Nuclear energy: The difference between costs and prices

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Author(s):
Mart Bles
Maarten Afman
Jos Benner
Martijn Blom
Harry Croezen
Frans Rooijers
Benno Schepers

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Mart Bles, Maarten Afman, Jos Benner, Martijn Blom, Harry Croezen, Frans Rooijers, Benno Schepers
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Further information on this study can be obtained from the contact person, Mart Bles (bles@ce.nl).

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Preface

Twenty-five years on from the Chernobyl nuclear disaster, the debate on nuclear power is more alive than ever. The renewed debate has been inspired mainly by the aftermath of the major earthquake and ensuing tsunami in Japan, which damaged several reactors at the Fukushima Daiichi nuclear facility. While these recent events have triggered a revision of nuclear policy by governments across the globe, the Dutch government appears unfased in its intention to approve construction of a new nuclear power plant. At the same time it has pledged to make no investments in energy technologies, which means potential constructors will have to fund their investments under market conditions, leading to a potentially significant rise in the cost of nuclear power. The aim of this study is to investigate the true costs of nuclear energy, both direct and indirect, and the effects the Fukushima incident may have had (or yet have) on the financial and safety aspects of nuclear power around the world. As such, this report does not represent a full-blown social cost-benefit analysis allowing a full comparison between nuclear with other generating technologies. Instead, it critically assesses some of the key claims that are regularly made about nuclear power.

Contents

Summary

WWF Netherlands wishes to critically assess the claims made by governments and politicians regarding construction of a new nuclear power plant in the Netherlands, in particular whether construction is feasible without government support. The issue here is not the marginal cost of nuclear-generated power, because nuclear can then indeed be termed cheap. Instead, the cost assessment should cover all the costs associated with construction and operation of a nuclear facility, including liberalised market financing, safety issues, liabilities and life cycle fuel effects.

Government or private party

The Dutch Minister of Economic Affairs, Agriculture and Innovation, Maxime Verhagen, has stated that the government's sole role in construction of new power plants, nuclear of otherwise, is to approve the permit, and that there will be no government funds for construction, which will therefore have to be privately financed under liberalised market conditions quite different from those prevailing when the country's present nuclear facilities were built. As the credit risk for private parties is greater than for governments, the former pay risk premiums to finance their investments, thus greatly increasing the investment costs of a new power plant.

In practice, though, some of these risks will accrue to the public, since one of the interested parties, Delta, is a public agency owned jointly by Dutch provincial and municipal authorities. It is unclear how a new plant construction will benefit from this backing by lower-tier government, and how the latter would be impacted in the case of major cost overruns. That such overruns are by no means unlikely is illustrated by the only two EPR reactors currently under construction (in Finland and France), both of which face delays and budget overruns. These overruns may rise still further if new insights post-Fukushima prompt additional safety requirements.

Liability: company risk or a government matter?

Another major issue with nuclear power is accident risk and liability. Recent events in Japan have revealed that previously made risk assessments are not as reliable as one would expect for a technology with such major accident consequences. Aside from the question of whether a nuclear plant can ever in fact be designed to cater for all possible risks, the issue arises of who is to pay for damages if something does go wrong. In Europe national governments have committed themselves through a series of treaties to be held financially liable in the event of a major accident. Although the costs of these liabilities are passed on in part to nuclear operators, this remains an implicit subsidy for nuclear power, since operators therefore need to pay less than market prices for their insurances. As things stand at the moment, moreover, maximum liability is only a fraction of the costs observed in the Chernobyl and Fukushima disasters, and citizens and other private parties are unable to insure themselves beyond this maximum. In the event of a severe nuclear accident, any costs beyond the liability maximum are consequently paid by society.

Responsible fuel cycle: a moving target?

In the list of preconditions for new nuclear plant envisaged for the Netherlands, Minister Verhagen has stressed life cycle responsibility throughout the fuel chain as an important criterion for approval, thereby stressing that the uranium should be mined in a responsible manner and that a decision on final storage will soon be made. It is to be queried, however, whether the tools with which he wishes to guarantee life cycle responsibility are appropriate. First, the certification schemes he requires of mining companies are no guarantee of responsible company management, as certified operators have previously been convicted for pollution, social misconduct and corruption. In addition, the issue of final storage has been contentiously debated for many years, offering little hope of an imminent solution that prevents us from saddling future generations with the radioactive waste we produce. Indeed, it is even unclear whether the budgets earmarked for storage are big enough for their declared purpose.

Cheap energy, a good idea?

The hallmark of nuclear power is that the bulk of its direct costs occur in the construction and financing phase, and that the marginal costs of power generation are relatively low. As such, it is similar to renewable energy technologies like photovoltaics and wind turbines, and it is up to private investors whether to take the risk embodied in the high construction and finance costs. When cheap base load nuclear power hits the market, there may be certain negative side-effects, though, lumbering the taxpayer with extra costs. For example, a lower electricity price will push up the level of the 'SDE' subsidy given to renewable energy technologies, potentially hampering their development and making it harder to meet long term climate targets.

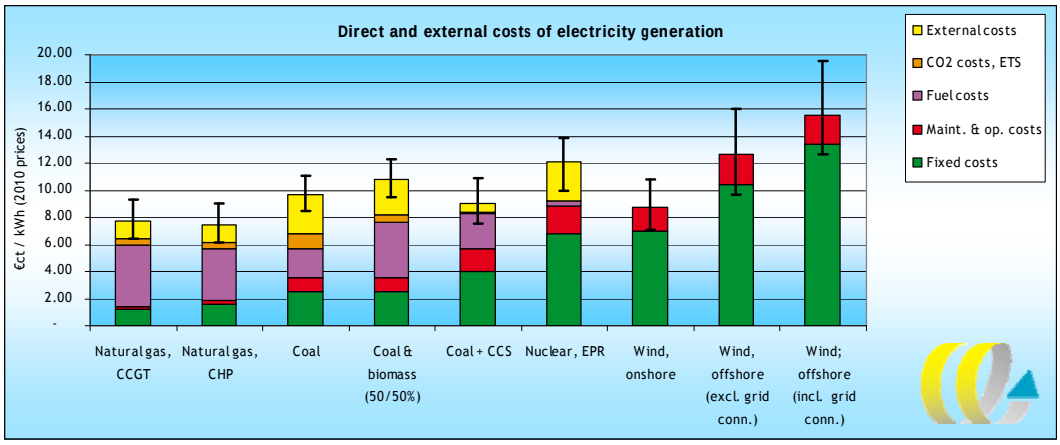
Innovation?

Another of the government's claims is that constructing a new nuclear plant will lead to positive innovation and economic benefits. The question, though, is who will benefit. Currently, only a handful of large international corporations like Areva, Westinghouse and Siemens are able to build nuclear power plants, and it is these companies that are most likely to benefit from their construction.

Conclusions

In conclusion, the benefits of nuclear power in terms of costs and contributions to Dutch energy policy ambitions are less positive then often stated. Although a social cost-benefit analysis would be needed to properly weigh all the costs and benefits, in this study we show that the benefits are smaller than generally assumed and that the costs are underestimated. At face value, renewable energy technologies seem to provide a better fit with the government's ambitions, at least in terms of energy security and earning potential. Although it is debatable whether renewables are presently cost-competitive with conventional fossil fuels, their costs are rapidly falling, unlike those of nuclear, where negative learning rates are still adding to the already high costs detailed in this report.

Figure 1 Costs of electricity generation including external costs



1 Introduction

In the year the 25th anniversary of the Chernobyl nuclear disaster was commemorated, a new incident in Fukushima has refuelled the discussion on the role nuclear power should play in our energy system. WWF Netherlands (WNF) is keen to adopt a more pro-active stance in this debate, thereby focusing on the social impacts of nuclear power in general and the effects of the Fukushima disaster in particular. This report sets out the background information required by WNF to position itself in the public debate.

The goal of this report is twofold:
1. To provide a quantitative assessment of the social costs of nuclear power.
2. To assess the credibility of information provided about nuclear power by the Dutch government.

In the following sections these goals are explained in more detail.

1.1 The social costs of nuclear power

Like many other forms of power generation, nuclear power profits from a variety of financial benefits provided by regulators. In this respect it is not unique, as many forms of renewable energy receive government subsidies, while coal plants benefit from tax exemptions on their fuel. In addition, some of the costs accruing to society are not yet internalised in markets, providing implicit benefits for the technologies causing those costs. Although most (if not all) energy technologies profit in one way or another from such implicit benefits, these are not equally spread. Indeed, it may be argued that nuclear power is associated with higher social costs than other energy technologies: government involvement in financing new plants, waste storage and plant decommissioning as well as the risk of severe incidents (and associated insurance costs) may all involve costs that are passed on in part to society as a whole and are lacking in the case of other technologies. Some of these costs are actually borne by the operators themselves, and in so far influence the business case on which their investments are made. Since WNF will have little if any influence on an operator's business case, the internalised costs of nuclear energy will mainly serve as a basis from which to explore social costs. If some of these costs are actually borne by society (either directly or indirectly), this may change the picture on the desirability of nuclear power. This is especially relevant in the light of recent statements by the Dutch Minister of Economic Affairs, Agriculture and Innovation, Maxime Verhagen that the government will provide no co-funding for construction of a newly proposed nuclear power plant (Volkskrant, 2010a; Elsevier, 2010; Tweede Kamer, 2011a). If the Dutch government in fact bears the costs of financial guarantees, insurance and liability, and perhaps decommissioning and waste storage as well, his statements may need to be reviewed. This leads to the second goal of this background report: to assess the credibility of government information on nuclear power, as set out in the following section.

1.2 The credibility of information on nuclear power

When the Dutch government insists it will not contribute a single euro to a new nuclear power plant, it does so based on a number of prior assumptions about the construction of such a plant. Presumably, the statement concerns the direct investment costs, which are deemed part of the business case of the operator and hard to influence by external parties. However, direct costs are only part of the true cost of nuclear power (or any other energy technology, for that matter). Loan guarantees, liability, accident risk and fuel cycle environmental impacts are all associated with risks and costs, and it is these costs for which it is untenable to state that the Dutch government and/or society do not contribute. In addition, the Dutch government has drawn up guidelines on the safety standards and life cycle aspects of new power plants. But how reliable are such standards? Similar claims about the unrivalled safety of reactor designs were previously made about the plants that eventually led to severe incidents, proving that safety is merely relative. Below, such issues are discussed in the light of recent statements by the Dutch government and previous nuclear incidents.

This report consists of two parts: the main document, containing the most important results and conclusions of our analysis, and a series of annexes providing further calculation details and background information. In Chapters 2 and 3 the direct and indirect cost of nuclear power are described, structured around the principal claims made by the nuclear sector and the Dutch government. Note that in these chapters the focus is on costs rather than benefits. A quantitative assessment of all the aspects of nuclear power compared with other energy technologies would require a full-blown social cost-benefit analysis, but this is beyond the scope of the present project. In Chapters 4 and 5 qualitative issues associated with risk assessment and life cycle responsibility, respectively, are explored in more detail. In Chapter 6 the cost of nuclear power is compared with that of other generating technologies. Chapter 7 considers nuclear power in light of the Dutch energy policy ambitions and describes its impacts on renewable energy. Chapter 8, finally, sets out our main conclusions.

2 Construction and finance costs

In this chapter we discuss the various cost components associated with the construction of a new nuclear power plant and the economic rationale for building such a plant. In today's liberalised energy market the initiative for new plant construction has shifted from governments to private investors, who are free to opt for any generating technology as long as they act within the constraints set by government with respect to construction permits, environmental permits, ETS and so on. In a well-functioning electricity market the integral costs of any utility investment should be borne entirely by the investor and, ultimately, by the consumer by way of the electricity price. However, market mechanisms may be disturbed if utilities know that governments are prone to assist if things go awry. This may result in utilities making investment decisions they would otherwise not make, with the attendant risk that some of the costs associated with the plant life cycle are borne by society . Any analysis of the economics of nuclear power should therefore give specific consideration to the question of who bears the risks of future uncertainties.

When making claims about the cost of nuclear power, one should look at the cost of plants financed under liberalised market conditions, not at plants built decades ago.

As is the case for all nuclear power plants currently in operation around the world, the Borssele plant on the west coast of the Netherlands was developed by a state-owned and regulated utility monopoly. In such a situation, the risks associated with construction costs, operating performance and fuel price are not fully priced at market values and not completely factored into the consumer price of electricity. Instead, they are and have been borne partly by consumers (high electricity price) and partly by state-owned companies (ultimately, the taxpayer). When comparing the cost of different generating technologies, such differences need to be taken into account; it is not fair to compare the cost of electricity from existing nuclear plants (constructed under a regulated utility monopoly, part-financed by the taxpayer, and with scope for full cost recovery) with power from a wind farm built in a liberalised electricity market. Instead, when debating the construction costs of a new nuclear power plant, comparisons must be based on financing dynamics under liberalised market conditions.

In this chapter we first highlight the main cost components of nuclear power: construction costs and finance costs, both of which are important factors in the rising price of nuclear power. We then investigate recent government claims that the Dutch state will in no way be investing in a new nuclear power plant. Operational costs are further discussed in Chapter 3.

2.1 "Nuclear power is affordable, and that is good news for Dutch industry"

– VNO-NCW, 2011.

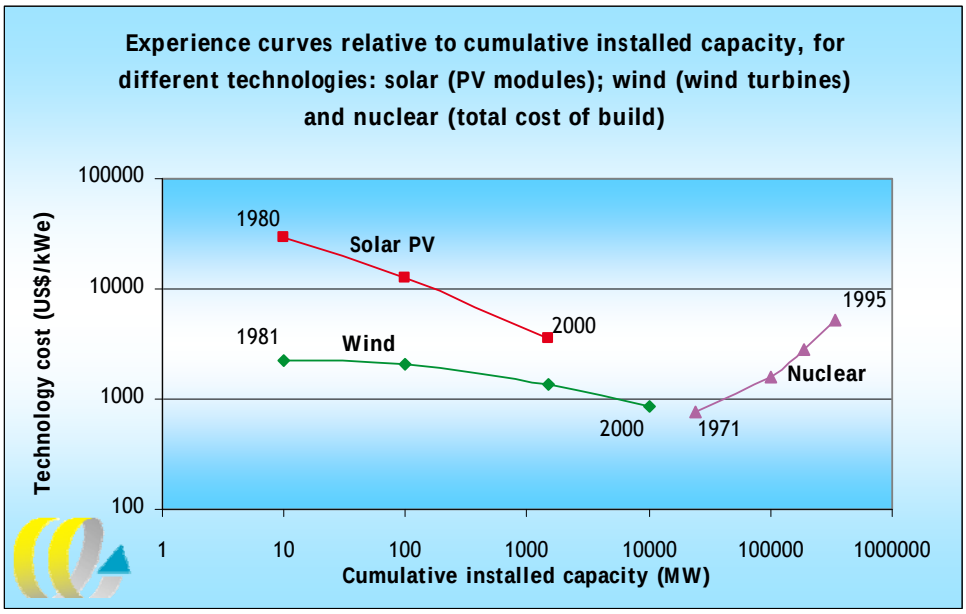
Escalation of construction costs

Nuclear technology is plagued by a negative learning curve, becoming more expensive with time.

Interestingly, while most technologies become cheaper over time because of scale advantages as well as technological learning curves and experience gained, the opposite seems true for nuclear power: it shows a negative learning curve (Cooper, 2009, 2010; Grubler, 2010). Factors contributing to the resultant negative cost curve include electricity market liberalisation, increasingly stringent safety regulations, continuous evolution of plant designs,

the small number of plants of a particular design being built and a declining properly educated workforce. The resulting rise in construction costs can be observed in the estimates of independent observers as well as utilities, and is likely to continue in the years ahead (Figure 2).

Figure 2 **Experience curves for technology options. Cost relative to cumulative installed capacity of nuclear, wind and solar PV**



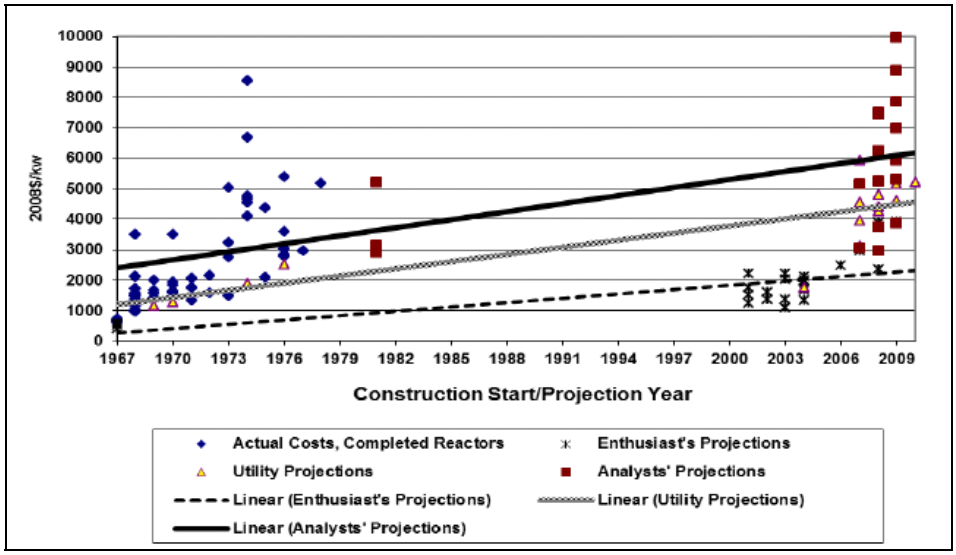
The figure indicates that the cost of PV-components and wind turbines has declined (although since 2000 the price of wind turbines has fluctuated), while the cost of nuclear has consistently risen (figure shows total cost of build).

Source: Data for Wind and Solar PV from IPCC (IPCC 2007, Fourth Assessment Report – Mitigation, citing Johansson et al. 2004). Prices expressed in US$2008. Data for actual cost of build of nuclear from Cooper, 2010. Cumulative installed capacity for nuclear from Earth Policy Institute.

Although both utility and independent observer estimates of nuclear construction costs increase over time, Cooper (2009, 2010) shows that cost projections by utilities are systematically lower than those by independent analysts (Figure 3). In addition, nuclear construction costs tend to overrun initial cost estimates significantly. This trend was already clear for construction projects in the 1970s and seems to be repeating itself. The most recent cost projections for new nuclear reactors are on average over four times as high as initial projections at the start of the decade, with actual costs of builds still unclear. Project risk can be incorporated into the full costs of capital by not accepting any other cost models than turn-key contracts. In this manner, a cap is put on total construction costs, and the full burden of cost overruns is imposed on the constructor. However, as litigation following cost overruns in Finland shows, turn-key contracts are not inherently risk-free, and allocation of risk should be made clear and transparent.

"Efforts to 'revive' this moribund technology only waste time and money. You'd expect the City to appreciate all the warning signs - there's not a penny of private money in the nuclear investments that are being made in countries such as China, Korea and France. As for public money, the UK industry has had two expensive bailouts already; making the same mistake a third time would astonish future historians."
Amory Lovins, Chairman Rocky Mountain Institute, 2006.

Figure 3 Institutional origins and levels of recent cost projections



Source: Cooper, 2010.

Liberalised energy market leads to increased finance costs

A liberalised market model is unfavourable for uneconomical nuclear power plants.

