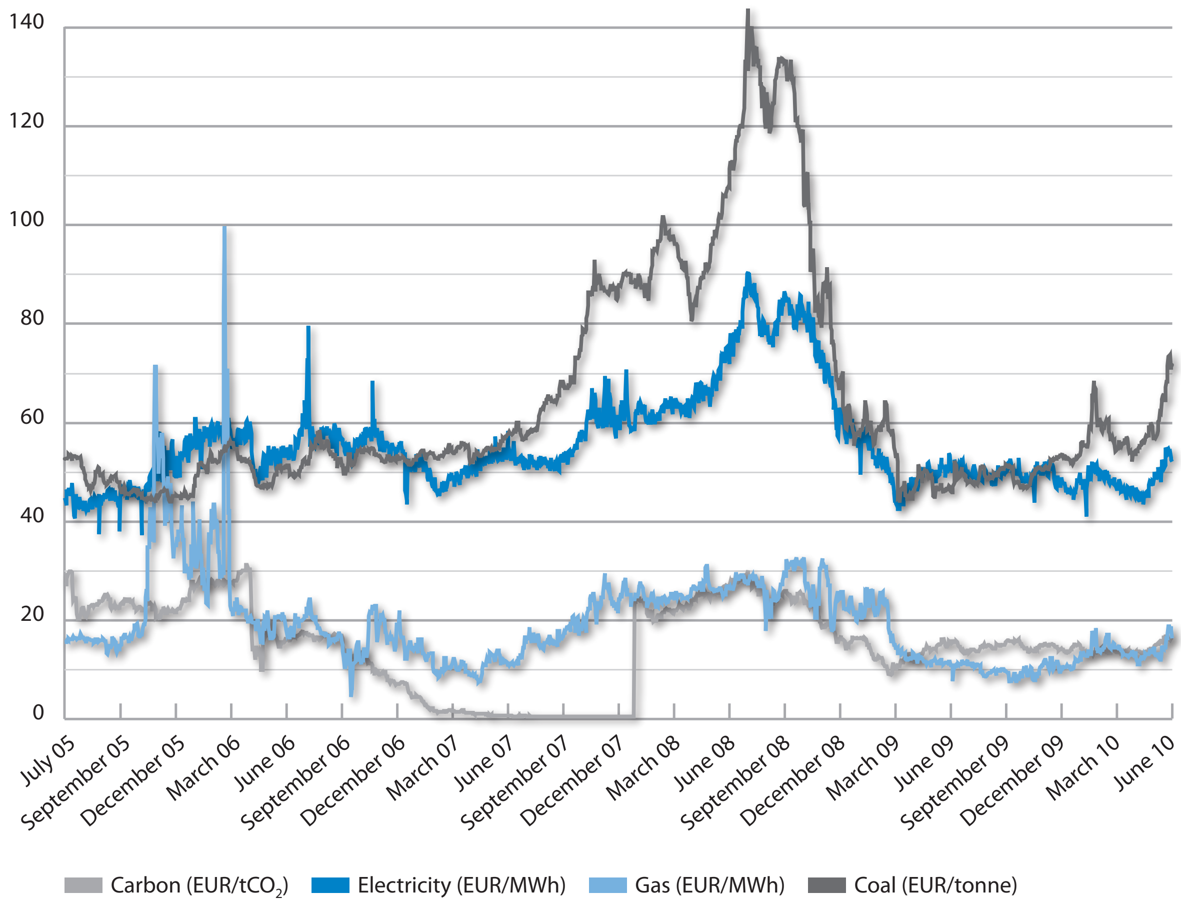
This NEA study works with a first-of-a-kind (FOAK) case and an industrial maturity case for Generation III+ reactors which can be interpreted as the upper and lower bounds of the future investment costs for nuclear energy. The precise cost of future reactors will be difficult to determine for some time for two reasons. Firstly, deployment of the new Generation III and III+ reactors will generate economies of scale, but how much precisely is difficult to say. Secondly, the partial fuel meltdown at three nuclear plants after the failure of the cooling systems in the wake of a major earthquake and a very large tsunami at the Fukushima Daiichi nuclear power plant in Japan will trigger a regulatory review of the safety features that will be required for existing as well as new nuclear power plants. It is too soon to draw conclusions on the cost implications of the requirements emanating from the lessons learnt at Fukushima. While there might be some impact in terms of added costs, there is reason to think that it might be limited given that Generation III+ reactors already have a number of safety features such as multiple (up to four) independent cooling systems, cooling systems that work by natural convection (passive cooling), core catchers and strong outer containment domes (in addition to the interior reactor containment vessel) able to withstand high pressures. In other words, the assumptions of this study would seem to remain a valid range for new European nuclear reactors in the coming years.

