Summary of 'Nuclear Energy and Fuel Mix: Effects of new nuclear power plants after 2020 as defined in the Dutch Energy Report 2008'

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This summary is the translation of the original summary of the report 'Kernenergie & Brandstofmix. Effecten van nieuwe kerncentrales na 2020 in de kernenergiescenario's uit het Energierapport 2008', ECN report ECN-E-10-033, March 2010. Authors: Ad Seebregts, Herman Snoep, Jeroen van Deurzen, Paul Lako (all ECN) and Arjen Poley (NRG).

The full Dutch report can be found at: http://www.ecn.nl/publicaties/default.aspx?nr=ECN-E--10-033. The project number of this report is 5.0289. ECN Contact person is Ad Seebregts, seebregts@ecn.nl.The contact person at the Ministry of Economic Affairs was Aart Dekkers.

Abstract

This report, prepared for Ministries of Economic Affairs (EZ) and of the Environment (VROM), presents facts and figures on new nuclear energy in the Netherlands, in the period after 2020. The information is meant to support a stakeholder discussion process on the role of new nuclear power in the transition to a sustainable energy supply for the Netherlands. The report covers a number of issues relevant to the subject. Facts and figures on the following issues are presented:

- Nuclear power and the power market (including impact of nuclear power on electricity market prices).
- Economic aspects (including costs of nuclear power and external costs and benefits, impact on end user electricity prices).
- The role of nuclear power with respect to security of supply.
- Sustainability aspects, including environmental aspects.
- The impact of nuclear power in three 'nuclear energy scenarios' for the Netherlands, within the context of a Northwest European energy market:
  - 1a No new nuclear power in the Netherlands ('Base case').
  - 1b After closure of the existing Borssele nuclear power plant by the end of 2033, the construction of new nuclear power plant that will operate in 2040. That plant is assumed to be designed not to have a serious core melt down accident (e.g. PBMR)[1] (200 to 500 MW_e).
  - 2 New nuclear power shortly after closure the Borssele nuclear power plant in 2033 (1000 to 1600 MW_e, Generation 3).
  - 3 New nuclear power plants shortly after 2020 (2000 to 5000 MW_e, Generation 3).

Two electricity demand scenario background scenario variants have been constructed based on an average GDP growth of about 2% per year up to 2040. The first variant is based on a steadily growing electricity demand and on currently established NL and EU policies and instruments. It is expected to be largely consistent with a new and forthcoming reference projection 'Energy and Emissions 2010-2020' for the Netherlands (published by ECN and PBL in 2010). A lower demand variant is based on additional energy savings and on higher shares of renewable electricity generation in particular wind energy. The study reported here has its focus mainly on the time period after 2020. Current trends in new build electricity production capacity determine the evolution up to 2020. The Netherlands appears to be a quite attractive location within Northwestern Europe.

[1] The term 'inherently safe' as used in the Energy Report 2008 (EZ, 2008) for this scenario 1b, is not used or further delineated in this ECN report. A separate NRG report 'Nuclear Energy and Conditions' (In Dutch: 'Kernenergie & Randvoorwaarden') covers the topic Safety and the definition of 'Inherently safe' (NRG, 2010).

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Summary

Framework
In the Energy report of 2008[2] it is stated that the Dutch cabinet 'Balkenende-IV (February 2007-March 2010) does not exclude any energy options in advance. In the liberalised European electricity market, the market parties are the ones taking the investment decisions, but the Dutch cabinet can establish preconditions. The Dutch cabinet agreed with the SER (the Social and Economic Council of the Netherlands) that it is desirable to discuss possible deployment of nuclear energy with stakeholders and experts, supported by a continuous process of fact finding.[3] To provide a basis, three scenarios for possible deployment of nuclear energy were sketched in the Energy Report 2008:

- Scenario 1, variant a (1a): no new nuclear power plants.
- Scenario 1: variant b (1b): no new nuclear power plants, unless inherently safe.
- Scenario 2: only replace nuclear power plant Borssele after 2033.
- Scenario 3: new nuclear power plants after 2020.