Financing upfront investment in a new nuclear plant is serious business, with a construction duration of 6-10 years and significant risks of time overruns (idle production time). One of the reasons for the increase in financing costs in recent years is the liberalisation of many electricity markets. Prior to market liberalisations, operators could rest assured they could pass on their costs to their customers owing to the lack of competition. The risk for investors was therefore negligible and a low risk premium was factored into the price of nuclear power, with interest rates often as low as 5 to 8% (Thomas, 2005). In a regulated market, revenues were quite predictable and a monopolistic provider could guarantee output requirements in the longer term. Consumers and taxpayers thus eventually paid the price of a regulated monopoly product. In today's competitive, liberalised electricity market, however, operators cannot count on a guaranteed price for their electricity, but must accept shorter output contracts and the risk of future lower-cost competition[1]. Furthermore, in a full competition model, banks want a faster return on investment and demand a higher share of the equity. In this situation the cost of private capital for capital-intensive investments will be much higher than in a regulated environment, making a 10-15% discount rate more appropriate for this kind of competitive, deregulated environment. As a consequence, the cost of capital will most likely increase substantially.

[1] For example, during the past decades solar PV enjoyed a learning rate of 18% annually; OECD estimates that solar PV can already be 40% cheaper by 2015, while wind energy can reach overnight costs of US$ 1,400 per kilowatt by 2020 (OECD/NEA & IEA, 2010).

Finance costs show an upward trend.

Finance costs face further upward pressure because credit-rating agencies such as Moody's and Standard & Poor's have issued warnings about nuclear energy (see Section A.4). Although no downward adjustment of credit-rating has yet taken place for companies willing to invest in new nuclear facilities, the credit-rating of the top 25 European utilities has slowly declined over the last few years (Standards & Poor's, 2010), and financing large construction projects may become increasingly difficult and expensive (Moody's, 2010).

2.2 "New nuclear power plants will have to make do without subsidies"

– Minister Verhagen, 2011[2].

Governments can decrease utility risks through bank guarantees, minimum prices or volume guarantees, thus reducing capital costs. These are direct government stimulus measures that reduce the costs to operators. However, in the context of European law these can be seen as forms of illegal state subsidy (Thomas, 2005) and the Dutch government has indeed stated that it will not resort to subsidies or other financial support for the construction of a new power plant (Tweede Kamer, 2011a).

Taxpayers are always at risk if an investor is (partly) publicly owned.

There are, however, also other kinds of indirect financial stimulus. Indirect support may come in the form of public participation in investment projects, for example, while governments may be satisfied with lower rates of return than market parties would be. A (partly) state-owned company is inherently financially more robust owing to the implicit scope for recovering certain costs from governments and taxpayers. While market investors will not allow a company to forgo dividend payments, (local) governments may be less strict. Governments can also prevent bankruptcy by increasing their equity share at the time of need. Currently, Delta's shareholders comprise a number of Dutch local and provincial authorities. Were Delta to build a new nuclear power plant, these echelons of government, and consequently taxpayers in the respective regions, would face an indirect risk in the case of construction problems and budget overruns. It should be noted, however, that Delta is a small player in the Dutch electricity market, with a moderately weak financial outlook and low liquidity. precluding it from independently contributing any sizeable portion of the investment in a new nuclear plant. As a consequence, additional financial support (e.g. by RWE or EDF) will be necessary and if this is in the form of equity, these parties will bear the greater risk burden.

"Government policy remains that the private sector takes full exposure to (construction, power price and operational risks). Nowhere in the world have nuclear power stations been built on this basis. We see little if any prospect that new nuclear stations will be built (..) by the private sector unless developers can lay off substantial elements of (these) risks." *CityGroup, 2009.*

Another type of indirect social cost associated with nuclear power plant construction arises from opportunity costs. The opportunity costs of a given investment are measured by the cost of the next best alternative. By committing financial assets to the construction project in question, investors suffer opportunity costs as they are now unable to forgo the investment and opt for an alternative generation technology instead. Missing opportunities can have a number of indirect effects. If the investor is a utility, money lost in this manner cannot be invested in more renewable carbon-free electricity.

[2] In: Volkskrant, 2011; NOS, 2011a.

Because the invested capital is fixed for a long period, the utility looses the flexibility to invest their resources in technologies that may face significant cost reductions in the near future. If the investor is an industrial manufacturer, his product's prices may be higher than they would have been otherwise, reducing competiveness. Ultimately this can have repercussions on employees, customers and taxpayers alike.

2.3 Conclusions

Nuclear energy is often regarded as a cheap source of electricity. Although true for old nuclear power plants built in regulated electricity markets, this no longer holds for nuclear power from newly constructed plants, which are facing rising construction and finance costs. With Dutch industry seeking low and stable electricity prices, it is questionable whether investment in nuclear energy best serves this purpose, especially when the risk of cost overruns is factored in.

Given the high costs of a new nuclear power plant, constructing parties are likely to seek government support and guarantees for their plans in order to reduce risk and costs. However, since the Dutch government has vowed not to give financial support to plant construction, there should be no externalisation of financial burdens on society. While the claim that the government does not invest in nuclear power plants is true in the sense of no actual cash reimbursements being handed out to operators, this is not the full picture. When nuclear investments are made by (semi-)public companies, it is the Dutch state – and ultimately citizens – that become financially liable for cost overruns.

3 Operational costs

In this chapter we discuss the costs associated with the operational aspects of nuclear power generation. The direct operating costs (so-called busbar costs) of electricity from a nuclear power station are made up of variable and fixed costs. Variable costs include those deriving from the uranium fuel, radioactive waste management and operations and maintenance (O&M), including insurance and safety. For fossil generating technologies the variable costs would also include the costs of CO_2 emission allowances. Fixed costs are costs that remain fixed throughout a plant's lifetime, independent on whether or not it is operational. These costs comprise on the one hand expenses relating to the cost of construction (interest on loans, debt repayment, payments to shareholders) and on the other the costs associated with building up a financial reserve for dismantling the plant at the end of its lifetime.

3.1 "Nuclear energy is cheap"

– VVD viewpoint on nuclear energy (2011).

Direct variable costs are not the only costs of relevance for operational nuclear power stations.

Nuclear power plants have relatively high fixed costs and low variable costs. If only the direct variable costs are assessed, the claim can indeed be made that nuclear energy is cheap. However, one should also take into account the *indirect costs* that may be incurred by the government directly and/or passed on to Dutch society. In this section we discuss not only the size of the various cost components, but also the risk of society having to shoulder any additional costs.

Uranium fuel

Uranium fuel is cheap.

The fuel costs of nuclear power plants are very low compared with those of other technologies. This is the main reason parties are tempted to regard nuclear energy as a cheap source of power (famously, in the 1950s, developers of nuclear technology promised energy 'too cheap to meter'). The fuel costs per kWh of electricity depend on the market uranium price and a range of technical issues, such as the burn-up rate achievable in a given reactor design. For a new reactor, at current milled uranium prices, fuel costs can be expected to be around 0.37 €cent per kWh, compared with 2.14 and 3.61 €cent/kWh[3] for natural gas and coal, respectively. Worldwide demand for uranium exceeds current mining capacity, which has led to a gradual increase in milled uranium prices since 2003 (OECD, 2010). Although higher fuel costs add to an operator's operational costs as well as profitability, this is to a limited extent only. Nuclear fuel costs would have to increase tenfold over current levels for them to exceed the current fuel and CO_2 costs of a coal-fired plant. Qualitative life cycle aspects of uranium mining are discussed in Section 5.1.

[3] Sum of fuel and CO_2 price.

Waste management

When nuclear fuel is spent, it is removed and stored temporarily at the power plant to allow it to cool. After the cool-down period, it is sent to France for reprocessing[4]. In the Netherlands, the resulting highly radioactive nuclear waste is stored at the Central Organisation for Radioactive Waste (COVRA) facility in Vlissingen for a planned 100 years. COVRA charges a fee for investment costs, a delivery charge per m^3 of waste for processing and a contribution for provision of O&M costs through to the year 2130. EPZ, the operator of the present Borssele nuclear plant, has thus far paid € 257 million in provisions for reprocessing and storage costs (EPZ, 2010). Historically, this translates to around €cent 0.2 per kWh.

The direct costs associated with waste management are low.

COVRA is also responsible for final disposal of Dutch high-level nuclear waste and charges a disposal fee per m^3 to EPZ for this purpose. In 2003 the EPZ 'provision for future supply costs of solid radioactive waste' amounted to € 22 million (Profundo, 2005). The total cost of final disposal in 2130 is estimated at € 2 billion (COVRA, 2009). The arrangement for a new power plant is similar: the proprietor contributes to a disposal fund managed by COVRA, which needs to cover all projected costs (Tweede Kamer, 2011a).

The risk of cost increases and insufficient fund build-up for final disposal is an indirect social cost, but is hard to estimate.

As operators pay COVRA fixed amounts for temporary storage and final disposal, utility companies are exempted from risks involving cost escalations for waste already delivered to COVRA. Future costs are in part unknown, particularly in the case of final disposal. In addition, while provisions take future interest rates into account, these too are uncertain. Recently, interest rates have been lower than anticipated by COVRA (Profundo, 2005), posing a risk of insufficient future fund build-up. Since COVRA is a public institution, the question is what happens if the built-up financial reservations prove insufficient at the time of final disposal. Most likely, public funds will be called on to cover the budget shortfalls. Owing to uncertainties in both disposal costs and interest rates, it is impossible to estimate the exact risk passed onto society. Qualitative life cycle aspects of waste storage are discussed in Section 5.2.

Decommissioning costs

The social risks associated with shortages in decommissioning funds are minimal.

In the Netherlands, institutions wishing to build a new nuclear power plant are obliged to provide financial guarantees covering the full cost of decommissioning the plant at the end of its operational life. These arrangements must be in place at the start of production (when the fuel rods are first placed in the reactor) and be updated every five years (Tweede Kamer, 2011a; see Section B.3 for more details). This arrangement prevents the State from being exposed in any way to shortfalls in reserves for the costs of decommissioning a nuclear facility and minimises the risk of socialisation of remaining decommissioning costs.

Liability for nuclear accidents

The Nuclear Incident Liability Act limits operators' exposure to damage risk.

Operators and the government together bear the legal liability in the event of an accident at a nuclear (power) facility. This shared liability is specified in the Nuclear Incident Liability Act (Wet aansprakelijkheid kernongevallen; Wako; see Rijksoverheid, 2008), which is based on the Treaties of Paris (1960) and Brussels (1963). This act divides liability for incident costs into four tranches (see Table 1). The first tranche is an insurance taken out by the

[4] During reprocessing the uranium and plutonium contents are removed from the fuel rods. The remaining high-radioactive nuclear waste needs to be stored for thousands of years. The uranium and plutonium may be re-used for fuel production. However, the Mixed Oxide (MOX) fuel that is created from reprocessed uranium and plutonium is currently not allowed at Borssele. EPZ has requested a permit for future MOX fuel use.

operator, covering liability up to € 700 mln. The second tranche, an additional € 500 mln, is covered by the state in whose territory the installation is located, in this case the Netherlands. The third tranche, € 300 mln, is covered by the Member States of the Brussels Convention. The fourth is an additional liability for the Dutch government of € 1,700 mln.

Table 1 **Liability under the Dutch Nuclear Incident Liability Act**

	Current
1st tranche (insurance)	€ 700 mln
2nd tranche (Dutch territory)	€ 500 mln
3rd tranche (Contracting Parties)	€ 300 mln
	€ 1,500 mln
4th tranche (addition ex art. 18 Wako)	€ 1,700 mln
Total	**€ 3,200 mln**

Adding up the four tranches brings total liability for a nuclear accident in the Netherlands to € 3.2 bln. The insurance premiums associated with the first tranche are paid directly by nuclear operators. Although the Dutch government is liable for the second and fourth tranches, the provision costs for these tranches are passed on to operators (Ministry of Finance, 2011). This does not hold for the third tranche, which is paid by EU Member States with nuclear facilities. The contribution to the third tranche depends on the number of nuclear installations on a country's territory. The current Dutch contribution to the third tranche under the Brussels Convention is calculated at € 6 million. If a new 2,500 MW_e nuclear power plant is built, this amount increases to € 9 million. Note that the limited liability of nuclear operators is an indirect form of subsidy: the operator does not need to pay the insurance premium that would otherwise be paid to insure the high potential damages.

New nuclear power means extra liability at a European level.

"The nuclear power industry receives a subsidy each and every quarter in which it does not have to buy insurance to cover the full risk associated with its activity. If the government were to offer to pick up my bill for car insurance, that would help me financially (by definition, a subsidy) whether or not I crash my car."
Anthony Heyes, Professor of economics, University of London, 2003.

Importantly, the liability act does not provide full coverage of damage costs ensuing from a major nuclear accident. Specifically, any costs over € 3.2 billion are not covered by any insurance or liability (Ministry of Finance, 2011). The nuclear incidents at Chernobyl and Fukushima have demonstrated that damage costs may amount to hundreds of billions of Euros (CE, 2007; Trouw, 2011). Damages to manufacturing and agricultural sectors, infrastructure, health effects, evacuation etc. are ultimately social costs. Note that while these costs apply only in the case of severe nuclear incidents, private parties cannot insure themselves for these costs, as nuclear incidents are virtually always an exclusion criteria for insurance policies. Qualitative aspects of risk assessment are further discussed in Chapter 4.

Only part of the damage costs of major nuclear disasters is provided for under the Nuclear Incident Liability Act.

Operational and maintenance costs

In addition to fuel and waste management costs come the costs of operations and maintenance (O&M), comprising such items as personnel costs, overhead costs, real estate expenses, insurance premiums, deprecation of equipment, equipment maintenance and replacement costs and so on. Together, these costs amount to 1.05 € cent/kWh for the variable part and around € 63 per kW per year for the fixed costs, and make up the bulk ofthe variable costs of nuclear power (costs figures from ECN 2007; see Annex E).

Security of nuclear facilities and transports amounts to some 0.11 €cent/kWh of social costs.

Of these costs, those associated with the security of nuclear facilities and transports can be characterised as a social cost. The 2011 budget of the Ministry of Environment and Infrastructure reserves € 5.5 million for 'Protection against radiation' (Rijksbegroting 2011). Assuming that 75% of this can be attributed to nuclear power generation, this would mean costs for society of some 0.11 €cent/kWh.

Financial aspects of operation

During operation, the utility bears finance costs relating to construction expenses, such as cost of debt, dividend payments and the cost of plant deprecations. The magnitude of these costs depends on the chosen financial construction and historical expenses (including the final cost of construction). These costs are direct costs incurred by the utility and are likely to be the largest operational cost component for utilities operating a recently constructed nuclear plant.

A nuclear phase-out may lead to compensation claims from plant owners.

In principle, these costs pose no risk of becoming social costs, unless power plants are closed prematurely. The value of the physical assets depends on the remaining plant lifespan and the expected revenue that can be generated. If in the political process a phase-out of nuclear power is decided upon, the resultant write-off of plant value can result in a financial loss for the utility, which may result in litigation to move the government to compensate for this damage. In Germany, for example, utilities are now preparing lawsuits against the government for premature closure of their nuclear power plants (Businessweek, 2011a). Although this argument holds for any type of power plant, nuclear facilities may be at special risk given the stronger public opposition to this energy technology.

> "Nuclear is a mature source of power that has benefited disproportionately from government support to date."
> *Joe Romm, Senior Fellow at the Center for American Progress 2008.*

Conclusion

Nuclear proponents often present nuclear energy as a cheap source of electricity. However, this only holds true if one bases one's assessment solely on the direct costs of existing nuclear power plants which have largely been paid for and were constructed under regulated utilities markets. In this situation, nuclear fuel prices and operational costs are indeed low, and the difference between the marginal costs and the market electricity price provides for a steady source of revenue. However, two important nuances need to be made. First, in liberalised markets the profitability of new nuclear power plants is likely to be substantially lower than has historically been the case, owing to higher finance and construction costs, as shown in Chapter 2. Second, the actual costs associated with nuclear power plant operation go considerably further than the direct costs to the operator, as part of the costs and risks are in fact borne by society. These include:

- The risk that funds set aside for final waste disposal will be insufficient to cover the actual costs.
- Under European treaties, new nuclear power plant construction means extra liability for Member States.
- Only part of the damage costs for nuclear accidents is covered by insurance and liabilities, with society at risk for the rest.
- The security of nuclear facilities and transports is partly paid for by government.
- Having more nuclear power plants operational means a greater risk of compensation claims if a nuclear phase-out is decided upon.

4 Risk assessment

In February 2011, the Netherlands' Minister of Economic Affairs, Agriculture and Innovation, Maxime Verhagen, published a series of preconditions with which nuclear operators must comply to be eligible for a new construction permit (Tweede Kamer, 2011a). Although the document does not contain specific technical requirements, it sets out a number of constraints concerning financial support and safety standards.

The core of this list of criteria is that the probability of a meltdown must be less than once in a million years. Presumably, this criterion reflects claims based on the Probabilistic Risk Assessment (PRA) method, in which engineers conceive a variety of accidents resulting from one or multiple events and failures, e.g. earthquakes, pipe ruptures, computer failure, human error, plane crashes, floods, etc. By calculating the probability of such events and the resulting consequences, engineers can design back-up systems that still work in the case of these events occurring. Although helpful in identifying weak spots in a complex system, the resultant risk estimates should be interpreted with caution (Ramana, 2011; Marais et al., 2004). Too much trust in the results of PRA calculations may give a false sense of security, as was amply illustrated by the aftermath of the 2011 Japan earthquake. Although risk assessments had been performed, the international nuclear watchdog IAEA concluded that Japan had underestimated the tsunami hazard for several of its nuclear power plant sites (Businessweek, 2011b).

Besides doubt about the applicability of the risk figures resulting from PRA, one also needs to take into account the magnitude of the consequences. Although it is obvious that one should take extra precautions for risks that are likely to happen but whose consequences are acceptable, the converse is not necessarily true. The consequences of a nuclear meltdown are so severe that one should not neglect to take countermeasures against such events, however unlikely they are deemed (Large, 2011).

> "As chance would have it, this means that the risk an iceberg, representing but a tiny speck in the vast geographical space of the North Atlantic, colliding with an even smaller speck of a transatlantic liner would be so remote, so infrequent as to be an incredible. Hence, there would be no need to render the SS Titanic unsinkable or to equip it with lifeboats before it sailed on its ill-fated maiden voyage."
> *John Large - British nuclear expert, 2011.*

4.1 "The probability of a nuclear meltdown must be less than once in a million years"

– Minister Verhagen, 2011[5].

Fundamental flaws in risk assessment methods

It is conceptually impossible to calculate the risk of nuclear incidents a priori.

As the recent nuclear incidents at the Fukushima Daiichi plant have shown, risk assessment methods are not flawless. A fundamental problem of probabilistic risk assessment methods is that it is conceptually impossible to take into account all possible events (Ramana, 2011); there are simply too many degrees of freedom. The effect of this information gap is that risk assessments need to be adjusted after new events. The March 2011 tsunami in Japan, for example, has led to re-evaluations of risk around the globe. Back in 1989, the average risk of a nuclear incident occurring in 104 US reactors was deemed less than 1 in 400,000 per year per reactor. Based on new calculations by the US Nuclear Regulatory Commission in response to Fukushima, the average risk of incident with the same reactors has now increased to 1 in 115,000 per year per reactor: an increase of risk of over 300% *on average* (MSNBC, 2011). Although the average 1 in 115,000 risk is still higher than the 1 in 100,000 risk the plants were once designed for, the 40 US plants at highest risk are now estimated to have a meltdown risk of over 1 in 50,000 per reactor per year. Note that the actual situation at any of these plants has remained unchanged since Fukushima; all that has happened is that information previously unthought-of has now become available about the actual risks involved. As there are many more unthought-of risks, the failure risk may well be even higher.

Historical statistical evidence of meltdown risk

Historical statistical evidence indicates that the risk of meltdown is higher than previously asserted by government and industry.

