The True Costs of Nuclear Power

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wiener umwelt anwaltschaft

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Foreword

The dangers of nuclear power accidents, the serious problems caused by radioactive waste and the threat of nuclear proliferation are all well known. The last remaining argument in favour of nuclear power – reality having shown that "safe" and "clean" are not the case – is "cheap." European discussions about a renaissance for nuclear, or rather measures to extend its life, are increasingly centred on the issue of costs, the claim that nuclear power is supposedly CO_2-free having not stood up to research.

Looking back at the promises made during the early days of nuclear energy, with claims that electricity would be almost free, electricity prices in those few countries that do have nuclear power programmes indicate that this is far from being the case. The current debate in Europe reflects the fact that, in spite of the direct and indirect support available for nuclear, not a single nuclear power plant has been constructed on the basis of economic considerations. In addition to the preferential financial treatment given to nuclear power, including massive limits to liability, state loan guarantees and similar, the utilities demand state guarantees for fixed electricity feed-in at price levels more than twice the market price, plus inflation, and indexed for periods of several decades.

Our study has researched the cost of nuclear power to provide a sound basis upon which to debate this topic. The study´s results show that reservations about the use of nuclear power due to legitimate safety concerns can be supplemented by reservations about its economic efficiency. The profits that individual stakeholders can make from operating nuclear power plants should not obfuscate the fact that, due to the legal framework conditions, these profits, as well as other costs not covered by the electricity price, are indirectly borne by society as a whole.

The support granted to a technology that not only has the potential to become a massive threat to the livelihoods of many people, but also represents a bigger burden to national economies than its alternatives, needs to be phased out as quickly as possible.

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Content

Summary

Worldwide, many nuclear power plants will be reaching the end of their lifetimes over the next few years. States must therefore decide now on the direction they intend to steer their energy policies. Possible options are the construction of new nuclear power plants, extending the lifetime of existing ones, or changing direction towards a sustainable energy future.

Arguments put forward by the nuclear power lobby in favour of new builds are, on the one hand, the claim that nuclear power is low in CO_2 emissions,[1]and on the other, that it is low cost. This paper examines the second claim and identifies the "true costs of nuclear power".

This paper provides an overview for the general reader and presents the most important aspects of "costs of nuclear power", as well as sound information to contribute to discussions of this complex issue.

The ***first part*** of this paper focuses on the ***costs of nuclear new-build***. Approximately two thirds of electricity generation costs consist of fixed costs, the largest part of which covers the construction of the nuclear power plant (NPP) itself, including the interest rates (capital costs). Consequently, construction costs are a crucial factor in the overall cost of nuclear power. The issue of nuclear new build is currently under discussion in many states in Europe which are considering replacing their aged nuclear power plant fleet, e.g. UK (Hinkley Point and further plans for new builds), Finland (Olkiluoto 3), France (Flamanville 3), the Czech Republic (Temelin 3/4), Slovakia (Mochovce 3/4) and Romania (Cernavoda 3/4). Those projects have one crucial point in common: problems with costs or financing. The *Massachusetts Institute of Technology* (MIT) has calculated that construction costs rose 15% per annum from 2003 to 2009; construction costs rose from 2,000 to 4,000 USD, amounting to total construction costs of US$ 4 billion for a 1,000 MW NPP. A current example of cost and construction time overrun is the Finnish reactor Olkiluoto 3: completion has been postponed from 2009 to 2014 and the construction costs have already more than doubled from the original estimate, currently reaching € 8.5 billion. This price is the same as that announced by the Confederation of British Industry in July 2013 for Hinkley Point: € 16.3 billion for 2 EPR á 1,600 MW - € 5 billion for 1,000 MW.

Potential investors are aware of high construction costs and the high risks connected with them: new builds in Europe appear impossible without state aid-like credit guarantees, tax relief or guaranteed feed-in tariffs. The UK is currently in the midst of a heated debate about the strike price, a guaranteed minimum price for electricity delivered into the grid for decades ahead, state aid being given for nuclear energy on the basis of it being a low-carbon technology; the outcome of this will have significant impact on European new build projects.