The basic question of this study, "what will be the impact of carbon pricing on the competitiveness of nuclear energy compared to coal- and gas-fired power generation in a context of liberalised electricity markets?" is thus as valid as ever. This study, which was started in September 2010 under the oversight of the NEA Working Party on Nuclear Energy Economics, is also the first-ever attempt to tackle the question of the competitiveness of different power generation technologies under carbon pricing on the basis of empirical data. In doing so, it analyses daily data from European power and carbon markets during a period stretching from July 2005 to May 2010. This encompasses very nearly the first five years of the European Emissions Trading System (EU ETS), the world's foremost carbon trading framework (see Figure ES.1). Nevertheless, many of the conclusions are applicable to other

OECD regions to the extent that power market liberalisation has taken hold. The study also provides calculations of the levelised cost of electricity (LCOE) for all three OECD regions, which constitute an important benchmark for cost competitiveness in regulated power markets.

Figure ES.1: European prices for electricity, carbon, gas and coal

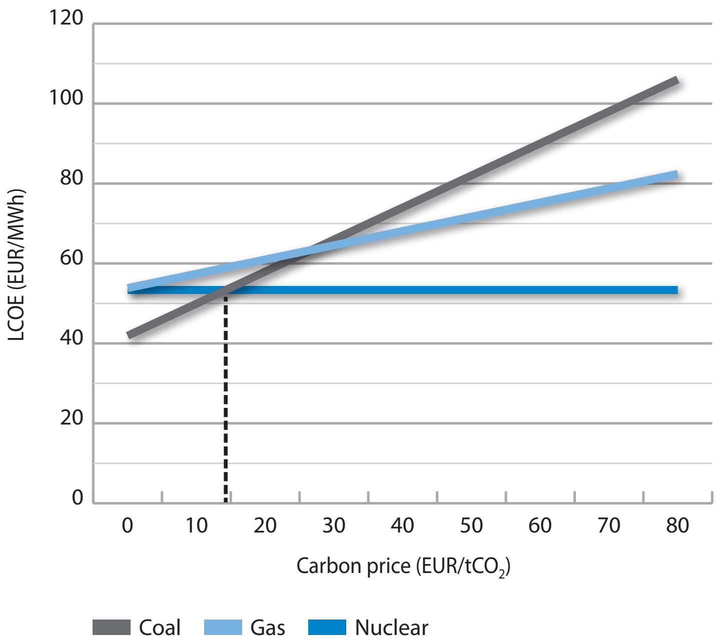
2005-10



This NEA assessment of the competitiveness of nuclear energy against coal- and gas-fired generation under carbon pricing consistently adopts the viewpoint of a private investor seeking to maximise the return of his/her invested funds. The study broadly confirms, albeit in far greater detail and considering a much greater number of variables, the results of the *Projected Costs of Generating Electricity* (IEA/NEA, 2010). And while the Projected Costs study adopted a concept of social resource cost based on the LCOE methodology rather than on private profit maximisation, one basic conclusion remains the same: competition in electricity markets is today being played out between nuclear energy and gas-fired power generation, with coal-fired power generation not being competitive once carbon pricing is introduced (see Figure ES.2). Whether nuclear energy or natural gas comes out ahead in this competition depends on a number of assumptions, which even for variations inside entirely reasonable ranges, can yield very different outcomes.