Minister Verhagen has demanded a design in which the probability of a nuclear meltdown is less than one in a million. If the very calculation method on which this probability is based is flawed, however, it is impossible to guarantee the safety of the new plant. Historically, plants designed for a meltdown risk of less than 1 in 100,000 per year per reactor have led to three meltdowns in 15,000 reactor years (Harrisburg (US), Chernobyl (UKR), Fukushima (JP); five if you count the three Fukushima reactors as separate events). In an interesting article in the Dutch newspaper NRC Handelsblad (2011), statisticians estimated what the probability is of three meltdowns in 40 years, if the actual per-reactor risk is 1 in 100,000 per year, for a fleet of approximately 500 reactors. They concluded that the a priori probability of so many meltdowns is less than 0.1%. In other words, the fact that three meltdowns have already occurred makes it highly unlikely that the true risk of meltdown incidents in the current reactor fleet is 1 in 100,000 per year per reactor. Note that although the risk is likely to be higher than claimed, it is not possible to calculate the actual risk.

> "I believe [over-confidence] is a risk. I have heard industry executives state that such an accident could never happen at their plants. Those words are dangerous, and I believe do not serve to build trust – in fact, just the opposite."
> *Laurent Stricker, Chairman of the World Association of Nuclear Operators, 2011.*

[5] In: Preconditions for the new power plant, Tweede Kamer 2011a.

Incident risk in third-generation nuclear reactors

The meltdown risk of the current EPR design does not meet the minimum safety standard required by Minister Verhagen.

In the document listing preconditions for a new nuclear power plant, Minister Verhagen points out that the reactor should be of a 'proven' design (Tweede Kamer, 2011a). The reactor must be of third-generation design, with the European Pressurized Reactor (EPR) being a likely candidate. Although not yet operational, Verhagen assumes that enough experience with plants under construction will be available by the time the Dutch reactor would come on-line. In its EPR brochure, nuclear construction company Areva (2009) states that the risk of accidents due to events generated *inside* the plant is less than 1 in 1,000,000 per reactor per year (corresponding to the criterion posed by Verhagen). However, the risk of meltdown resulting from *all types of failure and hazard* is estimated at less than 1 in 100,000 per reactor per year. Presumably, this includes external risks such as earthquakes and plane crashes. Westinghouse's AP1000 brochure claims a meltdown risk of less than 1 in 10,000,000 as calculated by PRA methods (Westinghouse, 2007), but this seems to entail internal events only. No risk assessment is given that includes external events, though it is mentioned that such assessments are site-specific. Assuming Minister Verhagen's risk acceptability reflects 'all types of failure and hazard', the EPR design does not meet his criteria, and not enough information is available to judge the AP1000 design.

4.2 "The containment vessel can withstand (..) accidents with passenger planes"

– Minister Verhagen, 2011[6].

Unless engineers can predict the future, it is impossible to design a reactor plant in such a way that it can withstand all future threats.

Let us assume, for example, that the containment vessel is designed in such a way that it can indeed withstand an accident with a fully-loaded passenger plane[7]. A decade ago, the largest passenger aircraft was the Boeing 747, with a maximum take-off weight of around 400 metric tonnes. With introduction of the Airbus A380 in 2005, any nuclear reactor designed to withstand a Boeing 747 would have to be substantially revised, as the maximum take-off weight of the Airbus is almost 600 metric tonnes, around 1.5 times that of a Boeing 747. This example illustrates an actual historical problem faced by the Borssele I nuclear plant. This facility was originally designed to withstand a passenger aircraft as well, but since the only airport near Borssele is the small airfield of 'Midden Zeeland', it was deemed highly unlikely that any aircraft larger than a Cessna would ever crash near or on it (Volkskrant, 2011b). This, of course, drastically changed after the September 11, 2001 attacks on the World Trade Center in New York, which illustrated that large aircraft do not necessarily crash due to technical failure and human error, but can also be intentionally flown into buildings. While EPZ (the operator of the Borssele plant) now states on its website that Borssele is likely to withstand a medium-sized aircraft collision (EPZ, 2011), it is unclear what the impact of a large aircraft would be. Although engineers may take into account currently perceived risks, future events may change design requirements in unforeseeable ways.

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6 In: Preconditions for the new power plant, Tweede Kamer 2011a.

7 Note that the twin towers of the WTC were actually designed to withstand the impact of a commercial aircraft (Chicago Tribune, 2001; Seattle Post, 1993).

5 Life cycle responsibility

Besides safety aspects, the list of preconditions for utilities seeking to build a new nuclear plant published by Minister Verhagen in 2011 (Tweede Kamer, 2011a) includes several criteria regarding the life cycle impacts of nuclear energy. Specifically, the minister demands that the overall impact of nuclear fuel production should be minimised and that due measures be taken to ensure proper treatment of nuclear waste. At face value, the demand for life cycle responsibility is praiseworthy, and should be considered not only for nuclear energy, but also for the sourcing of the coal burned in coal-fired plants, or the steel used in windmill production. In practice, however, such demands may be difficult to fulfil, since it is difficult to assess the whole fuel and materials chain and to hold companies accountable for environmental impacts outside the Netherlands. Uranium and other types of mining are associated with local environmental impacts often beyond Dutch jurisdiction. In addition, nuclear energy is associated with a radioactive waste problem for which no permanent solution is yet available for the Netherlands.

5.1 "The operator ensures that the nuclear fuel is manufactured in a responsible manner"

– Minister Verhagen, 2011[8].

According to the cited list of preconditions, upstream activities, in particular mining, are to be practiced in a responsible manner. However, the constraints set out by the government have little practical significance and may be difficult to uphold in practice. In the first place, the environmental impacts of in-situ leaching and long-term tailing reservoir integrity involve major uncertainties. Former in-situ leaching operations with sulphuric acid in Germany, the Czech Republic and other Eastern European states still form a significant threat to groundwater quality and potable water availability (WISE, 2010). The in-situ recovery mining in these countries is comparable to in-situ operations in Australia and Kazakhstan, the most likely source of Dutch uranium. In addition, various recent court cases against mining companies in Kazakhstan indicate that it is difficult to guarantee responsible life cycle management. Mining companies there have been tried for illegal dumping of toxic and radioactive waste, corruption, theft and illegal sales of uranium (Reuters, 2010), indicating that despite government efforts to clean up the production chain, problems persist.

ISO 14001 certification is not an adequate tool for guaranteeing the responsible life cycle management demanded by the minister.

One way the Dutch government wishes to guarantee life cycle responsibility is by demanding ISO 14001 certification of the companies providing the uranium. However, environmental damage and social misconduct have previously been associated with ISO 14001-certified mining companies. In Namibia, former miners charged their employer for gross neglect and cancers contracted while working at the mine (London Mining Network, 2010). In addition, this mine was using millions of cubic metres of fresh water up to 2010, despite local rainfall shortages, and was suspected of polluting local groundwater and using decommissioning funds for mine operations. This touches on a pivotal problem of the ISO 14001 requirements, which while demanding company efforts to improve social and environmental responsibility, provides no guarantees of

[8] In: Preconditions for the new power plant, Tweede Kamer 2011a.

effective results. Hence, ISO 14001 is not the right tool for the minister to guarantee responsible life cycle management on the part of the mining companies involved.

5.2 "Nuclear waste will be stored in a deep geological storage facility (..) to ensure it remains isolated from the human environment even in the long term"

– Minister Verhagen, 2011[9].

Claiming that nuclear waste will be stored in a deep geological storage facility implies that it is already clear how and where permanent storage of spent fuel and other high-radioactive waste will take place. However, these issues are yet to be decided on. Research on the fundamentals of storage is ongoing and there is still very little knowledge of the geological layers and structures in the Netherlands which are potentially suitable for permanent storage.
Minister Verhagen states in his list of preconditions that he will announce a proposal for final storage no later than 2014.

Neither the location nor the storage method has been decided on for Dutch nuclear waste.

The general consensus in the EU is that high-radioactive waste should be stored in the country of origin in deep geological repositories designed to minimise the possibility of emissions of radioactive substances to the biosphere for tens of thousands of years. In 2001 a commission studying storage solutions for the Netherlands came to the same conclusion (CORA, 2001). A subsurface repository is generally considered far less vulnerable to the influences of weather, water and human intrusion. However, storage of chemical waste and low and medium radioactive waste in salt caverns in Germany has proven to be less stable than initially assumed, as domes in Asse and Morsleben face problems with flooding and a threat of collapse, resulting in leaks of radioactive caesium-137 (see Damveld, 2008).

Figure 4 **Damaged nuclear waste containers at the Asse facility. Containers were rusting due to brine inflow, threatening groundwater security**

Source: DW3D, 2011 (http://www.dw3d.de/popups/popup_lupe/0,,3571028,00.html).

[9] In: Preconditions for the new power plant, Tweede Kamer 2011a.

After years of research and debate, storage in clay is often deemed the most viable type of permanent geological storage for the Netherlands (see e.g. Veer, 2011). However, fundamental issues such as the fate of mobile radioactive chlorine and the impact of radiation and heat on the host clay formation are still unclear, meaning that the risk of dispersion of radioactive material in the biosphere is not yet properly understood. There is very little information available on deep salt and clay layers in the Netherlands and their suitability for permanent storage(see Annex D).

6 The cost of nuclear power

It is widely assumed that nuclear energy is a cheap option for base load electrical power and that new nuclear power plants are required to lower electricity prices and improve the competitiveness of Dutch industry. When the full spectrum of costs of nuclear power are duly considered, however, the opposite conclusion in fact emerges. Although electricity from nuclear plants built decades ago under a regulated monopoly market regime is indeed cheap, the same cannot be said of electricity from plants currently under construction or being planned. Today's nuclear power stations are being built in a liberalised market, making the financial risks significantly higher than in a regulated market. Operators cannot single-handedly increase electricity prices to increase revenues in order to cover construction costs. Instead, cost recovery depends to a large extent on maintaining a high load factor and extending plant lifetime. From this perspective, it is insightful to have a look at the levelised costs of power generation of different technologies. Such a cost comparison provides a robust indication of the relative price of nuclear compared with other generating technologies over the lifetime of the generating facility.

Comparison of cost of electricity

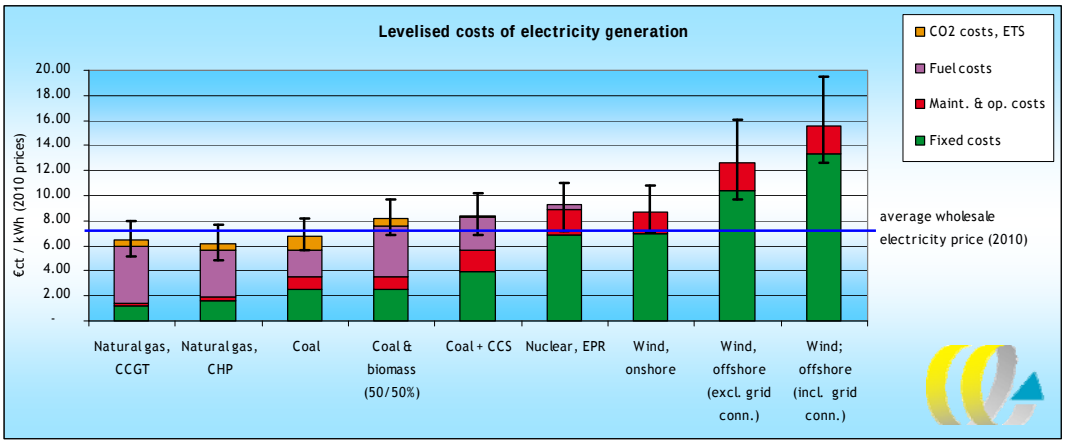
Figure 5 reports the results of such a comparison, showing the levelised cost of base load power from different kinds of plant. The levelised costs represent the integral (busbar) cost of power production by a particular technology over the plant lifetime, and comprise the capital costs, operational and maintenance costs and lifetime fuel costs, without government subsidies or other interventions. An analysis of levelised costs is the only valid way to assess the relative cost ranking of power generation options. In this approach, capital costs are calculated over the typical lifetime of a new investment. In the levelised costs model developed by CE Delft, costs are discounted to account for the return on equity (time value and risk premium), reflecting an actual accounting cost price that investors can work with. For further details the reader is referred to Annex A.

Nuclear power plants typically have high capital costs for plant construction, but low direct fuel costs. As a result, any comparison with other generating technologies hinges on the assumptions made about the construction timescales and capital financing of nuclear plants. As power plant revenue is zero during construction, longer construction times (compared with other plants) translate directly into higher finance charges in the form of interest accrued during construction. As nuclear plants generally take far longer to build than conventional plants, their finance costs are substantially higher.

At 2010 energy prices the direct electricity costs of 'new nuclear' are higher than those of any other conventional generating technology, including onshore wind.

The costs visualised in Figure 5 are termed *direct* costs as they are incurred directly by the operator. If possible they are internalised in the end-user electricity price, leaving headroom for a profit margin. If the levelised costs are higher than average market prices, the cost margin becomes negative and without subsidies operators cannot fully recover their investment costs. As Figure 5 shows, at 2010 fuel and electricity prices nuclear energy from a new plant would be unprofitable. The figure shows that the levelised *direct* costs of nuclear power are higher than for wind onshore, coal and coal with CCS and comparable with coal with 50% biomass.

Figure 5 Direct costs of electricity generation, investor's perspective in 2011

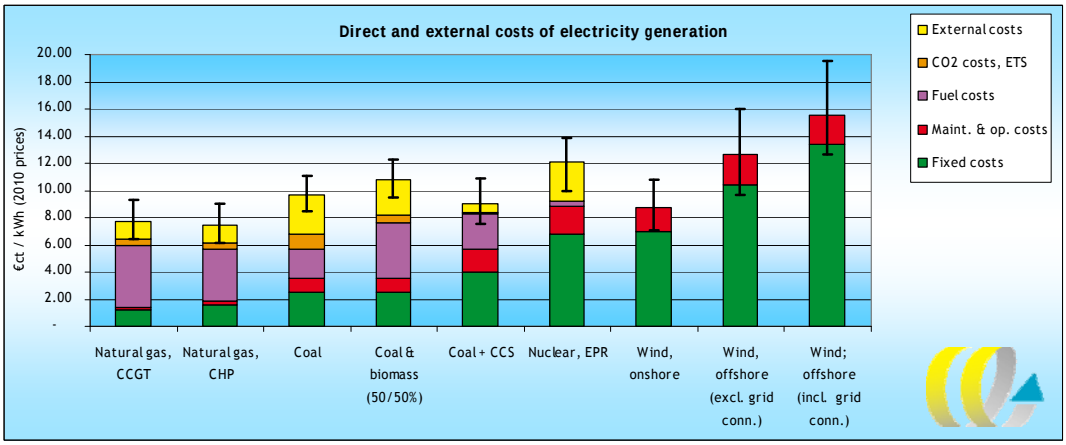


An analysis of the levelised cost of electricity, with estimates of real finance costs on the basis of commercial risk premiums, makes clear that at current market and CO_2 prices, nuclear power is more expensive than any other conventional generating mode. Other studies, e.g. MIT 2003, MIT 2009, confirm this result: new nuclear is too expensive to compete directly on cost price with electricity generated from coal and gas; additional policy measures or financial support are needed to finance the build.

Comparison including external costs

As argued in previous chapters, direct costs are not the only costs that should be taken into account in a cost comparison. Specifically, in the case of nuclear the indirect costs associated with the social risks of cost overruns and liability should also be incorporated. Figure 6 shows the levelised costs of electricity, now with these indirect costs included. In any assessment of the strengths and weaknesses of generating technologies for decision-making purposes, these external costs should be duly factored in wherever possible. In the present context the external costs of power generation include costs not paid by the operator but borne by society, such as accident risk and liability and environmental damage. For a more detailed discussion see Annex E.

Figure 6 Costs of electricity generation including external costs



From this comparison we can conclude that all fossil technologies as well as nuclear come with a sizeable external cost component. Natural gas is inherently cleaner and has lower external costs (note that this holds for conventional natural gas; this would perhaps not be the case for unconventional shale gas). The high environmental damage costs of coal are due mainly to the high CO_2 emissions. To a large extent this can be mitigated by storing the CO_2 underground; of all the fossil generating technologies the coal+CCS option has the lowest costs to society. The external costs of nuclear are also high, because of the risk-averse valuation of accidents and high damage costs. From the perspective of society as a whole, nuclear and coal score low. The 50/50% coal/biomass co-firing option also comes with high environmental costs that are only marginally better than standard coal. This is due to the land use changes associated with the use of biomass for power generation. From society's perspective, it is above all the wind energy and coal+CCS options that have the lowest external costs.

7 Impacts of nuclear power on renewables

As the previous chapters have shown, any discussion on the cost of nuclear energy should focus not only on the direct costs borne by operators, but also on the costs incurred by society as a whole. When aspects like accident risk and liability, life cycle responsibility and financial guarantees are factored into the picture, the cost of electricity from a new-build nuclear power plant proves higher than that of power from other energy sources. From this perspective, it makes more sense to invest in conventional or renewable generating capacity rather than nuclear, especially if construction consortia cannot defer part of their risks to society. Nevertheless, this decision is up to the utilities themselves. If the government refrains from financial support, it can only lay down the preconditions to be fulfilled to gain a construction permit.

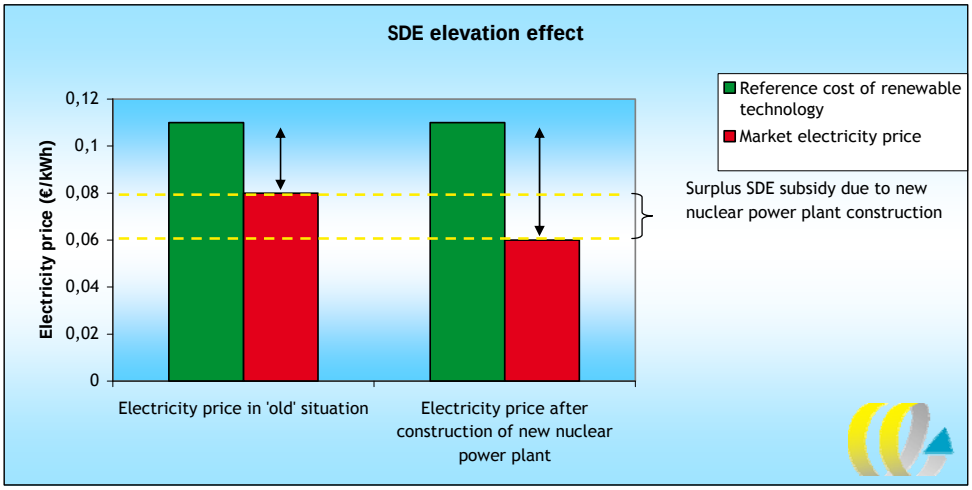
Once built, a nuclear power plant is a valuable asset for a utility, generating electricity at low marginal costs and with low CO_2 emissions. It is this cheap base load power and the small carbon footprint that constitute the main reasons for the Dutch government and the employers' association VNO-NCW to support construction of a new nuclear power plant. Expressing their support, the government has repeatedly lauded the benefits it sees for Dutch energy policy in general, mainly in terms of energy security, earning potential and European climate targets. It may be argued, however, that nuclear energy does not score as well on these issues as other energy sources. In particular, nuclear power may draw resources and attention away from renewables, and although nuclear is seen as a transition technology en route to a truly sustainable energy supply, it may actually delay the deployment and development of renewables. In the next few sections we explain why this is the case.

7.1 Cost amplification through SDE programme

It may be argued that cheap nuclear power impacts negatively on other renewable energy technologies, as subsidy programmes for the latter depend on market electricity prices. The most relevant example is the Dutch 'Stimulering Duurzame Energieproductie Plus' (SDE^+) subsidy programme, set up to bridge the financial gap between the cost of renewably generated power and the going electricity market price. The subsidy level is calculated by subtracting the average day-ahead market price for electricity in a given year from a calculated and fixed reference cost for the technology in question. For example, if a technology has a reference cost price of € 0.11 per kWh and the electricity price is € 0.06 per kWh, the SDE subsidy is € 0.05 per kWh. If the electricity price increases, the SDE subsidy decreases, and vice-versa. Because of the low marginal costs of nuclear power, construction of a nuclear plant can lead to a decline in the average electricity price, as other fossil power plants move upward in the cost ranking.