The second part of the paper focuses on the possible ***costs*** of a MCA – the ***Maximum Credible Accident*** – and the ***impact of full insurance for nuclear power on the costs*** of nuclear energy. This focus delivered the following results: several studies have shown the total cost of an MCA to reach anywhere between 71 und 5,800 billion USD. This wide range illustrates how unclear the actual costs of such an accident are. The liability sums currently used are way below this value, and cover only a fraction of the possible damage. Full insurance would cause electricity generation costs to skyrocket – even if the accumulation period was 100 years, the costs would increase 3 – 50 fold. If an accident had to be covered during the lifetime of a nuclear power plant, then costs would increase 80-1,300 fold. However, in reality a nuclear accident can never be covered by insurance.

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[1] The paper Wallner et al. (2011) „Energiebilanz der Nuklearindustrie" in detail researched the issue of nuclear power´s CO_2 emissions and contains an English summary.

Further cost components taken into consideration in this paper:

- ***External costs of the nuclear fuel chain:*** The costs of damages to the environment and health caused by the emissions of the nuclear fuel chain, including uranium mining or a final repository for highly active nuclear waste, are reflected only to a very minor extent in the price of nuclear electricity. These costs have to be covered by the public.
- ***Costs for decommissioning and the final repository*** for nuclear waste should be covered by annual provisions paid into a fund. The amounts paid into the funds, however, are discounted over decades and therefore much lower than the sum required in the end – how the costs will be covered at this later point in the future is unclear.
- Further benefits for nuclear energy, which the electricity price does not reflect, are state-financed nuclear research and the necessary institutional framework.

If all those factors were taken into account, nuclear power would be uneconomic. The following table explains how the increase in construction costs and theoretical costs for nuclear insurance would raise ***electricity generation costs:***

	Electricity Generation Costs [€/kWh]	**Source**
Range of construction costs of NPP already built	0.018 – 0.079	Thomas et al. (2007)
incl. increased costs for new build	0.118	MIT (2009)
Additional costs caused by insurance – lowest value of the range for 100 year accumulation period: + 0.139 €/kWh	0.26	Gunther et al. (2011)
Additional costs caused by insurance – highest value of the range for 100 years accumulation period: + 2.36 €/kWh	2.48	Gunther et al. (2011)
Additional costs caused by insurance – lowest value of the range for 10 years accumulation period: +3.96 €/kWh	4.08	Gunther et al. (2011)
Additional costs caused by insurance – highest value of the range for 10 year accumulation period: + 67.3 €/kWh	67.4	Gunther et al. (2011)

Those results show that, only taking into account the increased costs of construction, electricity generation costs would already be higher than the current electricity price of approx. € 0.09/kWh for industrial consumers in Austria.

A precondition for any nuclear new build is state aid – offered in addition to the wide range of pre-existing preferential treatments and special regulations in support of nuclear energy. The costs of these subsidies, as well as the damages inflicted by the nuclear fuel chain on the environment and health, must be paid for by the public. Therefore investing in nuclear new builds is both economically and socially unviable. Investments into a sustainable energy future yield greater benefits to national economies.

1 Introduction

Worldwide, many nuclear power plants will be reaching the end of their lifetimes over the next few years. States must therefore decide now on the direction they intend to steer their energy policies. Possible options are the construction of new nuclear power plants, extending the lifetime of existing ones, or changing direction towards a sustainable energy future.

Arguments puts forward by the nuclear power lobby in favour of new builds are, on the one hand, the claim that nuclear power is low in CO_2 emissions[2], and, on the other, that it is low cost. This paper is examines the second claim and identifies the "true costs of nuclear power".

This paper provides an overview for the general reader and presents the most important aspects of "costs of nuclear power", as well as sound information to contribute to discussions of this complex issue. For this purpose, results from existing literature were used and, where necessary, experts interviewed.

Firstly an overview of the cost of nuclear power is given, including the complete life cycle of the nuclear power plant, all the way to the nuclear waste repository (Chapter 2). Key cost components – both included as well as not included in the price – are identified. This has led to the definition of two focal topics:

Construction costs, the most important included cost component, are discussed in Chapter 3. This chapter also explains why construction costs are currently a subject of international interest and explosive in nature.

Severe accidents and their consequences for people and the environment are not usually reflected in the costs. Chapter 4 looks into how these costs are calculated, and the extent to which they are covered by NPP operator liability.

An overview of other cost components is provided in chapter 5. Chapter 6 contains the conclusions drawn from these results and the estimated impact of significant cost components on electricity costs and price.