An official project group worked out the scenarios along three pillars: (1) nuclear energy and fuel mix; (2) nuclear energy & preconditions; and (3) nuclear energy & society.

Working method
This report was written in support of the first pillar; nuclear energy & fuel mix. In this report the effects of the nuclear energy scenarios on the themes of affordable, reliable and clean are addressed. To this end, ECN developed two background scenarios, i.e. SA and SB, sketching the development of the Dutch electricity system within the Northwest European electricity market. The starting points of the two background scenarios were established in consultation with the Supervisory Committee of the Dutch Ministries of Economic Affairs and Housing, Spatial Planning and the Environment (see Table S.1).

Table S.1 *Starting points and background scenarios, end situation in the year 2040 (incomplete)*

Background scenario	Electricity demand Netherlands [TWh]	Volume wind capacity [GW]	CO_2 price [€/ton CO_2]
SA, 'trend-wise'no large scale CCS	149	13	50
- modest growth of renewable			
SB, 'normative'	128	21	100
- Meeting NL RES electricity targets in 2020 (35%)			
- High renewables			
- Large scale CCS			
- Biomass co-firing in coal power plants (20% on energy input basis)			
- More energy saving			
Both scenarios			
- GDP growth 2010-2040	2% increase/year		
- Fuel prices	About 7 €/GJ for natural gas About 2.5 €/GJ for hard coal		

2 See (EZ, 2008).
3 See (SER, 2008).

Neither of these two background scenarios assumes additional nuclear energy. The background scenario SB establishes an electricity system in the period 2010-2040 in which the share of renewable energy increases significantly: 35% in 2020 and 60% in 2040. The background scenario SA is more trend-wise: the electricity demand is larger and the share of renewable energy is smaller than in SB. E.g. wind energy grows at an average annual growth of 6% in 2010-2040 in SA, while in SB it grows much faster (almost 8%/year).

A nuclear power plant is usually deployed as a baseload unit because it has very low variable costs. In the case of a new nuclear energy plant a high number of full load hours will also be important from the point of view of business economics due to the relatively high investment cost. A new nuclear power plant is therefore expected to compete mostly with other units that have low variable costs, such as (new) coal-fired plants, for example. In this study it is assumed that in the scenarios without additional nuclear energy, producers investing in a new nuclear power plant will refrain from investing in a new coal-fired plant. In several sensitivity analyses situations were examined in which a new nuclear power plant is built instead of a gas-fired power plant as well as situations in which a new nuclear power plant is built as additional capacity, hence not replacing another new power plant. In both situations there are larger shifts in the order in which the plants are deployed (the so-called *merit order*) than in the case of a new nuclear power plant replacing a new coal-fired plant.

Scope

The effects of deploying new nuclear power plants in the Netherlands were projected for the themes affordable, reliable and clean. For each theme various aspects were considered, which are listed in Table S.2.

Table S.2 Policy themes and aspects studied with regard to the role of new nuclear power plants in the Netherlands

Theme	Aspects
Affordability	Electricity market prices • Wholesale market • End users Production costs • New nuclear power plant • Comparison with other types of generation External costs • Damage to health • Costs of the effects of climate change External benefits • economic effects • nuclear research infrastructure • employment Indirect costs
Reliability	Integration of larger units Controllability and flexibility Fuel diversification in (Northwest) European perspective Uranium reserves
Environmental effects	Radiological environmental effects External safety Greenhouse gases, particularly CO_2 Air quality • NO_x • SO_2, and • Particulate matter

S.1 Affordability

Electricity market prices

Expansion of nuclear energy capacity instead of new coal-fired power plants, as in nuclear energy scenarios 1b and 2, hardly has any effect on the electricity price of the wholesale market. As for nuclear energy scenario 3, the difference amounts to maximally 0.3 €/MWh in case of 2000 MW or more installed nuclear energy capacity instead of coal-fired capacity. If new nuclear power plants are built as additional capacity this may lead to large market price effects. If 2000 MW additional nuclear energy would be installed in 2034 (nuclear energy scenario 3) this would lower the electricity market price with 0.8 €/MWh. To compare these effects: the market price in the period 2020-2040 ranges from 60 to 80 €/MWh, depending on the CO_2 price. The end user electricity price will largely follow the developments of the electricity market price, even when electricity is bought via long-term contracts.