One consequence of a lower electricity price is a rise in expenditure on SDE subsidies. Hence, as new nuclear generating capacity comes on stream, existing SDE obligations become more costly, with in the future the ultimate effect that there will be less subsidy for renewable energy options.

Figure 7 **Schematic depiction of SDE elevation effect**



Green bars represent the reference price of renewable electricity, red bars the day-ahead market electricity price and black arrows the difference between the two: the SDE subsidy level. The left-hand bars depict the electricity price in the reference situation; on the right the electricity price has decreased due to new nuclear capacity. Owing to the lower market price on the right, SDE subsidies are higher than in the situation prior to new nuclear construction. The social costs associated with this increase are represented by the gap between the yellow dotted lines. Prices are arbitrary, for visualisation purposes only.

7.2 The context of Dutch energy policy

The Dutch government has frequently reiterated its desire to build a second nuclear power plant in the Netherlands. Following Fukushima, other countries have reconsidered their nuclear ambitions. After initially closing down older power plants for closer scrutiny, Germany has now decided to outlaw nuclear energy altogether (BBC, 2011). Likewise, Switzerland has decided to phase out nuclear power (Reuters, 2011), while Italy and Bulgaria are reconsidering construction of new plants (Schneider et al., 2011). The Dutch government, however, has stated that these decisions will not affect its plans to allow construction of a new nuclear facility (NOS, 2011b). One of the arguments put forward by the government is that nuclear power is in line with Dutch energy policy, which is based on three key principles: increasing energy security, a focus on the 'earning potential' of the Dutch economy and securing European climate targets. It may equally well be argued, however, that renewable energy technologies fit the bill much better than nuclear. Below, the fit of nuclear energy with government policy ambitions is discussed.

"New nuclear capacity is needed to increase energy security"

– Coalition Agreement, 2010.

Nuclear energy does not contribute to independence from oil.

One of the aims of Dutch energy policy is to become less reliant on fuels originating from a limited number of often unstable regions. Around 80% of the world's oil is found in just eight countries, many of which are in the Middle East (EIA, 2011a), and oil-consuming countries fear political unrest in this region may threaten their oil supply. Hence, independence from oil should increase energy security. Nuclear will make little contribution to oil independence, however, as nuclear energy is converted to electricity, for which purpose oil is scarcely ever used. Only in the case of a drastic transition to electric vehicles will nuclear electricity be a true alternative for oil.

Uranium reserves are just as sparsely distributed as fossil fuel reserves.

Nuclear energy is thus more likely to compete with gas or coal. Similarly to oil reserves, 80% of the world's proven gas reserves are found in just ten countries (EIA, 2011b), while 80% of coal reserves are in just six countries (EIA, 2011c). In just the same way, however, uranium deposits are sparsely distributed across the globe, with approximately 80% of known reserves found in ten countries (WNA, 2011a). Noteworthy is the major overlap in these country lists: of the top 10 countries with uranium reserves, only two (Namibia and Niger) do not recur in the top 10 countries with oil, gas or coal reserves (with many others present in more than one list). Hence, although a shift to nuclear energy broadens geographical origins to some extent, the effect is not dramatic. As is the case with most fossil fuels, fuel inputs to nuclear power plants must be imported from outside the EU.

In comparison, electricity from renewable energy sources can be imported from the European market, or indeed be generated onshore or offshore within the Netherlands itself. Biomass can be imported from many countries across the globe. Renewables would therefore make the Netherlands far less dependent on a single region of origin than fossil or nuclear energy.

"More attention is required for earning potential"

– Coalition Agreement, 2010.

There are only a handful of companies around the world that can build a nuclear power plant in the Netherlands, These foreign companies, including Areva (France) and Toshiba/Westinghouse (Japan), have limited resources to design, develop, build and 'run' a nuclear facility, most of which is done *in house*. For building a power plant and supplying the hardware, constructors depend primarily on non-Dutch suppliers, even if the plant is built in the Netherlands. All the key components of a nuclear power plant are built by specific contractors located around the world. Especially components requiring heavy engineering plants and forges (like the pressure reactor vessel) are built by highly specialised construction yards. Only three such very heavy forging works are in operation today: in Japan (Japan Steel Works), China (China First Heavy Industries and China Erzhong) and Russia (OMZ Izhora). New capacity is being built in France and the Czech Republic (WNA, 2011b). Electrical and mechanical parts are also likely to be manufactured outside the Netherlands. Large turbines, boilers and control elements are developed and manufactured by foreign companies like Siemens and GE. It is anticipated that only the generic components of a nuclear power plant can be supplied by Dutch companies, i.e. such items as reinforced concrete.

Construction of a new nuclear power plant would most likely benefit foreign economies.

Dutch industry lacks the nuclear knowledge and facilities to participate in any significant way in the construction of a commercial nuclear power plant. The Dutch nuclear research facilities at Petten and Delft are unlikely to make any contribution to a new nuclear power plant that has already been developed by Areva (EPR) or Toshiba/Westinghouse (AP1000). Only one major Dutch player, Urenco, is expected to play a significant role in the operational phase of a new nuclear power plant, for fuel enrichment.

In 2009 CE Delft (CE, 2009) conducted an analysis of the employment effects of construction and operation of a 1,600 MW_e nuclear power plant in the Dutch province of Zeeland, focusing solely on direct employment. While neglecting any indirect effects and thus showing only part of the picture, it does give a good indication of the order of magnitude of direct employment effects. In recent years only very few new nuclear power plants have been built in Europe or the US, so little reference material is available. For this reason the 2009 study uses literature from these two regions to estimate direct employment effects and their major contributing factors.
The study showed that average direct, on-site employment during the five-year construction period is 1,500 labourers, with a peak of 2,500-3,000 at any one time. During operation, the power plant creates approximately 500 jobs. A first-pass calculation of indirect employment shows 1,800 and 500 jobs created for construction and operation, respectively, but a more thorough analysis would be needed to determine an exacter figure.

By comparing the main factors of influence on the building and operation of a nuclear power plant (nuclear experience, international consortia, international tenders) with large construction projects already carried out in the Dutch energy sector, a translation can be made for the direct employment effects for the Netherlands and the province of Zeeland. The translation is based on types of jobs, level of education, local labour market and current capacity in the Netherlands.

On this basis, in CE (2009) it was concluded that a reasonable assumption for the peak direct employment effects during construction for Zeeland would be a total of 120-150 jobs. These are temporary jobs for the duration of plant construction. The number of permanent jobs in Zeeland associated with power plant operation was estimated at 150.

Very recently, the Dutch energy industry had the opportunity to present their thoughts on Dutch competitiveness to the 'Topteam Energie', one of the spearheads of current Dutch industry policy. On April 11th 2011 over 30 Dutch companies held a presentation on where the opportunities for Dutch industry lie. All but one (the Dutch nuclear utility Delta) spoke of competitive advantages in renewable energy technologies and not in fossil or nuclear technologies. According to Dutch companies themselves, then, Dutch entrepreneurial opportunities lie in renewable technologies and energy saving, not in nuclear power.

"Securing European climate targets is the guiding principle"

– Coalition Agreement, 2010.

A new nuclear power plant will not contribute to the 20-20-20 target.

The current Dutch government deems nuclear energy necessary to achieve European climate targets of 20% greenhouse gas (GHG) reductions and 20% renewable energy in 2020, the so-called 20-20-20 target. While non-zero, the greenhouse gas emissions throughout the nuclear fuel chain are indeed lower than those of the fossil fuel chains. Many life cycle studies of the carbon footprint of nuclear energy indicate that the CO_2 emissions per kWh of nuclear

power are less than 10 gCO_2/kWh (e.g. NEEDS, 2007; Beerten et al., 2009; Schneider et al., 2010). It is questionable, however, whether a new nuclear power plant will contribute significantly to European climate targets. Although it helps secure GHG reduction targets, nuclear power makes no contribution towards renewable targets, and renewable energy must be built anyway. Finally, in the Netherlands, a new nuclear power plant may compete with Combined Heat and Power (CHP) plants for base load generation. If a nuclear power plant pushes a CHP plant off the market, the CO_2 benefits will be less significant than in the case of nuclear replacing coal-fired plant, as is often assumed (see Annex F).

A tonne of CO_2 reduced now has greater effects than one reduced in 2025. It is therefore far wiser to invest in renewables than in nuclear.

No CO_2 effects are to be expected in the short term at any rate, even if planning during the permit and construction phase is very tight. Although the government claims a new plant could theoretically be operational by 2020, practical experience with nuclear power plant construction reveals large delays in construction time. It is unlikely that new nuclear generating capacity can be built in time to contribute to 2020 reduction targets. From a timing perspective, it makes more sense to invest in renewables rather than nuclear energy if the aim is to reduce CO_2 emissions. First, due to the cumulative effects of CO_2 in the atmosphere, CO_2 emission reduction now is much more effective than in the future. Since many renewable energy generation options can be built with a short lead and construction time, they are a more cost-effective way to prevent climate change effects. This argument can be taken further if one takes returns on investment into account: as many renewable generation technologies have a far shorter payback on initial capital outlay, this money can be re-invested in newer renewable capacity. With nuclear, financial assets are committed for a longer time because of the far longer construction time.

8 Conclusions

The new nuclear power plant the Dutch government is planning to approve may be less beneficial than presumed. Nuclear energy is not as cheap as is often thought, and two important reasons can be identified for cost underestimation. First, in building their case nuclear proponents often take as their point of departure the cost of the power plants in operation today. However, these plants were built under highly regulated utility market conditions, with strong government support. A fair comparison with competing generating technologies should proceed from the cost of a new nuclear power plant built today (or, in practice, in several years' time) under liberalised market conditions. Under such conditions, the cost of financing a plant increases dramatically. In addition, while many technologies are characterised by cost reductions over time, the overnight construction costs of nuclear power plants are actually increasing, displaying a negative learning curve.

The second reason for cost underestimation is that usually only direct costs are considered. The Dutch government has repeatedly stated that it will not invest in energy technologies, a statement referring to the direct costs, such as overnight investment costs and financing. However, energy technologies (including nuclear) are also associated with *indirect* costs, which are implicitly borne by society. For nuclear energy, the most prominent examples are liability in the case of accidents and cost overruns, and environmental effects associated with mining and waste.

If indirect costs were internalised and the cost estimate based on new plant construction in a liberalised market, nuclear power would cost more than electricity from other, conventional fossil fuels and onshore wind. This is an important argument against nuclear power, as its cheapness is so often stressed as the main advantage, outweighing the widespread public opposition to this mode of power generation. This illustrates a more fundamental mismatch between nuclear power and the energy policy ambitions set out by the Dutch government. According to the present coalition agreement, Dutch energy policy should be guided by three principles: energy security, earning potential and European climate targets. As we have shown above, though, while nuclear power may contribute marginally to increasing energy security, the earning potential lies mainly with foreign parties and construction of a new nuclear power plant would take too long to contribute to 2020 European climate targets. Instead, significant contributions to all three of these targets can be anticipated from investments in renewable energy sources.

In conclusion, the benefits of nuclear power in terms of costs and contributions to Dutch energy policy ambitions are rather less positive than frequently stated. Although a social cost-benefit analysis would be needed to properly weigh up the respective costs and benefits, we have shown here that any benefits are smaller than is generally assumed, and that the costs are substantially underestimated. At face value, renewable energy technologies seem to provide a better fit, at least in terms of energy security and earning potential. Although it may be argued whether renewables are currently cost-competitive with conventional fossil fuels, their costs are rapidly decreasing, unlike those of nuclear power, where negative learning rates are still adding to the already high costs identified in this report.

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Annex A Construction of a nuclear power plant

In this chapter the construction costs of nuclear power plants are explained in more detail. In doing so, we discuss not only the size of the various cost items, but also the risk of society having to shoulder any additional costs. Operational costs are described in Annex B.

A.1 Construction costs

In the Netherlands construction and exploitation of new generating capacity would be undertaken by utility companies part-owned by local and regional governments. In the Dutch liberalised market model, a utility is free in its investment decisions to develop, diversify and give direction to its generating portfolio. The choice for a specific generating technology is up the utility, within government-imposed constraints (construction permits, environmental permits, ETS and so on).

A.1.1 Overnight capital costs of construction

Capital costs for construction entail the costs of engineering, procurement and contracting (EPC) and financing costs. EPC costs are usually specified as overnight costs, the cost of the entire project if the whole plant were constructed overnight. Overnight costs exclude the costs of financing and costs related to the timing of the investment, delays, inflation during construction and so on. When it comes to quotes or estimates of overnight capital costs for new nuclear reactors, there is substantial variation. Although one would expect a reactor supplier to be able to come up with a reliable estimate of these essentially robust costs, there is too little actual experience in building new nuclear plants for them to provide reliable cost figures for construction.

Construction problems with Olkiluoto-III

The Olkiluoto-III power plant currently being built in Finland was originally presented as a prestige project sounding the renaissance of the nuclear industry in Europe. It is the first EPR reactor to be built and was intended to kick-start the EPR's further commercialisation and take-up by the nuclear market. Instead, because of delays and budget overruns it has turned into a headache for both the contractor (Areva NP) and operator (TVO). Originally planned to be operational in 2009, the plant is at least 3.5 years behind schedule owing to construction quality problems and design errors that have come to light. There are now a number of complexity-related safety concerns and it remains to be seen when the plant successfully completes its commissioning tests. Construction will not be completed before 2013 at the earliest (no new statements concerning planning have been released). The costs for this plant were originally estimated at € 3 billion, but have now risen to over € 5 billion. A bitter dispute has flared up between the contractor and operator over who should shoulder these overruns. Although initially presented as a 'turnkey' project (with budget overruns accruing to the contractor rather than operator), the contractor blames Finnish safety regulators for delaying the construction process.
See also: NY Times (2009), Thomas (2010).

A.1.2 Recent construction cost estimates

Table 2 summarises recent estimates of the construction costs of the nuclear power designs that are authorised in the Netherlands.

Table 2 Literature values for construction costs of new nuclear plants

Source	Site/reactor	€/kW[10]			Remarks
		Lower estimate	*Middle value*	*Upper estimate*	
Time 2008	AP-1000 Florida Power & Light, Turkey Point (2 reactors)	3,818	4,773	5,727	$ 12-18 bln, incl. interest during construction
Moody's 2008 (from NEI 2008)	Moody's cost estimates	3,500		4,900	All-in: incl. (IDC)
MIT 2009	New nuclear		2,800		Estimated overnight costs
Citygroup 2009	AP-1000 Georgia Power AP-1000 Tennessee Valley Authority EPR Finland (Olkiluoto-III)	 1,761 	4,452 2,507 3,300	 3,254 	Construction cost + IDC Overnight costs Construction cost
Bloomberg 2010	EPR France (Flamanv.-3)		3,030		Construction cost
NY Times 2009	New turnkey EPR		3,636		Estimate (€ 6 bln)
OECD-NEA & IEA 2010	New PWR in Netherlands New EPR in Belgium New EPR in Switzerland EPR in France, Flamanv. New EWR Germany New PWR Hungary New EPR (Eurelectric)	 2,830 2,871 	3,574 3,768 4,104 2,702 3,639 3,307	 	Estimated overnight costs. Estimate for the Netherlands includes 10% contingency costs. Value for Germany (unrealistically) low.
Mott MacDonald 2010	EPR in the UK	3,150	4,025	4,725	Estimate, first of a kind reactor, excl. IDC

To a large extent the costs reported in Table 2 are overnight construction costs for EPC. These are only part of the costs, however, for in addition to the above figures investors are also concerned with finance charges, i.e. interest costs incurred during construction (IDC). Assuming an EPR design, the impression to emerge from various sources for the average construction costs (installation and equipment costs) is a figure of about € 3,000-4,000 per kW For a nuclear plant with a 6-year construction period, IDC amounts to approximately 30% of overnight costs (+/- 5%). In addition, in practice many projects involve a number of other costs not included in EPC or IDC (land purchase, certain indirect costs). In the case of the Florida and Georgia Power plants the basic EPC figure has almost doubled (see World Nuclear Organization, 2011).

[10] In converting sums expressed in US dollars, no allowance has been made for the effects of inflation and exchange rates: 1.00 USD_{2008} ≈ 1.00 USD_{2009} ≈ 1.00 USD_{2010} ≈ 0.70 EUR_{2010} ≈ 0.64 $£_{2010}$.

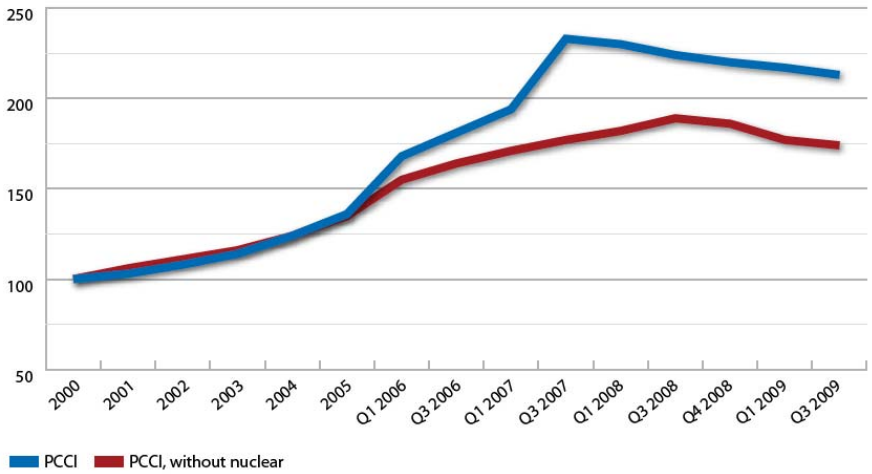
When comparing cost data from different countries due caution should be exercised, as plant location can lead to major differences. Statoil has an illustrative example in which they calculate that construction costs for chemical plants in Western Europe are about 50% higher than on the US Gulf coast (and in Norway around 87% higher) (Sintef, 2005). This said, though, the construction plans by Florida Power & Light are especially interesting because they are based on a thoroughly liberalised electricity market, providing a good idea of the magnitude of the capital outlay that is truly required under these conditions (although note that the AP1000 reactor is less complicated than the EPR).

A.1.3 Price indices for construction cost

Another caveat with respect to construction cost estimates is that while a particular estimate may be quoted and re-quoted in different literature, the prices of constituent cost items and labour do not remain constant over time but may vary significantly. The prices of specific commodities (e.g. high-grade steel, copper) as well as specific technical components each have their own dynamics, in which the effects of local scarcity may also play a role. To allow for such inflation, particularly for technical equipment, there exist cost price indices that are used together with fixed-sum estimates for turnkey projects. The project cost charged to a client is then not fixed, but is allowed to increase for components on which it is agreed the price index shall be used. Examples of price indices for technical equipment are the CEPCI (Chemical Engineering Plant Cost Index) and the IHS CERA Power Capital Costs Index. Construction cost indices can vary, according to some studies from 4% (low) to 10% (high) annually.

It is interesting to note that, since 2005, the capital costs of nuclear power plants have increased more than those of other types of power plant (OECD/NEA & IEA 2010). This is illustrated in Figure 8 below, which shows the IHS CERA Power Capital Costs Index between 2000 and 2010.