Figure ES.2: Carbon pricing and the competitiveness of nuclear energy in OECD Europe

LCOE of different power generation technologies at a 7% discount rate



Source: Adapted from IEA/NEA, 2010.

In order to assess the profitability of different options for power generation, the study employs three gradually more complete methodologies beyond the LCOE approach: a profit analysis looking at historic returns over the past five years, an investment analysis projecting the conditions of the past five years over the lifetime of plants and a carbon tax analysis (differentiating the investment analysis for different carbon prices) looking at the issue of competitiveness from different angles. They show that the competitiveness of nuclear energy depends on a number of variables which in different configurations determine whether electricity produced from nuclear power or from combined-cycle gas turbines (CCGTs) generates higher profits for its investors. They are:

1. *Overnight costs:* the profitability of nuclear energy as the most capital-intensive of the three technologies depends heavily on its overnight costs.[1] This is a characteristic that it shares with other low-carbon technologies such as renewable energies, but the latter are not included in this comparison. The study reflects the importance of capital costs by working with a FOAK case and an industrial maturity case, where the latter's capital cost is two-thirds of the former's.

2. *Financing costs:* since the Projected Costs study nothing has changed on this point. Financing costs have a very large influence on the costs and profitability of nuclear energy. Nevertheless, the study does not concentrate on this well-known point but works (except for one illustrative case) with a standard capital cost of 7% real throughout the study.

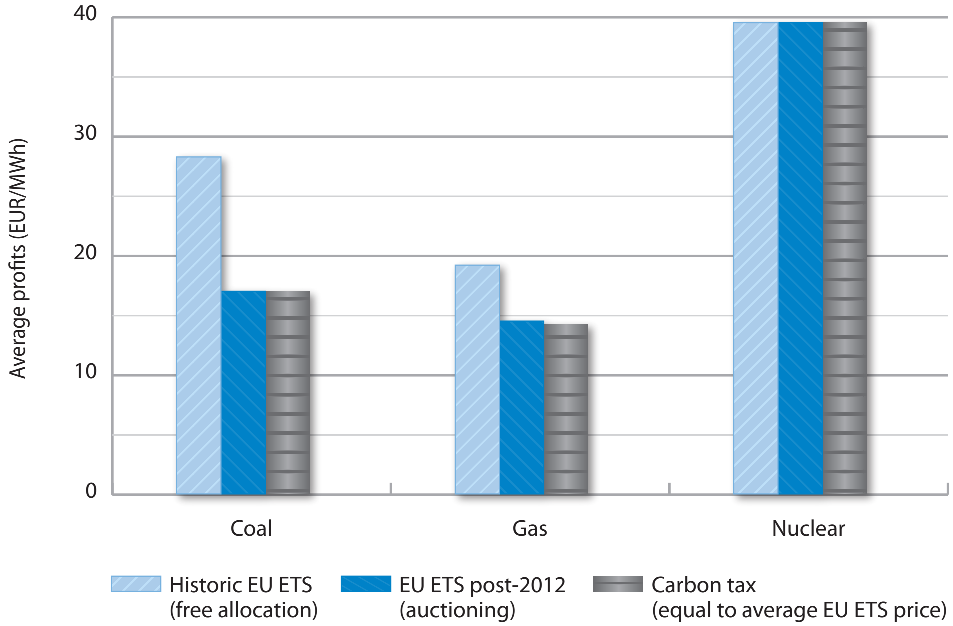
1. Capital costs are a function of overnight costs (which include pre-construction or owner's cost, engineering, procurement and construction costs as well as contingency costs) and interest during construction (IDC). The latter depends, of course, on financing costs as discussed under the next point.