Table S.3 *Effects on electricity market price*

Situation (assumption)	Effect	Reference
Instead of new coal-fired power plants	Maximum 0.3 €/MWh lower (- 0.5%)	Electricity wholesale market price is 60 to 80 €/MWh in the period 2020-2040
Instead of new gas-fired power plants or as additional capacity	Maximum 0.8 €/MWh lower (- 1%)	

Cost price of new nuclear power plants in 2020

The production costs of new nuclear power plants in the Netherlands can be projected to range from 43 to 71 €/MWh based on a recent OECD study[4]. These are the costs required for exploiting a new nuclear power plant that can enter into operation in ten years time. The range cost estimates in literature is wider. Due to different starting points with regard to fuel prices, discount rates, depreciation periods and capacity aspects, many studies cannot easily be compared to each other. Table S.4 provides an overview. The OECD projection is considered to be leading in this report.

Table S.4 *Projection of production costs new nuclear power plants in the Netherlands and Europe*

Study	Range
OECD, Netherlands	43 to 71 $€_{2008}$/MWh
OECD, other EU countries	34 to 83 $€_{2008}$/MWh
New French EPR, 2008 [5]	54 $€_{2008}$/MWh
ECN/AEA, 2008	38 and 82 $€_{2007}$/MWh
Fact Finding Nuclear Energy, 2007 (literature studies from 2003-2006) [6]	31 to 80 $€_{2006}$/MWh

Nuclear energy compared to other types of generation

Whether or not new nuclear power plants are able to generate electricity at higher or lower prices than other types of power plants strongly depends on the financial aspects and discount rates that are applied. Especially in the ranking of capital intensive options (such as nuclear energy or wind energy) and fuel intensive options (such as coal or gas), the discount rate that is used plays a very determining role (see Table S.5). Figures S.1 and S.2 provide the original estimates in USD/MWh.

[4] OECD (2010): *Projected Cost of Electricity Generation - 2010 Edition*, OECD, International Energy Agency (IEA)/Nuclear Energy Agency (NEA), Paris, 25 March 2010.

[5] (EDF, 2008).

[6] (Scheepers et al, 2007).

Table S.5 *Production cost of future Electricity generation in the Netherlands, new plants and installations that can enter into operation around 2015, in MWh (based on: OECD, 2010)*

	[€2008 per MWh]	
	Low 5%	High 10%
Nuclear energy	43	71
Pulverised coal (with 20% biomass co-combustion)	56	68
Natural gas, CCGT	53	56
Onshore wind	58	83
Offshore wind	88	134
CHP, CCGT (small)	70	81
CHP, CCGT (large)	64	72
Biogasifier (small-scale)	109	134
Biomass, solid (small-scale)	88	106
Solar-PV (larger system, 'industrial')	320	479
Solar-PV (smaller system. 'residential')	426	636