Figure 8 IHS CERA Power Capital Costs Index, 2000-2009

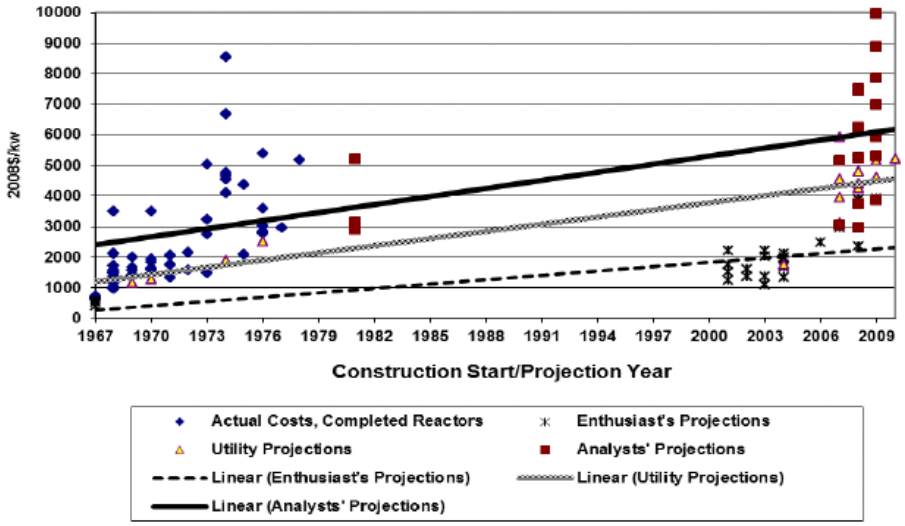


Source: OECD/NEA & IEA, 2010.

A.2 Nuclear: a technology with a negative learning curve

Unsurprisingly, cost estimates for construction of new nuclear power plants are difficult to provide. Such projects are very complex and relatively few power plants of a certain type are ever built. The newly planned plant at Borssele would be of a type that has never yet been completed, so real-world construction costs are still unknown. The estimate quoted by EPZ, the operator of the current Borssele plant, is € 4-5 billion, but the actual costs of the first plant of a similar design currently being built at Olkiluoto, Finland, are still unknown (but at least € 5 billion). Historically, the construction cost estimates made by utilities are lower than those of other parties and are systematically lower than actual costs (Cooper, 2010). Although cost estimates by independent analysts are generally higher and more accurate, they too underestimate the actual costs. Interestingly, the cost estimates of both enthusiasts and independent analysts have risen over the past few decades, as can be seen in Figure 9.

Figure 9 **Construction cost estimates versus actual costs**



Source: Cooper, 2010.

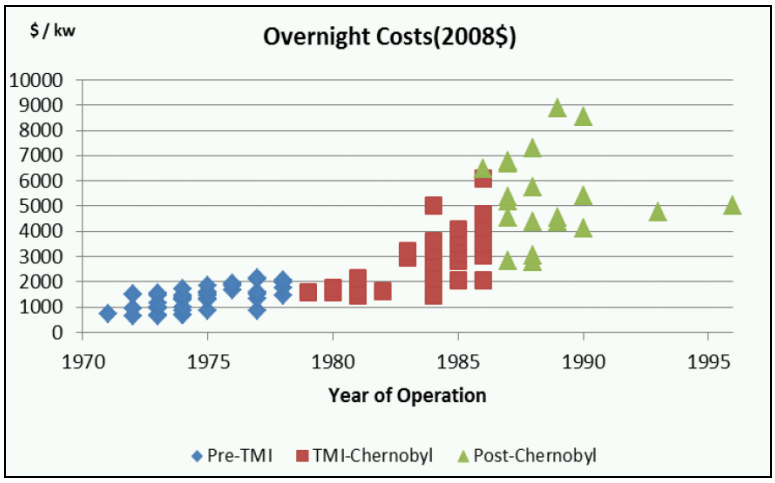
The rise of these cost estimates contrasts with the cost developments typically observed for most other technologies, where production costs generally decline over time as experience with the technology grows. It is thanks to these learning curves that renewable energy technologies like wind and solar are becoming more and more competitive relative to fossil fuels. The steadily increasing cost estimates observed for nuclear power plants, however, show a 'negative learning curve' (Cooper, 2009; 2010), with costs actually rising with increasing cumulative installed capacity. Although this effect may partly be explained by the slump in construction projects over the last few decades, a similar trend was already visible in the period 1967-1980 (see Figure 9). One reason lies in the additional technological demands made on new plants; as new incidents occur in operational facilities, safety guidelines become ever more stringent.

Consequences of the Fukushima disaster: effects of longer construction times

One likely consequence of the Fukushima disaster is that construction times for new nuclear power plants will increase as a result of new and tighter regulations, safety reviews of design specifications and consequently tougher technical safety standards. This has proven the case with the two historic major nuclear failures with core meltdown, Three Mile Island (TMI) and Chernobyl. These catastrophes were statistically significant causes of longer construction periods and higher costs, even after correction for differences in interest rates and finance costs (Cooper, 2011). The resulting rise in cost estimates for nuclear projects is shown in Figure 10.

In the initial years of the build, a new power station only incurs expenses, with income only materialising when the plant comes on stream and power generation starts. The longer the period of construction, the longer it takes before incoming revenue starts to balance the mounting expenses. In the meantime, expenses for the investor are mounting as a result of the compound interest paid on the debt on the construction costs up to that time.

Figure 10 Overnight cost estimates for 99 reactor projects in the US



Source: Taken from Cooper, 2011.

The colouring reflects the time period of the estimate.

ECN (2010) puts the figure for the interest paid during construction at 10-16%, with a best value of 13%. However, in the case of a liberalised market with finance costs carrying normal commercial risk premiums, the impact of several years' delay in construction is many times greater than this figure. In the comparison of levelised costs (Annex E), for nuclear we calculate with a factor for IDC of 30%, corresponding to a six-year construction period with the bulk of expenditure in the final three years[11]. Adding three years to the construction period would give an IDC factor of 40-43% if the delays occur in the earlier years of construction. If they occur at a later stage of the project they can be more costly, as more expenditure has then already taken place and the cost of debt is therefore mounting faster owing to compound interest. The combined effect of the above makes it likely that Fukushima will lead to increased capital costs, less scope for utilities to obtain debt financing from banks and higher interest payable on debt.

[11] This figure is calculated using a model with expenditure timing according to a triangular distribution with the median at 75% of the length of construction. The weighted average cost of capital during construction is 10%.

A.3 Financing construction

Overnight construction costs are the direct costs of technical components, engineering and so on, but the finance component must also be accounted for. During the construction phase, capital is expended before returns materialise. The capital outlay generates finance costs in the form of interest during construction (IDC). In cost estimates, when there is talk of simply 'construction costs', these are usually overnight construction costs, omitting IDC.[12] If a project has a long construction period and suffers construction delays, IDC costs can become quite significant, as illustrated above. IDC costs depend on such factors as the length of the construction period, the financial construction and risk premiums, the timing of the expenditure and so on. Because of the substantial project risk, project financing during construction often carries a risk premium. The risk concerned may be technical or otherwise, e.g. regulatory. The risk premium means an increase in the amount of interest paid during construction. Once construction is completed and the plant is operational, project risks are vastly reduced and at this point in time loans can be refinanced at lower interest rates. The risk premiums applicable are higher in the case of first builds of a particular generation (first-of-a-kind projects) compared with more standard technology (n^{th}-of-a-kind). Risk premiums are also higher in the case of an n^{th}-of-a-kind technology that is the first reactor in a new country, owing to a greater regulatory and political risk as well as a degree of inexperience with local circumstances.

There are several options available to financiers for mitigating risk, any or all of which may be applied:

- A higher interest on debt.
- A higher percentage equity share of the investment (debt/equity ratio).
- Higher principal repayment (shorter payback time).

The levelised cost model shows that capital costs make up 70 to 80% of the overall costs of electricity from nuclear power plants. The high capital costs and long construction lead times associated with nuclear reactors make them a risky asset vulnerable to market, financial and technological change. Because of the large capital and lead times, the financing of a nuclear power plant is the single most important factor determining the economic competitiveness of nuclear power. The weighted average cost of capital (WACC) therefore becomes the most sensitive parameter in overall costs. We argue that the way financial risks, as part of the WACC, are priced into nuclear power costs is a key factor in the economics of this form of power generation.

[12] The 'better' literature properly indicates whether or not costs are all-in, i.e. including finance.

A.4 Credit-rating of nuclear energy

The capital cost of building a nuclear power plant differs from country to country and from company to company. Factors of influence include the particular risk factors in the country of construction and national organisation of the electricity sector. In a regulated monopoly, operators are assured of being able to pass on their costs to their customers owing to the lack of competition. The risk to investors is hence negligible and interest rates may be as low as 5 to 8% (Thomas, 2005). In a competitive, liberalised electricity market, however, operators have no guaranteed price for their electricity, which means an increased risk for investors. In such countries, interest rates may increase to 15% or more. These rates are also influenced by the creditworthiness of the utility in question. Public utilities are generally rated higher than private ones, making it easier and cheaper for them to obtain loans. Governments may reduce risks to utilities through bank guarantees, minimum prices or volume guarantees, reducing capital costs. However, these may be seen as forms of state subsidy and it is unclear whether these are allowed under European law (Thomas, 2005).

The goal of this section is to investigate the influence of credit-ratings on the ability of utilities to obtain loans. In addition, the effect of the Fukushima disaster on creditworthiness is examined. The rationale is that companies with poor credit-ratings face higher costs when raising capital, increasing the price of nuclear energy. If companies investing in new nuclear plants receive lower ratings and/or the Fukushima disaster negatively influences credit-rating, the result may be increased costs for nuclear power. In order to investigate this hypothesis, contact was established with Moody's and Standard & Poor's, two world-leading credit-rating agencies.

A.4.1 Credit-rating of companies investing in new nuclear power plants

In 2008 Moody's published an article in which it observed that companies investing in new nuclear power plants run an increased credit risk due to the high capital costs and lengthy construction times involved. In the article Moody's recommends utilities to improve their balance sheets in time and to attract new capital, not only before onset of construction, but during the whole construction period as well. In particular, the period between 5 and 10 years after construction onset is held to be associated with increased credit risk. In 2009 a second publication warned utilities that Moody's had not yet observed balance sheet improvements, despite their earlier recommendation. Although the article acknowledges that no distress calls are yet necessary, Moody's does seem to urge utilities in stronger phrasing to improve their financial situation. They warn that if their recommendation is not followed, they may need to adjust the credit-rating of utilities downwards. This warning is mainly aimed at companies investing in new nuclear power plants. Once the power plant is up and running, it is a very valuable asset. Once investment costs are refinanced, marginal generation costs are relatively low and payback is high (Andreas Kindahl, Standard & Poor's, personal communication).

Despite these considerations, no downwards adjustment of credit-rating has yet taken place, because companies are still willing to invest in new nuclear power plants. On the other hand, the credit-rating of the top 25 European utilities has slowly declined over the last few years (Standard & Poor's, 2010).

A.4.2 Effect of Fukushima on credit-rating

After the disaster with the nuclear plants in Fukushima-I, several rating agencies speculated that their assessment of the nuclear industry could be negatively adjusted. There are several reasons for this. First, the disaster meant that public support for nuclear power deteriorated. This introduces the risk of governments slowing down or even halting existing regulatory procedures, and of already incurred costs never being recovered because the core business will never materialise. This has a negative impact on the industry as a whole and the position of the investing companies in particular.

Another factor is the possibility of tighter safety requirements being introduced. The Fukushima accident has led many countries to express a desire to verify the safety of their nuclear portfolio and assess whether current safety standards need updating or plant technologies and procedures require adjustment. In the latter case, operators of both existing power plants and plants under construction face additional costs, which in turn can reduce the creditworthiness of these companies. An example is Germany, where the government has shut down seven plants now considered obsolete, pending a decision on whether they should be modified or closed for good.

Credit-rating agencies are in the continuous process of reviewing their ratings for utilities and nuclear operators. On May 30th, 2011 the German government announced they would phase out nuclear energy by 2022. This has implications for German utilities operating nuclear facilities, who will likely receive less revenues and need to invest in new generating capacity to replace the phased-out plants. As a result of this decision, Moody's negatively adjusted the credit-rating of four major utilities owning German power plants (Moody's, 2011). This may affect these utilities' ability to attract new capital on the market, increasing the construction costs of any new facility.

Whereas Moody's seems more inclined towards downgrading the credit-rating of nuclear operators in general, Standard & Poor's seems to be of the opinion that, with the exception of Germany, nuclear operators' credit-rating requires no adjustment in the short to medium turn[13]. S&P's regards ownership of depreciated nuclear power plants as a very valuable asset for incumbent operators, as the returns are relatively high once the very high fixed costs are paid for. Furthermore, the reasoning is that although nuclear operators may face additional costs due to additional safety requirements, higher gas and electricity prices may lead to increased operator revenues. At the same time, however, Standard & Poor's notes that 'political and systemic risks on nuclear operators are mounting, and the consequences and effects are still difficult to assess at this early stage'.

The main energy companies operating in the Netherlands currently have the following credit-ratings:

- Essent N.V.: long term A, short term A-1 (S&P).
- N.V. Nuon: long term A, short term A-1 (S&P).
- Eneco Holding N.V.: long term A-1, short term A-2 (S&P).
- Delta N.V.: long term BBB (S&P).
- RWE A.G.: long term A, short term A-1 (S&P).

[13] 'Credit FAQ: Japan's Nuclear Crisis Could Have Lasting Effects For European Nuclear Operators'.

The conclusion is that, for the Netherlands, the credit-ratings of larger utilities with a larger mixed portfolio and mixed services are 'upper medium grade' (A, A-1), whereas Delta, the part-owner of Borssele, receives a poorer 'lower medium grade' BBB to reflect its weaker financial position.

A.4.3 Effect of credit-rating on finance costs and capital costs

As a company's credit-rating is an indicator of its financial health and outlook, the lower this rating, the greater the effort it must make to obtain financing for its projects and the higher the costs thereof. These costs will be higher because of the higher interest on its debt and the higher dividends to its shareholders. It is unclear to what extent this market mechanism also applies to nuclear energy, as the shareholders of a nuclear power company may be public bodies, influencing the financial risk to banks. For example, a large share of the financing of the Olkiluoto-3 nuclear plant comes from a € 1.95 billion loan syndicated from a bank consortium led by Bayerische Landesbank at significantly below market rates (2.6%), completely ignoring any project risk[14].

A.5 Who pays for cost overruns?

The type of risk ensuing from cost overruns differs according to whether investors in a new nuclear power plant are private or semi-public. In the case of private investors there is no possibility of overruns of direct construction costs being transferred to society, all the more so because Minister Verhagen has repeatedly claimed that the Dutch government would not contribute financially to construction of a new power plant (Tweede Kamer, 2011a). However, there is every possibility of *indirect* costs being incurred by society, particularly in the form of opportunity costs. Opportunity costs are the cost of an investment measured in terms of the next best alternative. In the case of investments in a new nuclear power plant, the utility's investment opportunities are reduced, precluding energy/cost-saving investments in other parts of its generating portfolio (installation of better boilers, investments in better heat recovery management, investing in renewable technologies such as wind and solar) (Lovins, 2006). This means cost price reductions cannot take place, and in the end consumers pay a higher price for electricity.

In the case of a (semi-)public investor, the story is rather different. First, cost overruns may lead to direct social costs in terms of less dividend payments by the utility. This has direct consequences for government finances. Indirect costs may also be incurred by public participation in investment projects. Governments may be satisfied with lower rates of return than market parties would be. A (partly) state-owned company is inherently financially more robust owing to the implicit scope for recovering certain costs from the treasury and taxpayers. While market investors will not allow a company to forgo dividend payments, (local) governments may be less strict in this respect. Governments can also prevent bankruptcy by increasing their equity share at the time of need. Delta's current shareholders are Dutch municipal and provincial authorities. Were Delta to build a new nuclear power plant, then these echelons of government, and consequently taxpayers in these regions, would face an indirect risk from construction problems and budget overruns. It should, however, be noted that Delta is a small player in the Dutch electricity market with a moderately weak financial outlook and low

[14] EU Investigation Requested Into Illegal Aid To Finnish Npp - http://www.klimaatkeuze.nl/wise/monitor/620/5659.
EPR: An expensive subsidised nuclear reactor for Finland, Greenpeace briefing June 5th, 2005 http://files.olkiluoto.info/pdf/GP_briefing_subsidies_EPR_Finland_050606.pdf.

liquidity and will be unable to independently contribute any sizeable part of the investment required for a new plant. Additional financial support (e.g. by RWE or EDF) would therefore be necessary and if this is in the form of equity, these parties will bear the greater risk burden.

Annex B Operational aspects and costs

In this chapter we discuss the costs of operational aspects of a nuclear reactor. The direct operating costs (busbar costs) of electricity from a nuclear power station comprise variable and fixed costs. Nuclear power plants have relatively high fixed costs and low variable costs. We will also discuss the revenue side (sale of electricity produced).

The variable costs (exploitation costs) of nuclear energy consist of the costs associated with the following aspects:
- Uranium fuel.
- Temporary and final storage of radioactive waste.
- Operation and maintenance, including insurance and safety.

The fixed costs include costs for the following aspects:
- Finance: interest and debt repayment.
- Build-up of a reserve for plant decommissioning.

Two general points need to be reiterated here. First, although the Dutch government has stated it will not contribute to the *direct cost* of running a nuclear power plant, the *indirect costs* also need to be taken into account, and here the government and/or Dutch society may well be called on to contribute. Second, when debating the construction of a new power plant, cost comparisons must be based on financing under liberalised market conditions, and it is from this perspective that that the various cost components of nuclear energy will be considered in this chapter.

B.1 Uranium fuel

With nuclear power generation, fuel costs are very low compared with other technologies. This is due to the high energy yield of the nuclear fission process from a given amount of uranium reactor fuel. The low fuel cost is the main reason parties are tempted to regard nuclear energy as a cheap source of power (famously, in the 1950s, developers of nuclear technology promised energy 'too cheap to meter').

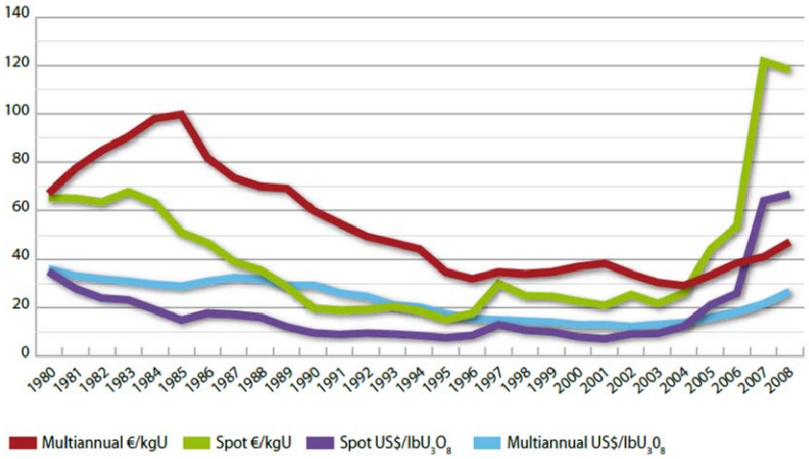
Production of uranium fuel for nuclear reactors comprises the steps of exploration, mining, milling, uranium conversion, enrichment and fuel rod fabrication. According to the World Nuclear Association, which publishes data on the cost of reactor fuel, in March 2011 the cost of 1 kg of uranium oxide (UO_2) reactor fuel was built up as follows (WNA, 2011)[15]:

Step	Amount	Cost (€)
Uranium, mined and milled	8.9 kg U_3O_8	885
Conversion	7.5 kg U	67
Enrichment	7.3 SWU	772
Fuel fabrication	per kg	164
Total, approximate	per kg	1,887

[15] WNA, 2011: 'The economics of nuclear power'. http://www.world-nuclear.org/info/inf02.html.