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[2] The paper by Wallner et al. (2011) *Energiebilanz der Nuklearindustrie* researched the issue of nuclear power´s CO_2 emissions in detail and contains an English summary.

2 Overview of Costs of Nuclear Power

2.1 Key Cost Components

This chapter surveys the individual cost components of nuclear power and identifies those which determine the total costs. The ***key cost components*** defined in this way and their impact on the "true costs of nuclear energy" are the ***focus of this study.*** An overview of other cost components is provided in chapter 5.

The following costs are incurred in generating nuclear power: fixed costs, e.g. construction and decommissioning of the NPP, and variable costs for operation and fuel. These costs are included in the final price of nuclear power – others, however, are not. Therefore, this chapter differentiates between "costs included in the price" and "costs not included in the price".

2.1.1 Costs Included in the Price

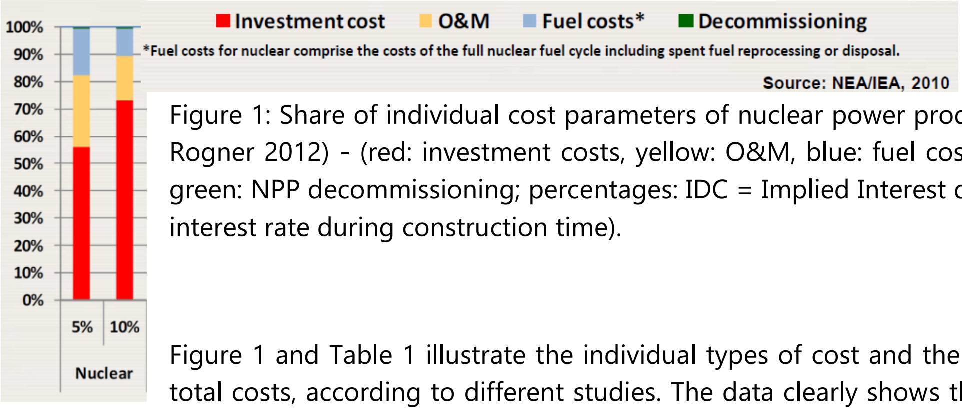
The total costs of nuclear power are made up from different components, each differing in the extent to which they are reflected in the total price.

The following provides an overview of those costs and explains their impact on price:

- Investment costs for construction, including interest costs during construction
- O&M – Operation and Maintenance (costs incurring during operation, excluding fuel costs)
    - Fixed costs (independent of the amount of electricity produced):
        - Maintenance costs: significant cost increase likely during times of operation
        - Personnel costs
        - Insurance, taxes
    - Variable costs components (exclusively dependent upon the amount of electricity produced)
        - e.g. costs of fuel purchase, variable maintenance costs
- Fuel costs including waste disposal management and final repository
- Decommissioning costs (dismantling the NPP = investment costs, which are incurred in the future)

Table 1: Cost Components of Nuclear Energy

Type of Costs	Total Share of Costs [%]	
	According to Figure 1 (Rogner 2012)	According to 4 (Rogner 2012)
Investment Cost	~ 56-72%	60%
Fuel Costs incl. Costs for Repository	~ 17-26%	20%
Costs for Operation and Maintenance	~ 10-17%	20%
Decommissioning	~ < 1%	1-5%



*Fuel costs for nuclear comprise the costs of the full nuclear fuel cycle including spent fuel reprocessing or disposal.

Source: NEA/IEA, 2010

Figure 1: Share of individual cost parameters of nuclear power production (excerpt from Rogner 2012) - (red: investment costs, yellow: O&M, blue: fuel costs incl. final disposal, green: NPP decommissioning; percentages: IDC = Implied Interest during construction = interest rate during construction time).

Figure 1 and Table 1 illustrate the individual types of cost and their contribution to the total costs, according to different studies. The data clearly shows that the variable costs of nuclear power plants are relatively high compared to the total costs. As a rule of thumb, it is legitimate to assume that ***fixed costs make up 2/3rds of electricity production costs*** (Thomas 2005). Also significant are an NPP´s investment costs, which again are heavily dependent on the interest rate used (as pointed out in Figure 1).