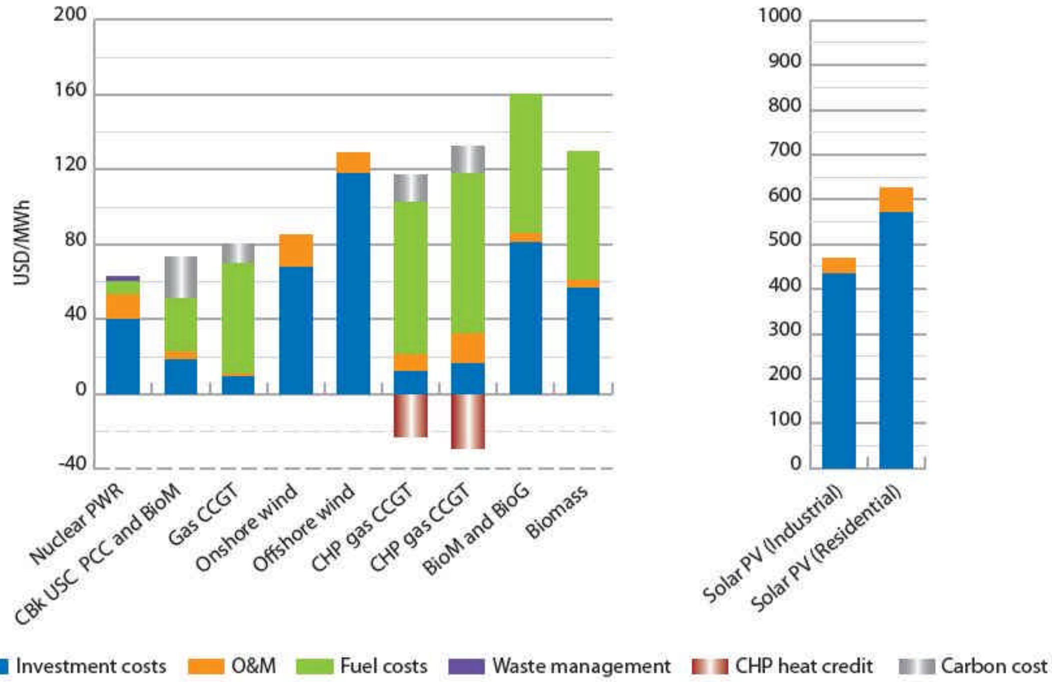

Figure S.1 *Production cost of future electricity generation in the Netherlands, new plants and installations entering into operation around 2015, 5% discount rate (Source: OECD, 2010). In USD2008/MWh (1 USD = 0.68 Euro)*

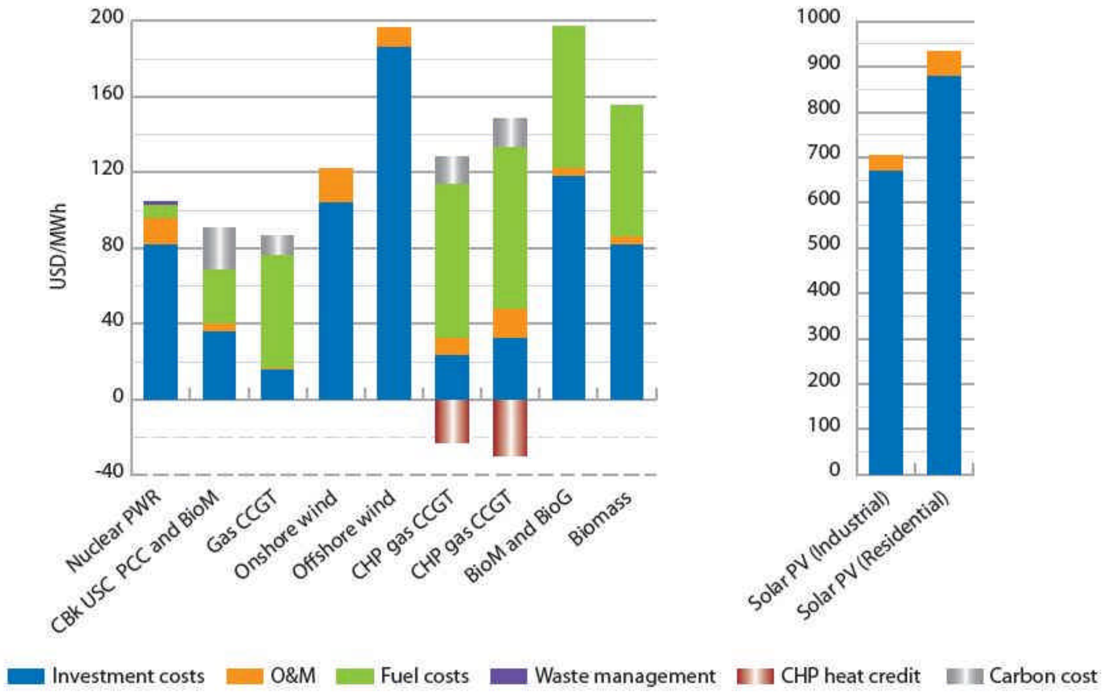

Figure S.2 *Production cost of future electricity generation in the Netherlands, new plants and installations entering into operation around 2015, 10% discount rate (Source: OECD, 2010). In USD2008/MWh (1 USD = 0.68 Euro)*

After 2020, innovations and increased practical experience may lead to cost reductions in sustainable technologies and deployment of CCS. The main uncertainty of nuclear energy continues to be the height of the investment costs.