At a burn-up rate of 60 GWd/t, for which an EPR-type reactor is designed, and a thermal to electric efficiency of 36%, this amount of reactor fuel yields 518,400 kWh, hence fuel costs amount to 0.36 €cent/kWh. The price of mined uranium fluctuates strongly, in 2010 spiking by 67% in six months (Figure 11). With mining capacity currently limited, such fluctuations are becoming sharper. While any rise in uranium costs has a strong impact on fuel rod costs, the impact on the operational costs of a nuclear plant is very limited.

Figure 11 Uranium U_3O_8 prices: long-term contracts and spot market (prices in €/kg and US$/lb)



Source: Euratom (2008), taken from OECD (2010).

The indirect costs to society of the nuclear fuel cycle relate to the external costs of (risks of) accidents, environmental damages and pollution resulting from mining, milling and processing (see also Annex E).

B.2 Treatment and storage of nuclear waste

At some point in reactor operation the fuel reaches a point where it is no longer sufficiently active to properly sustain the chain reaction. The spent fuel rods then need to be removed and temporarily stored to allow them to cool down. After the cool-down period, they are either sent to temporary and ultimately final storage or, alternatively, to a reprocessing plant.

B.2.1 Temporary storage of nuclear waste

In the Netherlands nuclear waste is first temporarily stored at the Central Organisation for Radioactive Waste (COVRA) facility in Vlissingen. Since 2003 highly radioactive waste (HRW) is stored in the High-radioactive Waste Treatment and Storage Building (Hoogradioactief Afval Behandelings- en Opslag Gebouw, HABOG). HABOG was built for storing the spent fuel from Dutch nuclear reactors in Borssele, Dodewaard (now closed), Petten and Delft. The waste will remain stored in HABOG for at least 100 years, at which time a solution must be available for final disposal. COVRA employs various types of charges to cover the costs of above-ground storage at the current location (Profundo, 2005):

- A contribution to the total investment in HABOG.
- A delivery charge per m^3 of waste, covering the direct costs of collection, transportation and HABOG storage of the radioactive waste .

– A contribution to the cost of storing the HRW in HABOG through to the year 2130. This includes the fixed costs of land and buildings, and the maintenance and management costs of active and passive operating periods[16].

EPZ pays these charges from its 'Provision for reprocessing and storage costs'. At the end of 2009 this provision had a volume of over € 257 million (EPZ, 2010). In 2002 € 101.6 million was withdrawn from this provision for investment in HABOG and for temporary and permanent storage of HRW produced until 2004 (Profundo, 2005). For HRW produced after 2004 a delivery charge and contribution (see above) is paid. The investment in HABOG totalled € 125 million, 60-70% of which was borne by the owners of Borssele (Profundo, 2005). HABOG was initially built to provide for storage of HRW in the light of the proposed closure of the Borssele power plant in 2004. Due to operation of Borssele now being extended, HABOG is not equipped to manage the resulting additional HRW. It is expected that HABOG will have sufficient capacity for all the HRW produced until 2007[17] (Provincie Zeeland, 2003), after which time modular extension of the facility will be necessary. When the Borssele plant was scheduled to remain operational until 2013, the required expansion of HABOG was costed at about € 30 million (ECN, 2005). With closure now postponed until 2033 (Rijksoverheid, 2011c), this figure looks set to become much higher.

Some customers pay their contributions for HABOG up-front. In the case of EPZ these contributions come from the 'Provision for future HABOG costs', which at the end of 2009 had a volume of € 55.8 million.

In calculations of operating costs, interest rates during fund build-up need to be duly factored in. In this study build-up is based on an interest rate of 3% (excluding inflation; the nominal interest rate is 5%), while real interest rates in recent years have been around 2%. This could lead to a deficit in operating costs (Profundo, 2005).

B.2.2 Final disposal of nuclear waste

In addition to temporary storage, COVRA is also responsible for the final disposal of Dutch nuclear waste. To cover the cost of final disposal a disposal fee per m^3 is charged when the waste is collected. At COVRA this fee is placed in the 'Provision for future supply costs of solid radioactive waste'. In late 2003 this provision had a volume of € 22.04 million (Profundo, 2005).

The total cost of final disposal in 2130 is an estimated € 2 billion (COVRA, 2009). Again, future interest income is already taken into account in this figure, based on an interest rate of 3% (excluding inflation). If long-term interest rates do not rise, investing might be an option, since with a term of 100 years, the risks are considerably smaller. However, both interest rates and estimated costs are uncertain at the present time, thus precluding any urgent need for action. In calculating the cost of final disposal COVRA makes the assumption that final disposal will be realised in 2130 (Profundo, 2005). In government documents, however, it is stated that final disposal should commence 'after 100 years, beginning in 2000' (Tweede Kamer, 2003). This means there is a risk of budget deficits being incurred at the time of actual disposal, as the earmarked funds will then accrue 30 years' less interest.

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16 The active period of exploitation is the period in which new HRW is stored (until 2014). After 2014 a passive period of exploitation will commence.

17 This HRW will be reprocessed in (most likely) France and will be stored in HABOG around 2015.

B.2.3 Cost overruns for waste management

There is a risk of cost overruns in both temporary and final storage of waste. As operators pay COVRA fixed amounts for temporary storage as well as for final long-term storage of nuclear waste, the utility companies are exempted from this risk as long as the risk has not manifested itself. The problem here is that, for final storage in particular, it is as yet unknown what the actual costs will be. Since COVRA is a public institution, the question is: what happens if the financial reservations that have been built up prove insufficient to cover any cost overrun? Here there is a potential risk of additional investments being required from public funds.

B.3 Fund build-up for plant decommissioning

In the Netherlands, institutions wishing to build a new nuclear plant must, by the start of production (when the fuel rods are first placed in the reactor), have concluded arrangements that are guaranteed to cover the full costs of decommissioning at the end of the plant's life.

This arrangement serves to prevent the State from being exposed in any way to any shortfall in reserves for the costs of decommissioning of a nuclear facility. A market party can obtain a guarantee by way of insurance, a bank guarantee, a specific fund or other instruments providing the same financial security (Rijksoverheid, 2011b). These arrangements are to be maintained until decommissioning is complete and be regularly checked and updated.

The scheme applies to licensees of nuclear devices in which energy can be released (i.e. nuclear reactors) and covers the following existing Dutch facilities: the Borssele nuclear power plant (licensee: EPZ), the High and Low Flux Reactor in Petten (NRG), the Delft Reactor Institute (Delft University of Technology) and the Dodewaard nuclear power plant (GKN, now closed). Apart for the research reactor at Delft University, all these plants currently have a decommissioning fund.

B.3.1 Synchronisation of fund build-up with plant lifetime

Against this background, however, it appears that fund structures are not always synchronised with the life expectancy of the installation concerned. For example, the € 163.6 million which EPZ had reserved (in 2006) for decommissioning the Borssele plant was well below the decommissioning cost estimate of € 700 million cited in (SEC (2007) 1654). According to the then-State Secretary of the former environment ministry, VROM, since initial production in 1973, EPZ had built up a financial provision for decommissioning that would be at least sufficient to cover deferred decommissioning 40 years after closure of the plant in 2013. If closure is to occur in 2033, fund build-up has continued another 20 years, decreasing risk of fund shortages. However, such risks are not to be expected for the construction of a new nuclear power plant, as the proprietor will be required to have decommissioning funds in place at the start of operations and update estimates every five years (Tweede Kamer, 2011a).

B.3.2 Other uses of the decomissioning fund

Research for the European Commission has shown that in some countries decommissioning funds have been used for internal management or financing purposes (COM (2007) 794). To avoid this in the future, the Commission has prepared a recommendation for the proper management of such funds, including management by an independent body, making non-commercial information public and investments with a low risk profile (2006/851/Euratom).

In answer to parliamentary questions, the Dutch Minister of Economic Affairs has stated that money from decommissioning funds may be used for other purposes, provided the full amount of the fund remains covered by a bank guarantee, insurance or other collateral (Tweede Kamer, 2006). In addition, the permit holder should bear in mind that on retirement of the nuclear plant the necessary funds are made available the moment they are needed. We currently have no insight into use of the decommissioning funds for purposes other than intended.

B.3.3 Decommissing fund risks for the Dutch state

By setting and enforcing these rules, the Dutch state appears to be at a low risk regarding the decommissioning costs of the nuclear plants that are currently operational or will be built in the future. The decommissioning funds are externally managed (COM (2004) 719 final) and are filled through a surcharge on the electricity price (in the case of Borssele) or a volume charge for waste (in the case of COVRA). Because COVRA and Borssele are largely publicly owned, however, the Dutch state is the ultimate guarantor of decommissioning funds (CEC, 2007). This would not be the case if Borssele were privately owned, although in the final count there is also a risk when a private operator defaults on its obligations.

In Great Britain a major dispute has recently broken out around the new electricity bill, as nuclear power opponents discovered a clause they found unacceptable (The Guardian, 2011). Clause 102 of this energy bill regulates how much money nuclear operators are required to spend on such issues as decommissioning. This issue of contention is that this amount, which is agreed on before plant operation commences, can only be modified by mutual consent of both the minister and operators. According to nuclear opponents, this lumbers the general public with the risks of future safety shortcomings and financial oversights, since operators are unlikely to accept tighter provisions resulting from progressive insight (resulting from new incidents or higher costs for decommissioning and final storage, for example). Nuclear opponents therefore insist that the phrasing be modified. Interestingly, this dispute was raised in the context of the government's statement that no tax money would be used to support the nuclear industry. In the Netherlands, the provision seems less susceptible to operator input. Minister Verhagen (2011) states in his list of preconditions that provisions need to cover the most recent decommissioning plans, which must be updated every five years.

B.4 Restricted liability for nuclear accidents

Operators and the government together bear legal liability in the event of emergencies in nuclear power plants. This shared liability is specified in the Dutch Nuclear Accident Liability Act (Wet aansprakelijkheid kernongevallen, Wako; see Rijksoverheid, 2008), which is based on the Treaties of Paris (1960) and Brussels (1963). The Act has not yet come into force, however[18]. Insurance arrangements for such incidents are divided into four tranches, as laid down in the Revised Brussels Treaty and its additions (Rijksoverheid, 2005):

- The first tranche is an insurance taken out by the operator, who is required to cover the first € 700 million of damages.
- The second tranche of liability is for the state in whose territory the installation is located, in this case the State of the Netherlands. In this tranche the Dutch government is liable for € 500 million. The amount is included in the Ministry of Finance's trial balance for the projected new nuclear plant as a (current) guaranteed obligation.
- The third tranche is paid by the Member States of the Brussels Convention, which together are liable for € 300 million (see text box)
- The fourth tranche is an additional liability for the Dutch government to make up the full liability to a maximum of € 3.2 billion (so, an additional € 1.7 billion).

Revised Brussels Convention

(Protocol to amend the Convention of 31 January 1963 supplementary to the Paris Convention of 29 July 1960 on Third Party Liability in the Field of Nuclear Energy, as amended by the Additional Protocol of 28 January 1964 and by the Protocol of 16 November 1982; Paris, 12 February 2004)

Under Article 3, paragraph b (iii) of the Revised Brussels Treaty the third tranche of € 300 million will be made available by the Contracting Parties according to the formula for contributions referred to in Article 12. The financial contribution of each of the Contracting Parties shall be as follows:

- As to 35%, on the basis of the ratio between the gross domestic product at current prices of each Contracting Party and the total of the gross domestic products at current prices of all Contracting Parties as shown by the official statistics published by the Organization for Economic Co-operation and Development for the year preceding the year in which the nuclear incident occurs.
- As to 65%, on the basis of the ratio between the thermal power of the reactors situated in the territory of each Contracting Party and the total thermal power of the reactors situated in the territories of all the Contracting Parties.

Based on available data, the height of the Dutch contribution, per incident, is currently calculated at € 6 million. Considering the existing power plants in construction by the Contracting Parties, then an additional 2,500 MW Dutch nuclear power plant would raise the contribution to € 9 million. If Borssele is closed, the Dutch contribution will still be around € 5 million.

[18] The amendments to Wako (Staatsblad, 2008, 509) still await implementation, contingent upon all partners to the Treaties of Brussels and Paris (BE/DE/DK/ES/FI/FR/IT/NO/NL/GB/SI/SE/CH) making the necessary adjustments to their national legislation (Kamervragen Thieme, 2011).

Since the Government has adopted the standpoint that the amounts set in the international framework are too low to guarantee appropriate compensation for victims of a serious nuclear accident, Article 18 of Wako has a provision that goes beyond the obligations arising from said Treaties (the fourth tranche). This provides for an additional € 1.7 billion from the Dutch government, raising the total liability to € 3.2 billion (see Table 3).

Incidentally, in the explanatory memorandum to the Wako legislation it is explicitly stated the impression should not be given that the cited amount would be sufficient to cover all the financial consequences of a serious nuclear accident. Costs above this amount are not internalised, but would be borne by society and are thus in effect external costs. Should a situation arise where the damage exceeds the amount for which the operator is liable and for which the State provides guarantees (now € 2.3 billion per nuclear incident), then government and parliament together decide on an ad hoc basis whether and to what extent the damage is recoverable (Kamervragen Thieme, 2011).

Tranches 2 and 4 are, in any case, the responsibility of the Dutch state and amount to € 2.2 billion per incident. Since the Netherlands presently has seven nuclear facilities, a (current) guarantee obligation of € 14 billion is included in the trial balance of the Ministry of Finance budget. For this guarantee under Article 19 of Wako the Dutch government charges the two major nuclear installations in the Netherlands (Borssele and COVRA) an annual fee. To determine the level thereof, a comparison is made with the premiums charged by commercial insurers to cover such liabilities. In this way the fee is in accordance with market premiums and with further international legal obligations and there is thus no state aid involved (Tweede Kamer, 2006).

Table 3 **Liability as specified by the Nuclear Accident Liability Act**

	Current
1st tranche (insurance)	€ 700 mln
2nd tranche (Dutch territory)	€ 500 mln
3rd tranche (Contracting Parties)	€ 300 mln
	€ 1,500 mln
4th tranche (addition ex art. 18 Wako)	€ 1,700 mln
Total	**€ 3,200 mln**

B.5 Securing nuclear facilities and transports

In the Netherlands the nuclear physics department (part of the VROM Inspectorate of the Ministry of Environment and Infrastructure) is responsible for nuclear safety and the implementation of several treaty obligations in the field of nuclear safety and waste management. This falls under the budget item 'Protection against radiation'. In 2010 this amounted to € 6 million, but it will also partially benefit other radiation-related activities such as research reactors for radioisotopes, policy development in the field of radiation around high-voltage lines and enforcement of regulations regarding use of radioactive materials in hospitals.

Assuming that 75% of the budgeted amount benefits nuclear power, this would be € 4.5 million per year. With a production of 4 billion kWh per year (Borssele plant) the cost amounts to 0.11 €cent per kWh. This is the amount used for protection of nuclear transports, implementation of legislation and international treaties, policy development in the field of nuclear fuel reprocessing and the granting of permits.

B.6 Finance and debt payment

During the operating life of a power plant the invested capital generates finance costs. These costs are largely fixed, with no dependence on actual power plant performance. The level of debt generates interest costs and costs of principal repayment, while for the equity share of the investment certain other costs are applicable, including an appropriate rate of return and dividend payments to shareholders. When the nuclear plant is operational, the applicable interest rate depends on such aspects as the operational performance of the plant, the financial capacity of the utility, and market and regulatory conditions. Loans are re-negotiated from time to time or terms may be adjusted (e.g. longer pay-back period, different risk-surcharge).

Plant deprecation

The value of the physical assets declines over time. At the beginning of the plant's lifetime its value will equal the construction costs. Towards the end of its life the value will depend on the amount of money that can be still made with it. This depends on the revenues from electricity produced and therefore also largely on the remaining regulatory lifespan (depending on the agreed maximum age of the plant, e.g. 40, 50 or 60 years).

When a political decision forces a utility to close a plant prematurely, i.e. earlier than previously allowed by the regulator, the utility suffers a loss, as a power station with a certain remaining economic value suddenly needs to be written off. Here there is a risk of the State being held accountable for this loss. In Germany the nuclear phase-out ordered by Mrs. Merkel's administration following the Fukushima disaster will likely result in litigation from the nuclear industry, which will want to be compensated for this loss (Businessweek, 2011a). This involves a risk of costs ultimately being passed on to the German administration and taxpayers.

Interest and risk

The cost of the debt moiety of plant financing is determined by the interest rate and the term of the loan. The interest rate consists of the base rate, which is taken to be a risk-free rate, and a premium for the risk of the project. For the risk-free part, the interbank financing rate (Euribor, see Figure 12) or the rate of government bonds of 'solid countries' (e.g. Germany) is usually used. The risk-free moiety at least covers the risks of inflation. The risk premium is calculated by banks from a quantitative and qualitative assessment of the level of project risk (technical, regulatory, price and so on). Risk premiums can range from a couple of percentage points to over 10%. The values that will be used in the financing of nuclear power plants are unknown, since there is presently no construction taking place in deregulated markets that are entirely free of distortion. In 2003 or 2004 TVO received a loan for Olkiluoto-III at an interest of 2.6%, which is marginally above base rate (see Figure 12). The terms of the contract are secret, but the deal involves generous export subsidies and state support.

Figure 12 Euribor European interbank rates, 1999-2010 (colouring: different time scales)

The equity moiety of the investment costs is the portion of the investment covered by the company's own financial assets. To obtain the required financial assets the company can sell stakes on the stock market or find investors prepared to provide the funding. For any investment project, shareholders at least want the risk-free rate of interest plus a premium for risk. Equity finance is more expensive than financing with debt, as greater risks are involved.

B.7 Revenues from nuclear plant operation

Because for a given level of generating capacity nuclear power plants are at least twice as expensive as their fossil counterparts (see Table 2, Annex A), they are also characterised by high fixed costs. Operational expenses, on the other hand, are lower, owing mainly to lower fuel costs. As a result the marginal costs of production are significantly lower than for other, fossil-based technologies, which means nuclear plants can achieve a higher number of full-load hours per year.

The high capital cost outlay needs to be recovered and it is the difference between the marginal costs of production and the market price of the electricity sold is used for this purpose. To maximise returns, operators are therefore likely to want to attain an as high as possible number of full-load hours, reflected in a high capacity factor, generating as much electricity as possible.

In OECD countries the average capacity factor of a nuclear plant is 80%[19]. Cumulatively, since its start-up in 1973, the existing Borssele reactor is 85% productive (IAEA, 2011). The capacity factor attainable for a new plant depends on a number of issues, including possible start-up problems, component failures and inexperience with operational control of the new plant. It is to be expected that at first the capacity factor of a new plant will be below target and then gradually improve up to the 90% level, a level that Borssele has been able to reach from 1999 onwards (IAEA, 2011).

[19] OECD/NEA & IEA 2010: the average capacity factor of 359 reactors was 80% (2008).

It is important to note that capacity factors constitute a key assumption in price estimates of nuclear power. The capacity factors of 90% observed today took a decades-long learning process to achieve, and to assume that a new reactor achieves this number of load hours right from day one will almost certainly be an overestimate (Cooper, 2009).

Annex C Risk assessment

Fundamental flaws in risk assessment methods

As the recent nuclear incidents at the Fukushima Daiichi plant have demonstrated, risk assessment methods are not flawless. Instead, it has become apparent that the plausibility of the assessment is a direct function of the imagination of the engineers conducting it. The problem at Fukushima was that engineers had designed the reactor with large earthquakes and tsunamis conceived of as separate and rare events. At face value, this assumption was not that reprehensible; tsunamis may be caused by earthquakes at a large distance, and a strong earthquake close to the plant would not necessarily lead to a tsunami. However, in this specific case the strong quake took place just offshore, leading to both a general power shutdown in the area (rare event number one) *and* the largest tsunami in recorded history, which knocked out the back-up power system. Simultaneously occurring events like these can have non-linear effects on reactor design. In this case, neglecting to appreciate the correlation between earthquakes and tsunamis led to severe underestimation of incident probability and flawed the designs of back-up systems. This provides a salient illustration of the fundamental problem of risk assessment methods, namely that it is conceptually impossible to take into account all possible events (Ramadjan, 2011 REF). There are simply too many degrees of freedom to predict all possible events (however rare), making it theoretically impossible to prevent the impact of any and all eventualities.