The issue of construction costs is a currently much discussed topic; it has returned to the international agenda because the current power plant fleet is aging. The average age of operating reactors worldwide reached 27 years in May 2012; in comparison, the last 145 reactors which were shut down had an average age of 24 years. This explains the nuclear industry's need for new builds. This situation is a consequence of the wave of new builds in the 1970s and 1980s, which then slowed down and was overtaken by the number of shutdowns (see Figure 5). (Schneider et al. 2012)

For this reason, the ***costs of new build*** were chosen to be the ***first focal point of the present study*** (see Chapter 3).

2.1.2 Costs Not Included in the Price

Since the very beginning of commercial use of ***nuclear power*** this type of energy generation has enjoyed ***an exceptional position***. As part of the Manhattan Project, research was undertaken into nuclear fission with the purpose of building nuclear weapons – financed by state funds. After the "Atoms for Peace" speech of U.S. President Eisenhower in 1954, the results of this research were spread worldwide for non-military use. In 1957, this led to the founding of the IAEA (International Atomic Energy Agency) with the goal of accelerating and spreading nuclear power´s contribution to peace, health and prosperity worldwide – simply put, the spreading of commercial (non-military) use of nuclear power was to be promoted. The IAEA currently employs around 2,300 people; in 2012 its budget was more than 400 million euros[3].

The legal status of nuclear energy is also extraordinary: since its founding in 1957, the EURATOM Treaty has held a unique legal position in Europe, dedicated to promote the development of nuclear power in Europe by means other than just research. Since 1957, research and the expansion of nuclear power have been driven using public funds – a special status not granted to any other form of energy generation. This special status has made it possible to shift parts of the cost to the taxpayers.

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[3] http://www.iaea.org/About/budget.html, accessed 20 June, 2013

The following is an overview of the costs that are not included:

- **Costs of Full Insurance**
  Due to current liability regimes, nuclear power plants do not have to pay for insurance to fully cover any damage caused by a Beyond Design Basis Accident (BDBA). In case of an accident, the costs will have to be borne by those potentially damaged, and by the state – i.e. the taxpayer again.
- **External Costs of the Fuel Cycle**
  External costs are costs that are not born by the polluter – usually society has to pay for those costs. When assessing processes and products, their environmental impact over the complete life cycle must be taken into account. Therefore, in the case of nuclear power it is necessary to assess aspects such as impact on the environment and health, not just during the operation of the nuclear power plant but along the entire nuclear fuel chain; this starts with uranium mining, enriching the fuel, and all the way to decommissioning the plant and final disposal of the fuel. Negative impacts on the environment and health caused by the nuclear fuel chain are not reflected in the electricity production costs and therefore count as external costs.
- **Coverage of insufficient resources for decommissioning and final disposal**
- **Nuclear power research (EURATOM)**
- **Institutional framework of nuclear power (IAEA, state safety authorities, …)**
- **State aid for new build (loan guarantees, tax relief)**

Calculating the theoretical impact of all these outsourced costs on the overall costs of nuclear power would be very difficult, and falls far outside the framework of this study – partly due to the availability of data and partly due to the multitude of influencing factors. Therefore, only those cost components which exert a significant influence on the overall costs and for which data is available are considered in more detail.

Hiesl (2012) has stated that a full insurance to cover a Beyond Design Basis Accident would have high potential impact on the electricity costs. Possible ***costs*** of a ***BDBA*** and the ***influence of nuclear full liability on the costs*** of nuclear power has therefore been selected as the ***second focal topic*** of the present study (See Chapter 4).

An overview of other external costs (e.g. insufficient costs for decommissioning and final disposal, and external costs of the nuclear fuel chain) is provided in Chapter 5.

2.2 Overall costs: Electricity generating costs, LCOE

The individual cost components have different levels of impact on the overall costs of nuclear power, and are also called electricity generating costs. Chapter 6 looks into the overall costs of nuclear energy and the influence of increasing cost components and not included costs. However, we first need to provide a few definitions:

Generating Costs
Generating costs are the costs that are needed to transform energy into electricity. Usually they are given as euros per megawatt-hour. Possible method of calculation: annual overall cost for the operator per operational year in relation to the yearly produced amount of electricity (e.g. in MW).