3. *Gas prices:* what capital costs are to the competitiveness of nuclear energy, gas prices are to the competitiveness of gas-fired power generation, which spends a full two-thirds of its lifetime costs on fuel. If gas prices are low, gas-fired power generation is very competitive indeed. If they are high, nuclear energy is far ahead. The study reflects this fact by working with a low gas price case and a high gas price case in addition to the base case scenario.
4. *Carbon prices:* low and medium-high carbon prices, up to EUR 50 per tonne of CO_2 (tCO_2) increase the competitiveness of nuclear power. However, in contrast to the conclusions of the LCOE methodology employed in the Projected Costs study, high carbon prices do not unequivocally improve the competitiveness of nuclear power in a market environment. As carbon pricing makes coal with its high carbon content the marginal fuel, the revenues of gas increase faster than its cost, with an overall increase in profitability that matches that of nuclear and can surpass it at very high carbon prices.
5. *Profit margins* or "mark-ups" are the difference between the variable costs of the marginal fuel and the electricity price, and are a well-known feature of liberalised electricity markets. They have a very strong influence on the competitiveness of the marginal fuel, either gas or coal, for which they single-handedly determine profits. The level of future profit margins can thus determine the competitiveness between nuclear energy and gas.
6. *Electricity prices:* in a liberalised electricity market, prices are a function of the costs of fossil fuels (natural gas and coal), carbon prices and mark-ups. The higher they are, the better nuclear energy fares, both absolutely and relatively. This is also due to the fact that higher electricity prices go along with higher prices for fossil fuels and carbon.
7. *Carbon capture and storage (CCS):* the standard investment and carbon tax analyses do not assume the existence of pervasive CCS for coal-fired power plants. However, an alternative scenario does and it shows that CCS will remarkably strengthen the relative competitiveness of nuclear energy against gas-fired power generation. The profitability of gas declines significantly once it substitutes for coal as the marginal fuel at high carbon prices.

The particular configuration of these seven variables will determine the competitive advantage of the different power generation options. The profit analysis showed that during the past five years, nuclear energy has made very substantive profits due to carbon pricing (see Figure ES.3). These profits are far higher than those of coal and gas, even though the latter did not have to pay for their carbon emission permits during the past five years of Phase I and Phase II of the EU ETS. Operating an existing nuclear power plant in Europe today is very profitable.

The conclusion that an existing nuclear power plant is highly profitable under carbon pricing is independent of the particular carbon pricing regime both in absolute and in relative terms. Given that nuclear power would not have to acquire carbon permits under any regime, its profits would not change as long as electricity prices stay the same. Profits would change instead for coal- and gas-fired generation. The switch to auctioning permits under the EU ETS in 2013, which will oblige emitters actually to pay for their emissions, will thus increase the competitive advantage of nuclear energy due to carbon pricing. Substituting an emissions trading scheme characterised by volatile prices with a stable carbon tax equivalent to the average trading price would actually increase the volatility of profits for coal and gas and thus increase the relative competitiveness of nuclear energy even further. Contrary to the opinion that nuclear would be better served by a stable tax, the empirical evidence indicates that nuclear energy does at least as well under carbon trading, including when carbon prices are volatile.

Figure ES.3: Average profits with suspension option



However, the profit analysis does not consider investment costs. It is more difficult to summarise the results for the investment and the carbon tax analysis, which both take into account the investment costs and compute the costs and benefits over the lifetime of the different plants. Again, a new coal plant is highly unlikely to be a competitive or even a profitable technology option under the price conditions prevailing during the 2005-10 period once it has to pay for its carbon emissions. Concerning the competition between nuclear energy and gas-fired power generation measured in terms of an appropriately defined profitability index (PI), one needs to differentiate and to specify the particular configuration of the seven variables presented above. If the seven variables above are grouped in three broad categories, investment costs, electricity prices as a function of gas, and carbon prices and CCS – then one may summarise the results of this study in the following manner. *Nuclear energy is competitive with natural gas for baseload power generation as soon as one of the three categories – investment costs, prices or CCS – acts in its favour. It will dominate the competition as soon as two out of three categories act in its favour.*