Cost of permit granting and liability

Currently, operators of nuclear installations make financial contributions to finance the permit granting procedure and government supervision. The height of this contribution has been legally established. In case of a nuclear accident, the operator is liable for an amount of maximally € 340 mln, according to the Paris Convention. This amount will be increased to € 700 mln. In addition, the government will make additional public means available, guaranteeing coverage of a maximum amount of € 2.3 bln, which is in accordance with international treaties and partly based on national legislation. The height of the total coverage will be increased to € 3.2 bln. The operator pays the government an allowance for the additional coverage.

External cost and benefits

External costs are those costs that have not been incorporated in the system, for example damage to health due to air pollution and the cost of climate change. European studies have shown that the external costs of nuclear energy are low; approximately 2 €/MWh, which is comparable to wind energy. Natural gas and coal have external costs amounting to 10 €/MWh and 20-30 €/MWh respectively. These European studies did not include the external costs resulting from a serious nuclear reactor accident. Cost estimates in other literature for such events range from a minimum of 0.04 €/MWh[7] to 5 €/MWh[8]. However, the calculation methods are quite different from each other and both are not accepted by scientific methodology.

[7] Original number 0,03 to 0,3 £/MWh, study for the United Kingdom (Kennedy, 2007).

[8] Study by CE for Greenpeace (CE, 2007).

The external risk policy has found a way to weigh the 'small chance - large effects' with regard to deaths. This weighing will be incorporated in the standard for the group risk. As the number of deaths increases, the accepted chance of occurrence is lowered in a quadratic way: for every 10 x larger number of victims, the corresponding risk should be 100 times smaller. However, with regard to consequences, these risk standards pertain to deaths (group risk) and death risk (individual risk). Such a standard and accepted corresponding calculation method is not yet available for external costs linked to material damage resulting from serious accidents. There is no method and standard that is both scientifically and socially accepted. That is the reason why European external cost studies avoid calculations of external costs of 'small probability - high consequences' events. It has been mentioned though that the cost of serious nuclear reactor accidents are not included in the external cost estimates. It is a political and social discussion about which standards should be used for issues related to risk perception or risk aversion, and the consequences in terms of material damage.

Employment and economic effects
External benefits could be found in increasing employment and favourable economic effects. Expansion of nuclear energy in the Netherlands is expected to stimulate nuclear research, especially at research institutes and universities. A new nuclear power plant increases the nuclear sector in the Netherlands. This may have a (minor) positive economic effect on the region where the nuclear plant is located. These effects have already been listed and substantiated in the report *Fact Finding Nuclear Energy 2007*[9] that was written for SER. This study did not re-evaluate or reanalyse these effects.

S.2 Reliability and security of supply

Integration of large units, flexibility
In case of sudden failure of a nuclear power plant the reliability of electricity supply is no more or no less threatened than in case of sudden failure of a coal-fired plant. The degree of flexibility becomes more important in an electricity market with increasingly less predictable intermittent renewable sources, such as wind energy. Both new coal-fired plants and nuclear plants are therefore designed for more flexible operation. The capacity of new nuclear and coal-fired power plants can be lowered up to 20%. New nuclear power plants have no notable effect on integration in and flexibility of the electricity system.

Diversification
Security of supply usually improves by a large spread in technology, fuel and supply routes. The share of nuclear energy in the electricity production in Europe currently amounts to about 30%. In Northwest Europe, including France, this share is even higher. Adding several new nuclear power plants to the Northwest European production parks with a limited share of nuclear energy will therefore result in limited improvement of the medium to long-term security of supply on the Northwest European market. Adding nuclear power plants in the Netherlands would lead to a contribution that is similar to the situation in which the nuclear power plant is built in other Northwest European countries.