Levelized Energy Costs, Levelized Cost of Electricity (LCOE)
To compare the generation costs between different power plants, it is useful to calculate the average generation costs for the complete operational life time of a power plant: the ÖkoInstitut (1998) describes the following calculation method for average electricity generation costs, and helps to understand this term better:

> *"The average generation cost is determined in two steps: the cash value of all costs is determined by discounting the costs of each operational year from the time of the plant start-up. In a second step, this cash value is levelled, i.e. transformed into an annual constant payment over the observation period. The average annual cost of operation is determined using this method of financial mathematics. The generation costs of electricity are derived from the relationship between these annual average costs and annual levels of electricity generation."*

The following formula can be used to calculate the average electricity generating costs:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}}$$

LCOE	electricity generating costs in €/kWh
I_o	investment expenditure in €/kWh
A_t	annual overall costs in € in year t
M_{el}	produced electricity in the respective year in kWh
I	real calculated interest rate in %
N	period of economic use in years
T	year of economic use (1,2,...n)

Figure 2: Formula for the calculation of electricity generating costs (Fraunhofer 2012)[4]

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[4] Note: This model also discounts the produced amount of electricity at the time of start-up, because as with the discounting of monetary value, also in future produced electricity is assumed to have less value than currently produced electricity.

3 How Much Does it Cost to Build a Nuclear Power Plant?

3.1 General Information

3.1.1 Definitions

Construction costs for a NPP are usually calculated as so-called ***overnight costs***. These are the costs which would incur if the nuclear power plant could be build "overnight" – i.e., all costs occurring at once, at today´s prices. The overnight costs usually include the cost of the first fuel charge, however they exclude the interest rates incurred during the construction period (building interest) and price increases in real terms. Overnight costs are usually given as costs per kW of installed capacity (Böll 2010). There is no standardized calculation of overnight costs – sometimes the overnight costs only include the EPC costs (engineering, procurement, construction), and in other cases they also include costs of land purchase, project management and license costs (Radovic 2009).

Investment costs include overnight costs and the IDC (IDC = Implied interest during construction) (IEA/NEA/OECD 2010). If the rates incurred during construction time (costs of capital) and price rises are also included, the construction costs increase significantly – an increase of the assumed interest rate of e.g. 5% to 10% results in a significant change of costs (see Figure 1 and Figure 3):

The ***interest rates*** incurred for this purpose and other costs constitute the ***costs of capital*** (equity costs and debt costs). The costs of capital differ significantly depending on the company´s credit rating, project risk and the county-specific risk. When the risk of default of payment is assessed as being low, e.g. due to state guarantees, the credit costs decrease (Böll 2010, p. 81-82). The risk rating for nuclear power plants is of particular importance, because high-risk interest quickly makes construction economically uninteresting for investors (see Chapter 3.3.2).

Large scale projects, such as the construction of nuclear power plants, are usually financed using debt capital (loans) and equity capital.

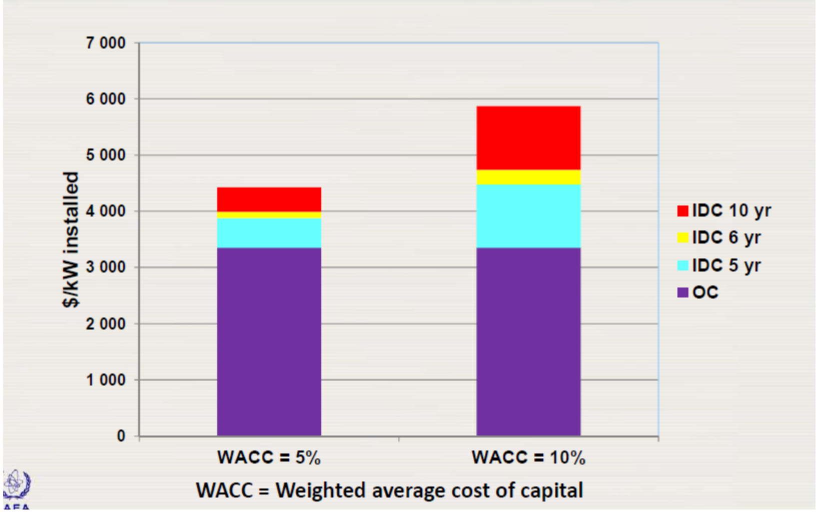

Figure 3: Construction cost dependence on interest rate and length of construction period – OC = Overnight Costs, IDC = Interest during Construction (Rogner 2012)

3.1.2 Share of the Overall Costs

Investment costs are of key importance to the overall costs of the NPP: depending on the selected assumptions and methods of calculation, they account for half or even two thirds of the overall costs (see Figure 1, Figure 4 and Figure 10). The data provided by different studies, however, differs significantly.