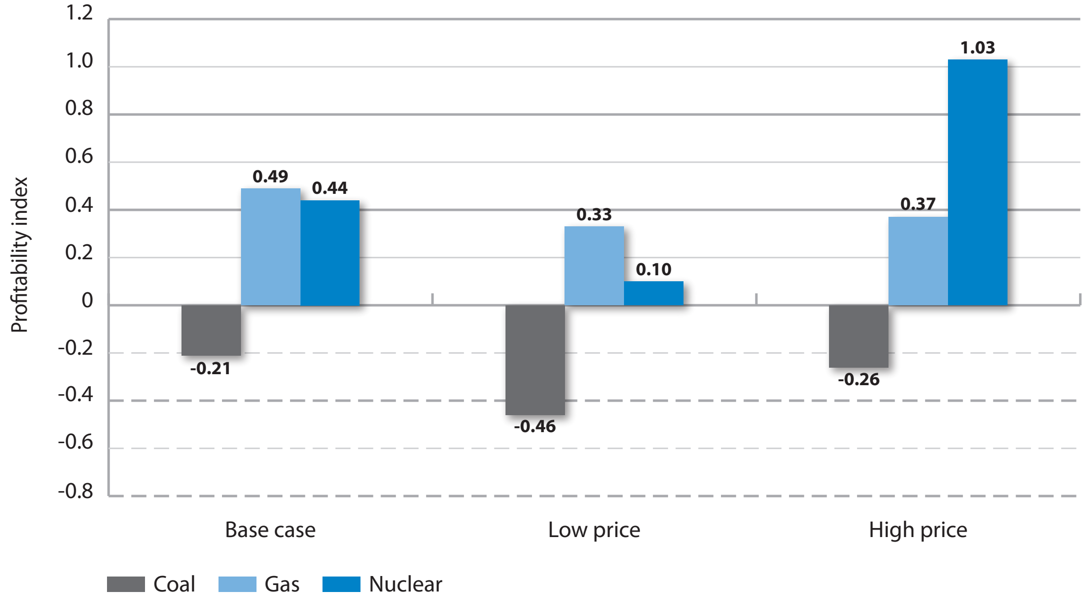
It is important to recall that according to the parameters of this study, a new nuclear power plant being commissioned in 2015 would produce electricity until 2075. While final appreciations are the prerogative of each individual investor, there is clearly a very strong probability that gas prices will be considerably higher than today and that coal-fired power plants will be consistently equipped with carbon capture and storage during that period. Readers are thus invited to pay particular attention to the CCS analysis in the second part of Chapter 7.

The competition between nuclear energy and gas-fired power generation remains characterised by the dependence of each technology's profitability on different scenarios. Gas, which is frequently the marginal fuel, makes modest profits in many different scenarios, which limits downside as well as upside risk. The small size of its fixed costs does not oblige it to generate very large profit margins.

High electricity prices are not necessarily a source of significant additional profits as they frequently result precisely from high gas prices. Nuclear energy is in the opposite situation, where its profitability depends almost exclusively on electricity prices. Its high fixed costs and low and stable marginal costs mean that its profitability rises and falls with electricity prices (see Figure ES.4).