Uranium reserves
The uranium reserves amounts to approximately 5.5 million tons at a price of 130 USD/kg, which will last for about 100 years if its use remains unchanged. Improved techniques will enable the recovery of another 10 million tons of conventional supplies. Moreover, unconventional supplies of uranium are present in phosphate deposits (22 million tons) and in sea water (4000 million tons at 3 to 4 ppb). The production capacity of the existing uranium mines is limited though and will only be able to follow the growing short-term demand (around 2015) with difficulty.

[9] (Scheepers et al, 2007).

S.3 Environmental effects and external safety

Radiological effects

The environmental effects of nuclear energy are mainly determined by the ionizing radiation, emissions of radioactive particles and radioactive waste. The radiation levels and emissions to air and water must meet permit limits. Due to these permit limits the dosages for residents currently stay below the legal limits. Regardless of the type of nuclear plant, the maximum annual received additional dosage amounts to 0.01% of the dosage that is annually received from natural radiation sources and medical applications.

External safety

Industrial installations, including nuclear plants, must meet certain requirements with regard to risk of death as a result of accidents. The current Dutch installations for nuclear energy meet these requirements easily, both with regard to individual risk and group risk. According to NRG the new nuclear power plants may be expected to have higher safety scores than the current nuclear plant in Borssele, implying that external safety of future plants will continue to adhere to the existing safety standards.

Avoided CO_2 emissions and other emissions into air

A nuclear power plant has low variable costs and is therefore high in the merit order. In view of the emissions within the Netherlands the volume of the installed capacity is not as important as the extent to which the installed capacity is actually deployed. A new nuclear power plant will most likely oust more expensive fossil plants. Whether or not this will actually lead to lower emissions in the Netherlands depends partly on mutations in the import to or the export from the Netherlands. The Netherlands is expected to become an electricity exporting country. The deployment of new nuclear power plants leads to lower electricity production from fossil fuels (see Table S.6). Burning these fossil fuels leads to emissions of CO_2, NO_x, SO_2 and particulate matter. The largest effect is achieved when new coal-fired plants are replaced by or ousted from the merit order by new nuclear power plants. Additional nuclear power plants have roughly the same effect as a new nuclear power plant that replaces a gas-fired plant.

Table S.6 *Avoided fossil emissions when deploying nuclear energy instead of coal- or natural gas-fired power plants*

Scenario New capacity nuclear energy	1b (low) 200 MW	3 (high) 5000 MW
New coal-fired plant		
CO_2 [Mton]	1.2	29.2
NO_x emission [kton]	0.2	5.2
SO_2-emission [kton]	0.2	4.0
Particulates emission [kton]	0.01	0.3
New gas-fired plant (CCGT)		
CO_2 [Mton]	0.5	13.7
NO_x emission [kton]	0.1	3.1
Coal-fired plant with 75% CO_2 capture		
CO_2 [Mton]	0.4	9.1

Note: Emissions are annual emissions.

CO_2 emissions resulting from electricity production generated from fossil fuels are covered by the CO_2 emission trading system. It is true that nuclear energy decreases the deployment of fossil fuels and leads to lower CO_2 emissions at first. However, due to the generic emission ceiling in the emission trading system the decreased CO_2 emissions of electricity production will result in decreased emission reduction (or even increased emissions) in other industrial sectors. After all, the total CO_2 emissions in the emission trading system are capped.

Indirect CO_2 emissions of nuclear energy during the life cycle[10]

Literature indicates that indirect CO_2 emissions of existing nuclear power plants range from 5 to 65 grams CO_2 per kWh. European nuclear power plants have calculated CO_2 emissions of 8 to 32 grams CO_2 per kWh. To compare; wind energy CO_2 emission have been calculated to range from 6 to 32 grams per kWh and CO_2 emissions of electricity generated by current types of solar panels are calculated to range from 30 to 100 grams CO_2 per kWh. Thus, the CO_2 emission per produced kWh of nuclear energy during the life cycle of a nuclear power plants is comparable to the CO_2 emission produced by electricity generation from renewable sources.

[10] Based on (Scheepers et al, 2007).

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