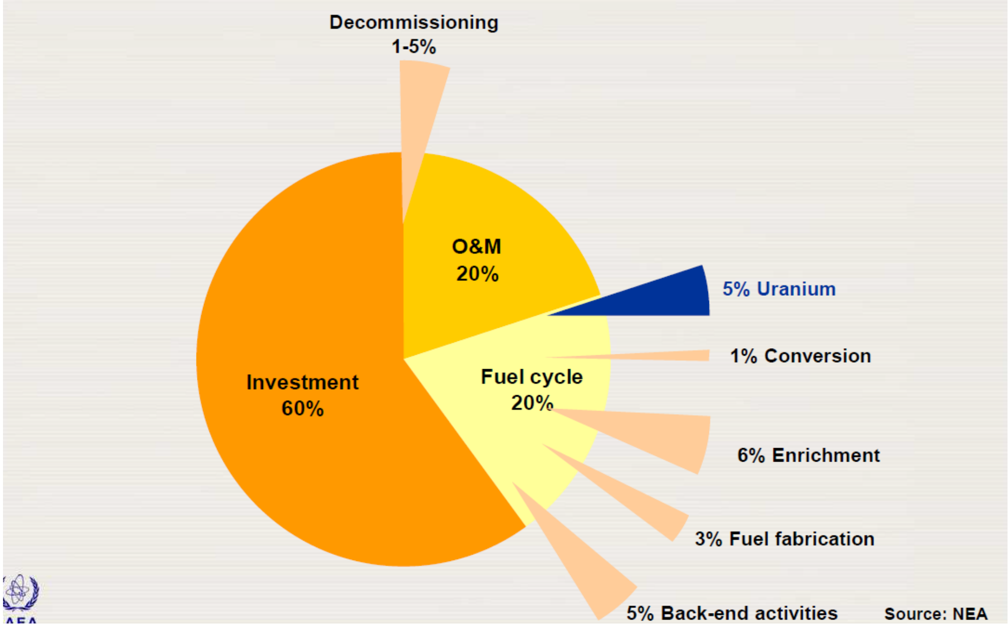

Figure 4: Distribution of overall costs of nuclear energy generation (Rogner 2012)

According to the rule of thumb, ***approximately two thirds*** of the overall costs are made up of ***fixed costs***. The ***largest portion*** is devoted to the ***construction*** of the nuclear power plant – or the related payment for loan instalments and interest rates. Only a small part is set aside – at least mathematically – for the decommissioning of the nuclear power plants (see explanation in Chapter 5). The operational and fuel costs of nuclear power plants are relatively small in comparison to the fixed costs. (Thomas 2010)

This leads to creation of a ***paradox situation***: once the nuclear power plant has been completed, it makes more sense to continue operating the NPP, in order to amortize the construction costs, even if cheaper, alternative forms of energy generation are available (Thomas 2010).

3.1.3 New Build

Figure 5 explains why the subject of nuclear new builds is currently of such interest. Since the start of commercial use of nuclear energy, there have been two main construction waves: in the mid-70s and mid-80s. Until 2002, almost more reactors went online every year than were shut down. After 2002 this trend reversed: the ***reactors*** built during these main construction waves successively reached the ***end of lifetime***. Their host countries now have the following options to maintain installed capacity: construction of new reactors, extending the lifetime of existing nuclear power plants, and steering energy policy towards an alternative, nuclear power-free direction.