Figure ES.4: Profitability index in different electricity price scenarios

7% real discount rate, industrial maturity case and average 2005-10 carbon price



Carbon pricing will, of course, increase the competitiveness of nuclear energy against coal and to a lesser extent against gas. In the competition between nuclear energy and gas, carbon pricing will favour nuclear, in particular in a range up to EUR 50 per tonne of CO_2 (in comparison, the five-year average on the EU ETS was slightly over EUR 14). Beyond that range, coal-fired power generation will consistently set electricity prices and gas-fired power plants will thus earn additional rents faster than their own carbon costs increase. This may, at very high carbon prices, enable gas to even surpass nuclear energy (see Figure ES.5). While coherent at the level of the modelling exercise, it should be said that market behaviour and cost conditions at carbon prices above EUR 50 per tonne of CO_2 are quite uncertain, and results for any configuration in that range should be considered with caution. One would, for instance, expect that high carbon prices applied consistently over time would generate a number of dynamic effects and technological changes, such as a quicker penetration of carbon capture and storage (CCS). This would substantially alter results by enhancing the relative competitiveness of nuclear against gas (see Figure ES.6).

Figure ES.5: Evolution of profitability indices in the base case scenario

Constant profit margin of EUR 10, 7% real discount rate and industrial maturity case

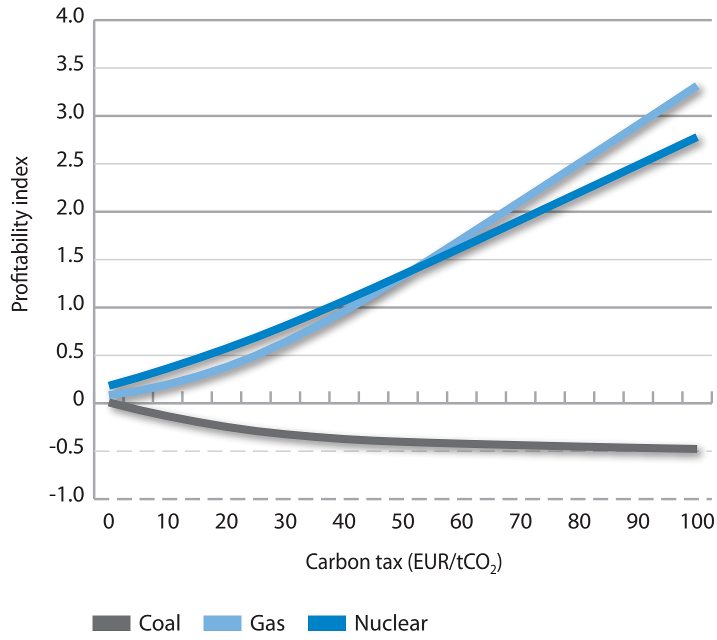
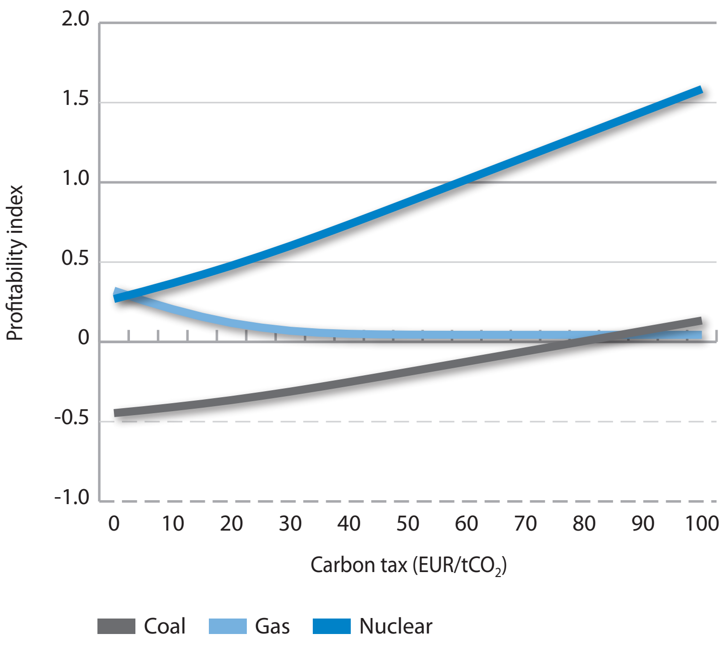