In 2002 the Japanese Nuclear Energy Safety Organization concluded that a risk assessment of its plants had revealed a probability of core damage incidents of less than 1 in 100,000 per year per reactor. The frequency of accidents leading to containment damage was estimated at less than 1 in 1,000,000 per year per reactor (JNES, 2009). Recent events in Japan have shed new light on risk assessments, and re-evaluations of risk are now being performed all over the globe. Back in 1989 the average risk of nuclear incidents in 104 US reactors was deemed less than 1 in 400,000 per year per reactor. Based on new calculations by NRC in response to Fukushima, the average risk of incidents with the same reactors has now increased to 1 in 115,000 per year per reactor: an increase of risk of over 300% *on average* (MSNBC, 2011). In the new ranking, the top 40 US plants once designed for a 1 in 100,000 risk per year are now estimated to have a risk of less than 1 in 50,000.

Evaluation of risk criteria for new Dutch power plant

How is this relevant for the reactor planned near Borssele? Minister Verhagen is calling for a design in which the probability of a nuclear meltdown is less than one in a million. If the very calculation method on which this probability is based is flawed, however, it is impossible to guarantee the safety of the new plant. Although Verhagen appears to have the EPR reactor design in mind when he cites a criterion of a less than 1 in 1,000,000 year risk of meltdown, such a guarantee cannot be given on the basis of PRA calculations. Historically, plants designed for a meltdown risk of less than 1 in 100,000 have led to three meltdowns in 15,000 reactor years (five if the three Fukushima reactors are counted as separate events). In an interesting article in the Dutch newspaper NRC (2011), statisticians calculated the probability of three meltdowns in 40 years, with a fleet of approximately 500 reactors and a per-reactor risk of 1 in 100,000 per year. The resulting probability, according to a binomial distribution, is 1 in 1,000. In other words, the probability that the average fleet risk of a meltdown is indeed less than 1 in 100,000 is 0.1%.

Although greatly simplified, this implies that the actual risk of a nuclear meltdown for the existing fleet is higher than 1 in 100,000 (but unknown). A similar argument may also hold for newly designed reactor types, although true probabilities can only be calculated with sufficient data points (which we will hopefully never obtain, as this means a significant number of meltdowns need to occur). Note, by the way, that in its brochure for the EPR, Areva (2005) states that the risk of accidents due to events generated *inside* the plant is less than 1 in 1,000,000 per reactor per year (corresponding to the criterion posed by Verhagen). However, the risk of meltdown resulting from *all types of failure and hazard* is estimated at less than 1 in 100,000 per reactor per year. Presumably, this includes external risks such as earthquakes and plane crashes. Assuming Verhagen's risk acceptability reflects 'all types of failure and hazard', the EPR design would not meet his criteria[20].

C.1 "The Fukushima disaster was the result of the largest earthquake ever recorded; the risk of such a disaster in the Netherlands is minimal"

– René Leegte, liberal politician (VVD), radio interview, 2011.

Earthquake risk

The current nuclear power plant at Borssele was designed to withstand an earthquake of 5.2 on the Richter scale (Rijksoverheid, 2011a). Presumably, a new power plant will be subject to the same minimum safety standard, although no mention of earthquakes is in fact made in the government's list of preconditions. The largest recorded quake in the Netherlands occurred in Roermond in 1992 and measured 5.4 on the Richter scale. Ranking second is a 5.0 quake in Uden in 1932. Neither of these quakes damaged Borssele, nor is it to be expected that similar quakes in that region would do so in the future. Figure 13 shows a historic record of earthquakes in the Netherlands, indicating that Borssele is located in a stable region.

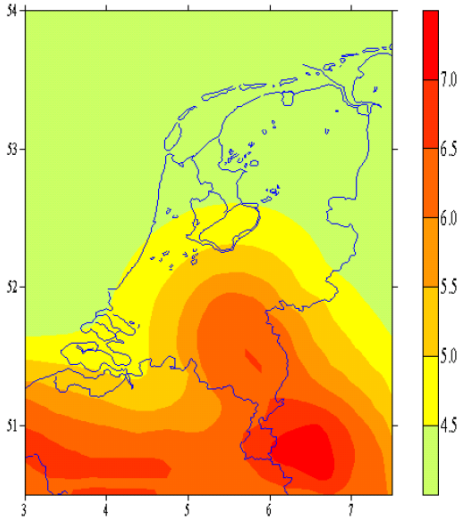
[20] The PRA document of the EPR itself reports a meltdown risk of 1 in 61,000,000 per year per reactor, but this is as result of internal events. External events are not named in this document.

Figure 13 Historic earthquakes in the Netherlands

Source: VU, 2011. Red circles indicate 'natural' earthquakes, yellow circles indicate 'induced' earthquakes (e.g. by gas extraction). The blue square indicates the location of the Borssele power plant.

Note, though, that Japanese designers only took into account earthquake records post-1890, because of the absence of reliable records before that date. According to the Faculty of Earth Sciences at the Free University of Amsterdam (VU, 2011), historic records indicate that a Roermond-strength quake occurs once every 2,000-5,000 years, but the record is too short to exclude heavier quakes. Similarly, a 1996 study by de Crook published a risk map of the Netherlands. In this map (see Figure 14) Borssele lies in an area with an associated risk of a magnitude 5.0 quake once every 500 years. The margin of error is not very large when one takes the 5.3 earthquake resistance of Borssele into account, or the low-risk probabilities (once per million years) demanded of nuclear power plants.

Figure 14 Earthquake probability in the Netherlands (Richter scale)



Source: de Crook et al. (1996).

Risk of flooding

The current nuclear plant at Borssele is said to be designed to withstand flooding of 7.8 metres above sea level (NAP). By way of comparison the water levels of the country's 1953 flood disaster are often cited, which rose up to 4.5 metres above NAP. After the Fukushima disaster, certain media reported elevated risk levels of flood waves for the Netherlands. Vrij Nederland (2011), for example, quotes Belgian nuclear expert Gilbert Eggermont, who claims that a volcanic eruption on Iceland may lead to a funnelled flood wave travelling down the North Sea. Similar claims sometimes cite geological evidence of a major flood following an undersea landslide off the coast of Norway some 8,000 years ago (NERC, 2000). After this event, sand was deposited as high as 20 metres above sea level in parts of Britain and Norway, but no evidence of such deposits has yet been found in the Netherlands. Similarly, a 1993 RWS study concluded that, owing to the shallowness of the North Sea, a tsunami would probably be diminished before it reaches the Dutch coast (Bijl, 1993). Hence, although tsunami events have occurred every few thousand years in the North Atlantic basin, the Dutch coast seems to be protected by the surrounding countries and the shallow sea.

Note that on a smaller scale risks at Borssele are higher. After the Fukushima incident Minister Verhagen reported that the dyke directly protecting Borssele has weakened and that it is at risk of breaking in a heavy storm with an incidence of once every 4,000 years (PZC, 2011; Tweede Kamer, 2011b). Although it is deemed unlikely that rupture of the dyke at Borssele would lead to a nuclear meltdown, it could damage the power plant and, as was the case in Fukushima, lead to unforeseen side-effects.

C.2 "The containment vessel can withstand high overpressure from within, as well as accidents with passenger planes"

– Minister Verhagen, 2011.

Let us assume, for example, that the containment vessel is designed in such a way that it can indeed withstand an accident with a fully-loaded passenger plane. A decade ago, the largest passenger aircraft was the Boeing 747, with a maximum take-off weight of around 400 metric tonnes. With introduction of the Airbus A380 in 2005, any nuclear reactor designed to withstand a Boeing 747 would have to be substantially revised, as the maximum take-off weight of the Airbus is almost 600 metric tonnes, around 1.5 times that of a Boeing 747. This example illustrates an actual historical problem faced by the Borssele I nuclear plant. This facility was originally designed to withstand a passenger aircraft as well, but since the only airport near Borssele is the small airfield of 'Midden Zeeland', it was deemed highly unlikely that any aircraft larger than a Cessna would ever crash near or on it. This, of course, drastically changed after the September 11, 2001 attacks on the World Trade Center in New York, which proved that large aircraft may be intentionally flown into buildings. While EPZ now states on its website that Borssele is likely to withstand a medium-sized aircraft collision (EPZ, 2011), it is unclear what the impact of a large aircraft would be. Note that the twin towers of the WTC were actually designed to withstand the impact of a commercial aircraft (Chicago Tribune, 2001; Seattle Post, 2001).

Annex D Life cycle responsibility

D.1 Provisions for final storage

The general consensus in the EU is that high-radioactive waste will be stored in the country of origin in deep geological repositories, designed to minimise the possibility of emissions of radioactive substances to the biosphere for tens of thousands of years. A subsurface repository is generally far less vulnerable to the influences of weather and water and human intrusion. The potential of deep geological repositories to remain sealed for a very long time is to some extent illustrated by natural gas and oil reservoirs and by the Oklo natural reactors in Gabon, the fission products of which have remained trapped for two billion years under a few metres of clay (Allegre, 1999). In these cases, however, no direct artificial pathway to the biosphere has been created. Deep geological repositories require minimal maintenance and – in contrast to surface storage facilities – are not situated directly in the biosphere, meaning that any substance leaking from the repository is not automatically dispersed into the biosphere but has to traverse a pathway to reach it. The perception that deep geological repositories are the best means for permanent removal of undesired substances from the biosphere is also the motivation for storage of hazardous chemical waste in abandoned coal mines and salt domes in Germany (e.g. backfilling of fly ash in coal mines, see Bertin, 2000) and the global initiatives for deep geological CO_2 storage. However, storage of chemical waste and low and medium radioactive waste in salt caverns in Germany has proven to be a failure, with both the Asse and Morsleben domes in threat of collapsing and the Asse repository being flooded and leaking radioactive caesium-137 (Damveld, 2008).

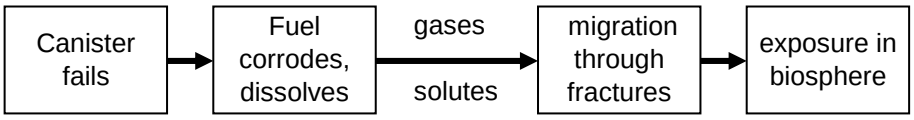
In the Netherlands the only likely option for high-radioactive waste storage is in a clay repository, since the country's deep geological structure contains no granite or other rock formations with high mechanical stability and moderate heat conductivity (see e.g. Veer, 2011). Storage in clay has been investigated in Belgium since the early 1980s. Other countries with significant research experience on storage in deep clay layers are France and Switzerland.
Although the Belgians have 25 years of research experiences, NIRAS (Belgian Agency for Radioactive Waste and Enriched Fissile Materials) cannot yet positively state that permanent storage in clay is indeed safe.
The uncertainties concern, among other things, two key aspects of importance for the risk of radioactive material being emitted to the biosphere:

- The fate of radioactive halogens.
- Potential changes in the clay as a result of heat and high-radioactive radiation released by the stored waste.

For deep geological spent-fuel repositories the main risk of radioactive substances dispersing into the biosphere is expected to derive from the dissolution of radioactive halogens (mainly Cl-36 and I-129) in groundwater. The 'deep' geological repositories in clay, salt or rock being considered for storing high-radioactive waste at 400–1,000 metres' depth are in fact relatively shallow (compared with CO_2 storage facilities, for example) and are at depths at which groundwater can re-circulate to the biosphere. As a consequence, there is a risk of radioactive halogens being transported to the biosphere by or through (dispersion) circulating groundwater.
This risk could be increased if the clay were to become more porous and ruptured as a result of heat and high-radioactive radiation released by the stored waste, thus facilitating the circulation of water.

For the Netherlands there is an additional uncertainty. The Belgians have extensive knowledge of the clay layer considered for permanent storage (Boom clay). In contrast, the available data on the properties of deep clay layers in the Netherlands is very limited.

Figure 15 Pathway posing highest risk for dispersion of radioactive substances from deep geological repositories



Source: Derived from Large, 2007.

D.2 Fuel-chain responsibility

One of the arguments put forward by Minister Verhagen with respect the fuel-chain responsibility is that if mining companies are certified under ISO 14001 they will produce uranium ore or concentrate in a responsible way. As the case of Rio Tinto's Rössing mine in Namibia proves, however, a mining company operating an uranium mine can be ISO 14001 certified and still be associated with major social and environmental issues (London Mining Network, 2010; WISE, 2011), including:

- Charges by former employees for gross neglect and for compensation payments for the cancers they contracted while working at the mine.
- Consumption (up to 2010) of millions of cubic metres of fresh water annually in a region where rainfall totals only about 3 centimetres per year.
- Suspicions of groundwater pollution.
- Use of money from the decommissioning fund to keep the mine operating.

The Dutch government is aiming at a mining company employing *in-situ leaching*[21] as the mining method. The government's aim for in-situ recovered uranium is intended to work as a precautionary measure, minimising problems with tailing storage and acid mine drainage from abandoned mining sites associated with underground and open-pit mining. This in itself already illustrates the problems and risks associated with conventional mining of uranium and the resultant tailing reservoirs.

The storage reservoirs currently used for tailings are not designed for permanent storage and are unable to withstand the long-term effects of wind and rain, associated erosion, floods, landslides, large-scale climate change and ice ages, earthquakes and human intrusion. This is illustrated by the permit requirements for surface storage for environmentally hazardous materials such as uranium ore tailings, which require designs for reservoirs for this radioactive and poisonous material to remain sealed for a (minimum) period of 1,000 years (see e.g. EC, 2004).

[21] (uranium-)mining methods can roughly be divided into three categories. Open-pit mining involves the large-scale mechanical removal of the top layers of the earth, digging until the mineral deposit is reached. In underground mining, earth is mechanically removed to form underground shafts reaching to the mineral deposits. In-situ leaching involves pumping a leaching agent into mineral deposit, dissolving the mineral of interest, and pumping the liquid back up in order to recover the mineral content. See http://www.wise-uranium.org/uwai.html or http://www.world-nuclear.org/info/inf23.html for more information.

However, in-situ recovery mining operations, too, probably pose a significant risk for the environment. In-situ leaching operations with sulphuric acid in Germany, Czech Republic and other Eastern European states today still pose a very significant threat to groundwater quality and potable water availability (WISE, 2010), despite years of work on remediating these sites, sponsored in part by the EU. The in-situ recovery mining in these countries is comparable to in-situ operations in Kazakhstan and Australia. Overall, it seems more likely that in-situ leaching has the potential to leave behind an environmental time bomb or, at the very least, a highly polluted and permanently changed subsurface environment.

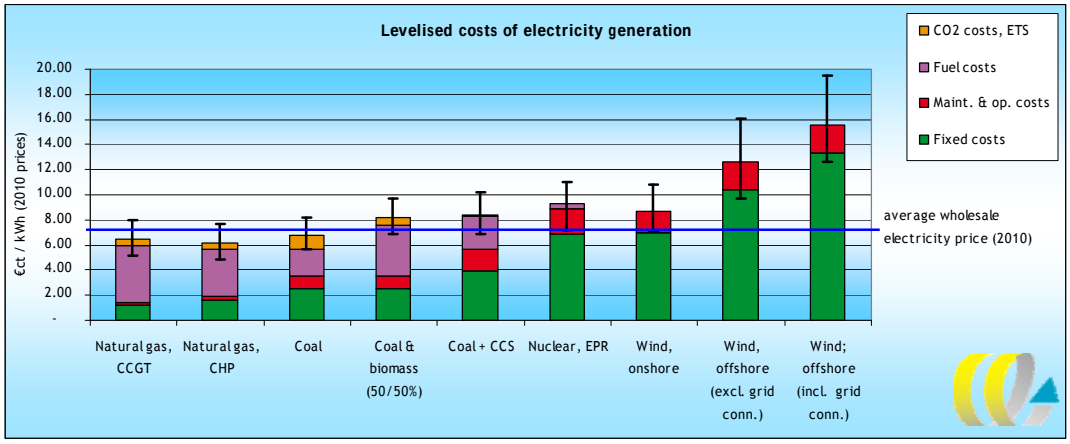
A third risk may derive from the integrity of mining operators in such countries as Kazakhstan. In recent years various mining companies have been brought to court for illegal dumping of toxic and radioactive waste and for corruption, theft and illegal sales of uranium, indicating that although there are an environmental department, justice department and judicial system doing their best to uphold law and environmental quality, these organisations can be evaded, sometimes for a very long time. In 2010, for example, a Kazakh court sentenced a former uranium business leader to 14 years imprisonment on corruption charges (Reuters, 2010). Given such examples, the question is how the Dutch government can guarantee the sustainable production of uranium in countries in other parts of the world.

Annex E Power generation cost comparison

E.1 Comparison of direct costs with other technologies

It is widely assumed that nuclear energy is a cheap option for base load electrical power and that building nuclear power plants is essential for reducing electricity prices and improving the competitiveness of Dutch industry. To examine the truth of this claim, CE Delft has developed a calculation tool to compare the direct costs of different generating options. Figure 16 shows the results of this modelling exercise. Displayed are the direct costs of electricity from different new generating facilities, broken down into four main cost components. In the model, costs are discounted to account for the time value of money, reflecting an actual accounting cost price that investors can work with[22].

Figure 16 Direct costs of electricity generation, investor's perspective in 2011



Generating technologies are shown in order of increasing fixed costs. The calculation is performed for a new base load power plant with a capacity of 1,000 MW_e, constructed using the best available techniques and assuming recent fuel prices. For all technologies a discount rate of 12.5% has been taken (which is varied -/+ 2.5% to indicate a range of possible outcomes (black bars)). The parameters used in the calculations are described below in Section E.2. For fossil-fuelled plants the cost of power generation is governed largely by fuel costs, for renewables and nuclear largely by capital outlay for investment. Nuclear power stations can produce electricity at low marginal costs at the expense of high fixed costs.

22 Prices are calculated using an investment model that compares the costs of different generating technologies, using the calculation method 'levelised cost of electricity production'. The model incorporates a number of financial aspects to reflect the decision-making situation of an investor under free-market conditions: different debt service ratios for different risk profiles, different interest rates for high/low risk, taxes and tax deductions.

The blue horizontal line in the figure indicates the average wholesale price of electricity in 2010[23], 7.4 €cent/kWh. Comparison of the direct costs of the various generating options with this line provides an indication of the relative appeal of the technologies given current fuel and CO_2 prices. What transpires is that at historic and current electricity prices, a new nuclear power station will not be able to generate a profit (at the 90% load factor assumed in the model), since its combined fixed and variable costs exceed the market price for electricity. Only gas-fired technologies and conventional coal have lower direct costs than the market price and hence generate net income for the investor. The coal & biomass and coal+CCS options have higher direct costs, exceeding the electricity price; these options will require subsidy to be competitive in a base load configuration. The high fixed costs of nuclear arise from the assumed market financing structure, the high capital expenditure, aggravated by a long build time (see Annex A). Under these conditions, new nuclear is almost guaranteed to be uncompetitive compared with fossil given fuel and CO_2 prices. Onshore wind is more competitive than nuclear, being nearly cost-competitive without subsidies. Offshore wind is the least competitive option, owing to the very large capital outlay. A sizeable share of the fixed costs derive from the capital investment required for the offshore grid connection. To reflect a situation where the Transmission System Operator (TSO) provides for the offshore electricity infrastructure, the costs of offshore wind without the grid connection are also shown[24].