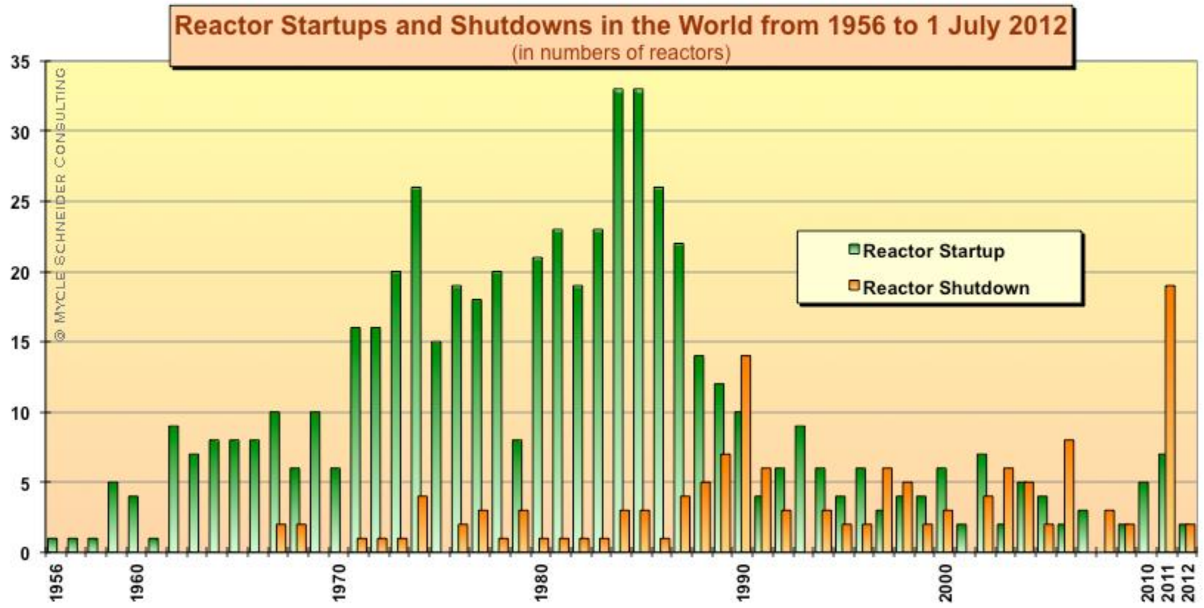

Figure 5: Reactor Startups and Shutdowns - Source: (Schneider et al. 2012 based on IAEA-PRIS data)

The nuclear power lobby hopes to turn this potential new build boom into a chance to obtain new orders. However, new builds have become much more expensive and difficult than in the 1970s. The following chapter examines the development of costs for new build. After this we show how states and the nuclear lobby are attempting to overcome the obstacle of high and risky investment costs and enable new builds.

3.2 Level and Development of Costs for New Builds

3.2.1 Level of Costs of New Build

The different data on costs of nuclear power plants are ***hardly comparable***, because cost estimates usually rely on different definitions of costs, assumptions and goals. For example, the overnight costs compared to the investment costs do not take into account cost overruns. Moreover, the different costs definitions are not standardized. In addition, the assumed ***interest rate*** has a significant impact on the calculated costs (See Figure 1). The interest rate level will vary according, amongst others, to perceived investment risk – long-term guaranteed purchase contracts can keep the perceived risk and thereby the interest rate low.

For outsiders, these ***in-transparent estimates*** make it almost impossible to compare the different costs. Operators can manipulate those figures to fit their purposes.

A very good illustration of this was calculated for the MIT[5] study in 2009: the study compared the costs of two bids made for a U.S. reactor – which originally differed by a factor of 3. However, once the cost estimates were broken down to fit the same method of calculation, it turned out that the costs of the reactors on offer were almost the same ($ 3,480/kW vs. $ 3,530 kW) (Du/Parsons 2009).

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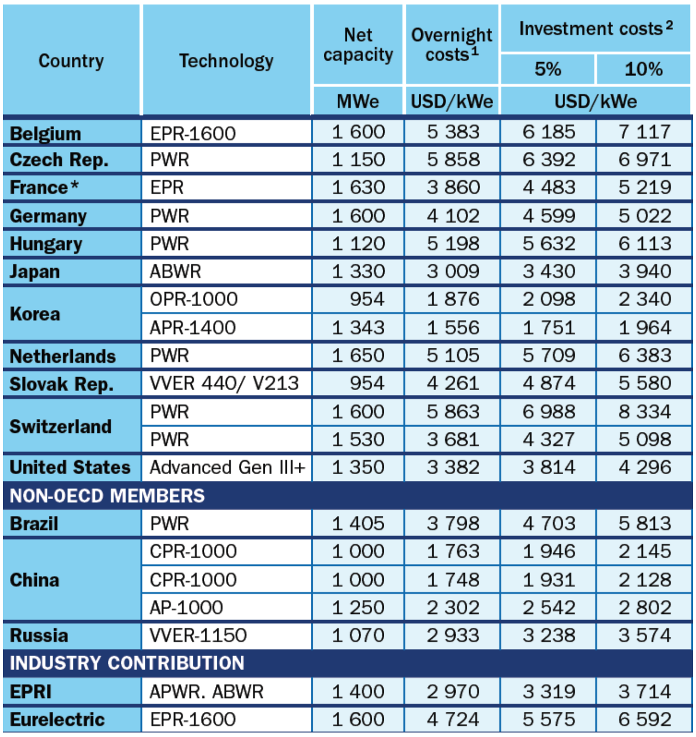
[5] Massachusetts Institute of Technology