Figure ES.6: Evolution of profitability indices in the CCS base case scenario

Constant profit margin of EUR 10, 7% real discount rate, industrial maturity case and coal with carbon capture



For investors, it is thus important to make their own assessment of the probability of different capital costs and price scenarios. If nuclear succeeds in limiting overnight costs and electricity prices in Europe stay high, nuclear energy is by far the most competitive option. With high overnight costs and low electricity prices, only a strong logic of portfolio diversification could motivate an argument in its favour. As far as prices are concerned, it is quite likely that European electricity prices will stay high or even increase in the foreseeable future. The progressive exit from both fossil fuels and nuclear energy in Germany, Europe's biggest market, will inevitably push electricity prices higher, which in conjunction with carbon pricing opens opportunities for nuclear energy in other European countries. Similar dynamics may also assert themselves in the United States, where ambitious greenhouse gas reduction targets also ensure a floor under electricity prices.

A high electricity price scenario is thus likely, but by no means assured. In this context, policy makers need to be aware of the fact that the profitability of nuclear energy in liberalised electricity markets depends on specific electricity price scenarios. It is thus not unthinkable that risk-averse private investors may opt for fossil-fuel-fired power generation instead of nuclear, *even in cases where nuclear energy would be the least-cost option over the lifetime of the plant*. Liberalised electricity markets with uncertain prices can lead to different decisions being taken by risk-averse private investors than by governments with a longer-term view. Care has to be taken to reflect the specificities of high fixed cost, low-carbon technologies such as nuclear energy and certain renewables in the process through appropriate measures, for example, long-term contracts for electricity provision. Otherwise, the risk of private and social optimality disconnecting is very real.

An additional aspect of public policy making concerns the profit margins or mark-ups of electricity prices over the variable costs of the marginal fuel which benefit, in particular, the competitiveness of the last fuel in the merit order. Regardless of whether they are an expression of spontaneous or consciously constructed monopoly power, nuclear energy is favoured by limiting these welfare-reducing mark-ups. Market opening and competition in the provision of baseload power favour the competitiveness of nuclear energy.

In the end, the outcome of the competition between nuclear energy and gas-fired power generation (coal-fired power generation being uncompetitive under carbon pricing) depends on a number of key parameters such as investment costs and prices. The profitability of either nuclear energy or gas-fired power generation, however, cannot be assessed independently of the scenario in which they are situated. Given the realities of the large, integrated utilities that dominate the European power market, which need to plan ahead for a broad range of contingencies, the implications are straightforward. Risk minimisation implies that utilities need to diversify their generation sources and to adopt a portfolio approach. Any utility would thus be advantaged by a portfolio approach. Such diversification would not only limit financial investor risk, but also a number of non-financial risks (climate change, security of supply, accidents). Hence, portfolio approaches and the integration of non-financial risks will both be important topics for future research at the NEA and in the wider energy community.

Carbon Pricing, Power Markets and the Competitiveness of Nuclear Power

This study assesses the competitiveness of nuclear power against coal- and gas-fired power generation in liberalised electricity markets with either CO_2 trading or carbon taxes. It uses daily price data for electricity, gas, coal and carbon from 2005 to 2010, which encompasses the first years of the European Emissions Trading System (EU ETS), the world's foremost carbon trading framework. The study shows that even with modest carbon pricing, competition for new investment in electricity markets will take place between nuclear energy and gas-fired power generation, with coal-fired power struggling to be profitable. The outcome of the competition between nuclear and gas-fired generation hinges, in addition to carbon pricing, on the capital costs for new nuclear power plant construction, gas prices and the profit margins applied. Strong competition in electricity markets reinforces the attractiveness of nuclear energy, as does carbon pricing, in particular when the latter ranges between USD 40 and USD 70 per tonne of CO_2. The data and analyses contained in this study provide a robust framework for assessing cost and investment issues in liberalised electricity markets with carbon pricing.

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