Conclusions from the levelised cost of electricity model

- Nuclear energy has low marginal costs but high fixed costs.
- Electricity costs from a new nuclear plant are higher than from a coal or natural gas plant or from an onshore wind farm.
- In a liberalised market and under free-market financing conditions, new nuclear does not appear to be cost-competitive.
- Once the investment expenditure has been paid off in one way or another and the fixed costs are consequently lower (or perhaps part-covered by a party other than the utility), a nuclear power station is of considerable value to a utility as the electricity generated has very low marginal costs and can consequently have a high profit margin per kWh.

E.2 Model parameters

E.2.1 Financial

For the comparative calculation of direct generating costs the following financial parameters were used:

- Nominal discount factor: 12.5%.
- Required percentage return on equity: identical to the discount factor.
- Nominal interest, normal risk: 5%; high-risk: 7%.
- Debt-equity ratio, normal risk: 70-30; high-risk: 60-40.
- Corporate tax level: 25%.
- Linear depreciation.
- Annuitized debt repayment.

23 ECN reference estimate 2010, average of large-volume and small-volume customers.

24 From a societal perspective this will be more efficient as the TSO, being a public company, is able to secure better financing deals and use longer depreciation schedules compared with market parties.

E.2.2 Technology-specific

The technology-specific parameters used in the comparison are shown in Table 4. For the build of a third-generation nuclear power plant an EPR type was taken, with an assumed burn-up rate of 60 GW_{th}day per tonne uranium. For this plant the investment amounts to 3,400 €/kW_e (overnight costs). With 30% for interest during construction, based on a 6-year construction period(OECD/NEA and IEA 2010), this becomes 4,420 €/kW_e when all finance charges are included. The coal plants are assumed to use pulverisation technology, while the coal & biomass option assumes 50% (by energy content) co-firing of wood pellets. Data for the offshore wind projects are from a number of projects currently under development. Fuel prices have been taken from APX-ENDEX, Eneco and the World Nuclear Association and are valid for 2010/2011. For the CO_2 price we assumed a value of € 15 per tonne CO_2 emitted, which is not far from the EU ETS average value for 2010-2011.

Table 4 **Technology parameters for levelised direct costs of electricity generation**

	Duration of constr., years	Interest during constr. (IDC)	Investmt cost ex. IDC €/kW_e	Op. & maint. costs	Fuel costs (€/GJ)	Full load hours	High inv. risk
Gas, CCGT	2.5	14%	700	14 €/kW_e	7.3	7,000	No
Gas, CHP	2.5	14%	1,080	14 €/kW_e	7.3	7,000	No
Coal	4	20%	1,400	56 €/kW_e 0.23 €cent/kWh	2.8	7,000	No
Coal & biomass	4	20%	1,400	56 €/kW_e 0.23 €cent/kWh	Coal 2.8 Biom. 7.8	7,000	No
Coal + CCS	4.5	21%	2,100	87 €/kW_e 0.23 €cent/kWh	2.8	7,000	No
Nuclear, EPR	6	30%	3,400	63 €/kW_e 1.26 €cent/kWh	1,938 €/kg fuel	7,900	Yes
Wind, onshore	1	10%	1,350	39 €/kW_e	-	2,229	No
Wind, offshore (ex. grid conn.)	2	13%	2,450	80 €/kW_e	-	3,650	Yes
Wind, offshore (inc. grid conn.)	2	13%	3,140	80 €/kW_e	-	3,650	Yes

E.2.3 Operational and maintenance costs of nuclear power

For the purpose of the above comparison, the following values were used for operational and maintenance (O&M) costs.

- For the variable O&M costs we took a figure of 1.26 €cent/kWh, the average of four studies cited in ECN, 2007: MIT, 2003; RAE, 2004; DTI, 2006 and IEA, 2006. This amount is made up of the variable costs of O&M (1.05 €cent/kWh), decommissioning costs of 0.1 €cent/kWh and costs for treatment of radioactive waste of 0.11 €cent/kWh. The amount does not include the costs of the fuel cycle.
- For the fixed O&M costs we took € 62.67 per kW/year. This is the average of three studies cited in ECN, 2007: MIT, 2003, DTI, 2006 and IEA, 2006.
- Fuel costs were calculated as 0.37 €cent/kWh, assuming a burn-up of 60 GW_{th}day per tonne of enriched uranium fuel.

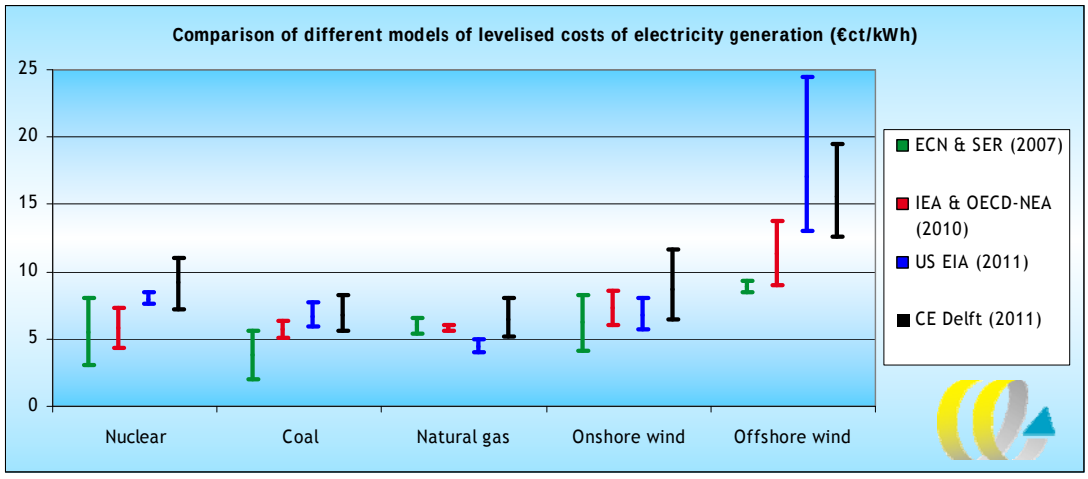
– Costs for other aspects such as grid connection and construction of the decommissioning fund are not included separately. OECD/NEA & IEA (2010) estimate the decommissioning costs for nuclear plants as 15% of the construction cost, modelled as a cash outlay at t = 60 years (end of service life). Because in that study the decommissioning takes place 60 years after the first delivery of electricity, it does not add significantly to the levelised costs of nuclear power.

E.3 Comparison with other studies

For the purpose of comparison, in Figure 17 the average cost of electricity over plant lifetime as calculated by the above model is compared with the results of other studies. The vertical bars indicate the range between the lower and upper estimates cited in the respective studies. The colour coding is as follows:

– On the left, in green, are the values published in 'Fact-finding on Nuclear Energy' (ECN, 2007). Note, however, that the values cited there should now be viewed as obsolete because they are based on studies from 2003-2007 (e.g. MIT 2003) and it has been shown that these studies significantly underestimated the cost of new power plant construction (in the MIT, 2009 update, the cost of nuclear was doubled). The ECN report 'Nuclear power and fuel mix' contains updated LCOE data based on, amongst others, OECD/NEA & IEA, 2010.
– Next, in red, are the values for the Netherlands from 'Projected Costs of Generating Electricity' (OECD/NEA & IEA, 2010). While these are in fact the most recent currently available LCOE data for this country, only the upper limit of this study (with a 10% discount rate) should be taken as a valid cost estimate for a liberalised energy market - the lower limit, with a 5% discount rate, does not cover a realistic cost of capital.
– Third, in blue, are the values from 'Levelised Cost of New Generation Resources in the Annual Energy Outlook 2011', published by the US Energy Information Administration, DOE (US EIA, 2011). This study, which provides three values: upper, lower and middle, is valid for the North American situation. The middle value is not displayed here.
– Finally, in black, the bandwidth of the values used in the present study ('CE Delft').

Figure 17 Comparison of different models of levelised costs of electricity generation



From Figure 17 we conclude that the CE Delft model is consistent with other approaches, although it gives somewhat higher costs[25] for all the generating technologies considered because of more conservative estimates of finance aspects (discount factor, interest and debt-equity ratio).

In ECN (2010) it is mentioned that the discount factor is especially relevant when it comes to the relative difference between capital-intensive and fuel-price-sensitive generating technologies. In OECD/NEA & IEA (2010) two values are used for the discount rate: 5 and 10%. The 5% value is too low to cover the average weighted cost of capital in a liberalised energy market, where 10% is a more appropriate value to cover the average cost of debt and equity.

External cost of power generation

In assessing the relative strengths and weaknesses of generating technologies, for decision-making or other purposes, wherever possible the external costs of power generation should also be taken into account. The external costs of generation include costs that are not experienced by the operator but are borne by society as a whole.

In this study external costs have been quantified for the following items.

- Environmental damage: climate-changing emissions (contributing to global warming); air-polluting emissions (contributing to acidification, eutrophication and respiratory/human health problems); radioactivity (leakage, emissions).
- Uninsured deaths and long-term damages resulting from accidents (using a risk-averse valuation of the cost of deaths).
- Land-use changes for biomass (assuming 90% biomass from sustainably managed Canadian production forests, with 10% biomass originating from primary tropical forests).
- Also we include the 'hidden' subsidies, where quantifiable (security of nuclear facilities and transports).

The following external costs were not quantified: security of supply impacts (the severity of which depends on diversification and other measures; however, the general impression is that nuclear has a positive externality here relative to fossil alternatives); lost load and supply disruptions (this is possibly a high cost, but there are too many uncertainties to be able to attribute these costs to specific technologies); flexibility requirements (applicable to intermittent sources of generation such as solar and wind). (These latter costs have been quantified in a study for VME (CE, 2010a). If other generating capacity is shifted from base-load operation to part-load (7,000 → 3,500 full-load hours) this would amount to an externality of 12 €cent/kWh. However, it is uncertain if this situation will ever occur, certainly not in the near future.). Also not calculated are environmental impacts associated with shale gas production, which would be needed for a fair assessment if this were to become a significant element of the consumption mix.

[25] Note that the Italian Nuclear Association, an insider in the nuclear business, has published a memo calculating the levelised cost of nuclear electricity at between $cent 10-15 per kWh, 50% higher than the figure estimated in this study and about as high as offshore wind (AIN, 2010).

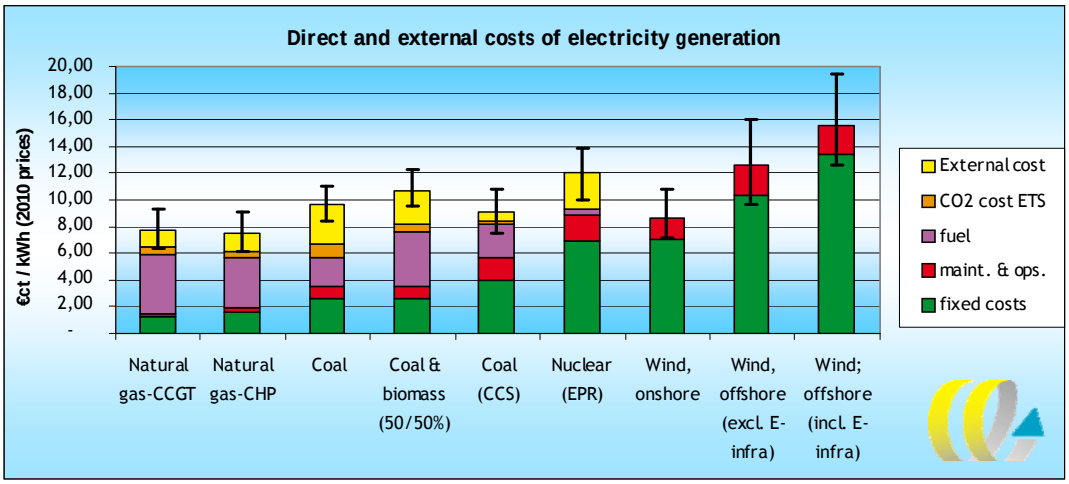
Shadow prices methodology

Two main approaches are used for valuing external costs: the prevention costs and the damage costs approach (CE Delft: Shadow Prices Handbook (CE, 2010b)). The general rule is: if a project results in changes in environmental quality, these should be valued according to shadow prices based on damage costs: the external costs of pollution are equal to the costs of the resultant environmental damage. Where environmental policies are already in place, however, a certain fraction of the external costs can be internalised, which means the external costs are no longer equal to the damage costs. In this case shadow costs based on prevention costs must be used. Also, if a project may lead to changes in environmental policy-induced abatement efforts, these should also be valued according to shadow prices based on prevention costs. It may be noted that in a hypothetical equilibrium situation, policy goals should reflect socially optimal levels of pollution, which means both methods of shadow price estimation (based on damage costs and on prevention costs) should yield the same outcome.

In this study we have adopted the damage cost approach, except in the case ofCO_2 emissions, for which the prevention cost approach was used. This is because the electricity sector falls under the ETS and there is an active environmental policy to reduce climate impacts. For the prevention costs of CO_2 emissions we assume 50 €/t, an upper value corresponding to a reduction target of -30% in 2020. This also roughly equals the damage costs of CO_2 emissions in 2030, as well as the middle value of the scenarios in the cited study for VME (CE, 2010a). Part of the cost of CO_2 emissions is already internalised and accrues to the operator; here we have assumed an ETS certificate price of 15€/tonne (roughly equal to the prices seen in 2010–2011 (Q1)). Quantified are both the cost of 'combustion' emissions at the generating plant and the 'pre-combustion' emissions in the upstream fuel chain. The latter emissions generally occur in other countries. As the shadow prices in the Shadow Prices Handbook (CE, 2010b) include emission values for the Netherlands, these prices were adjusted for different countries of fuel origin (e.g. Algeria, Australia, Canada) in the study for VME (CE, 2010a), using values from the EU NEEDS and CASES projects. For further elucidation of the methodology, the reader is referred to the latter study.

Figure 18 reviews the external costs calculated in the present study. In this case only central estimates are given, because the uncertainty surrounding these numbers is high. For example, for classical pollutants the confidence interval can be calculated as being between $^1/_3$ and three times the central value (Spadaro & Rabl, 1999, in CE, 2010b).

Figure 18 **Costs of electricity generation including external costs of environmental damages, uninsured damage costs of accidents, and land use changes**



From this comparison we can conclude that all fossil technologies as well as nuclear come with a sizeable external cost component. Natural gas is inherently cleaner and has lower external costs (note that this holds for conventional natural gas – this would perhaps not be the case for unconventional shale gas). The high environmental damage costs of coal are due mainly to the high CO_2 emissions. To a large extent this can be mitigated by storing the CO_2 underground – of all the fossil generating technologies the coal+CCS option has the lowest costs to society. The external costs of nuclear are also high owing to the risk-averse valuation of accidents and damage costs. From society's perspective, nuclear and coal are not preferable. The 50/50% coal/biomass co-firing option also comes with high environmental costs that are only marginally better than standard coal. This is due to the land use changes associated with the use of biomass for power generation. In terms of social costs, it is above all the wind energy and coal+CCS options that have the lowest external costs.

Annex F CO_2 effects of a new nuclear power plant

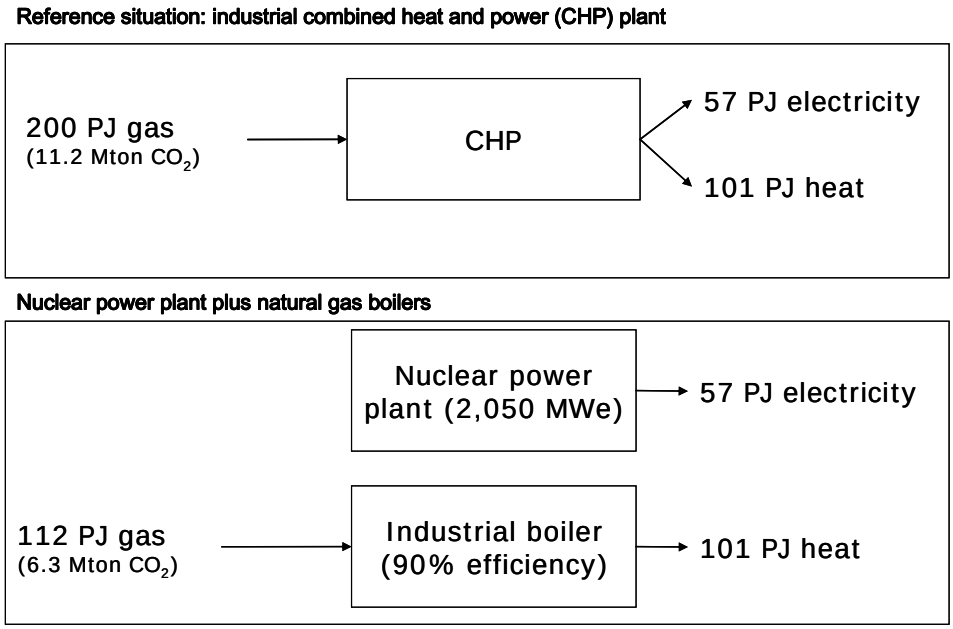
"Nuclear power is necessary to reduce CO_2 emissions"

– VNO-NCW, 2011.

Although nuclear power is often heralded as carbon-free and a beneficial replacement for coal-fired power plants, realisation of a new nuclear base load power plant may change the CO_2 profile of power generation capacity in the Netherlands in a more sophisticated manner. In particular, a new nuclear power plant may directly compete with highly efficient combined heat and power (CHP) plants, which would significantly reduce the emission reduction often ascribed to nuclear power.

Power demand – which fluctuates every day as well as in the course of a year - is met partly by base load power plants and partly by peak power plants. Base load plants (typically coal-fired or nuclear) deliver a constant supply of electricity. Since they have high fixed costs but low fuel costs, it is most economical to operate them at constant levels. Peak demand, on the other hand, is met by flexible (typically gas-fired) plants that have high fuel costs but low fixed costs. Assuming base load demand is met by the cheapest set of base load plants, any new plant that has lower production costs than existing ones has the potential to push the most expensive plant off the base load market. In the Dutch power market the most expensive base load plant is likely to be a CHP plant, with which a new nuclear power plant may compete directly. In that case the heat normally delivered by the CHP plant must be replaced by other means, partially offsetting the lower carbon emissions for electricity production associated with nuclear power generation.

Figure 19 **CO_2 effect of a nuclear power plant replacing a CHP plant**



Reference situation with a CHP plant, and the new situation where the electricity is delivered by a nuclear power plant and the heat by a high-efficiency industrial boiler. Assumptions: CHP with an electric efficiency of 27% and a thermal efficiency of 50%. Nuclear power plant (2,050 MW_e) running 7,684 hours per year. Industrial boiler efficiency: 90%. CO_2 emissions natural gas: 56.1 kg CO_2/GJ. CO_2 emissions coal: 97 kg CO_2/GJ.

Suppose, for example, a hypothetical CHP plant requiring 200 PJ natural gas (11.2 Mton CO_2) to generate 57 PJ electricity and 101 PJ heat (the remainder is counted as a loss). If the electricity were generated by a 2,000 MW nuclear power plant, the heat otherwise delivered by the CHP plant would now require a high-efficiency industrial boiler, burning 122 PJ of natural gas (6.3 Mton CO_2). Hence, the net effect of the nuclear power plant in terms of CO_2 emissions is a reduction of 4.9 Mton, considerably less than if a coal-fired power plant were replaced by the nuclear power plant (approximately 12.8 Mton savings). Hence, the net CO_2 reduction of the nuclear power plant is approximately 56% of the emissions of the CHP plant. The exact percentage emissions reduction depends on the efficiency of the CHP plant and the gas boiler, but it is important to note that not all the CO_2 emitted by the CHP is prevented by installing the nuclear plant.