In spite of the enormous difference in the cost estimates, one fact is obvious – nuclear power plants are expensive. Some figures on this:

- Du/Parsons (2009) gives the overnight costs in 2007 for several offers for U.S. reactors at between ***2,930 and 7,745 US$/kW***. The overnight costs of NPP actually built in Japan and Korea between 2004- 2006 are given at 2,759 to 3,357 $/kW.
- The overnight costs for 2007 are given at 4,000 US$/kW in the MIT basic scenario (Du/Parsons 2009, p. 41) – for ***2013*** overnight costs were calculated at ***4,776 US$/kWh.*** For a 1,000 MW NPP, this amounts to overnight costs of ***4.8 billion US$ (ca. € 3.6 billion)***[6]***.***
- OECD provides the following figures for new build costs – the enormous difference between overnight costs and investment costs becomes clear:



Country	Technology	Net capacity	Overnight costs[1]	Investment costs[2]	
				5%	10%
		MWe	USD/kWe	USD/kWe	
Belgium	EPR-1600	1 600	5 383	6 185	7 117
Czech Rep.	PWR	1 150	5 858	6 392	6 971
France*	EPR	1 630	3 860	4 483	5 219
Germany	PWR	1 600	4 102	4 599	5 022
Hungary	PWR	1 120	5 198	5 632	6 113
Japan	ABWR	1 330	3 009	3 430	3 940
Korea	OPR-1000	954	1 876	2 098	2 340
	APR-1400	1 343	1 556	1 751	1 964
Netherlands	PWR	1 650	5 105	5 709	6 383
Slovak Rep.	VVER 440/ V213	954	4 261	4 874	5 580
Switzerland	PWR	1 600	5 863	6 988	8 334
	PWR	1 530	3 681	4 327	5 098
United States	Advanced Gen III+	1 350	3 382	3 814	4 296
NON-OECD MEMBERS					
Brazil	PWR	1 405	3 798	4 703	5 813
China	CPR-1000	1 000	1 763	1 946	2 145
	CPR-1000	1 000	1 748	1 931	2 128
	AP-1000	1 250	2 302	2 542	2 802
Russia	VVER-1150	1 070	2 933	3 238	3 574
INDUSTRY CONTRIBUTION					
EPRI	APWR. ABWR	1 400	2 970	3 319	3 714
Eurelectric	EPR-1600	1 600	4 724	5 575	6 592

Figure 6: Overview of costs of new build (IEA/NEA/OECD 2010, p. 59)[7]

3.2.2 Construction Time

Radovic (2009) examined the construction times of all commercially operated reactors and arrived at the conclusion that the average construction time is ***6.9 years*** (with a standard deviation of 3.34 years). However, current projects in particular are significantly exceeding this average construction time.

This average construction time is subject to significant fluctuations: Figure 7 shows the continuous increase in construction times since the 1950s. While the first decades of commercial nuclear power use were characterized by very homogeneous construction times, the variations between different

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[6] Notes from the .xls of the study by Du/Parsons (2009) = basis for MIT (2009): "Example assumes a total EPC overnight cost of $3,333, an inflation rate of 3%, a 20% factor for owner's cost and an allowed capital recovery charge of 11.5%."

[7] Overnight costs include pre-construction (owner's), construction (engineering, procurement and construction) and contingency costs, but not interest during construction (IDC).
Investment costs include overnight costs as well as the implied interest during construction (IDC).

countries have continued to grow since the 1990s. While Japan, South Korea and China have enjoyed construction times of 4.4 – 4.6 years and 5.8 years respectively in the past two decades, construction times in other parts of the world are escalating, reaching to ***over 10 years*** (Schneider et al. 2012).

Due to interest payments, construction time overruns inevitably lead to overruns of scheduled costs.

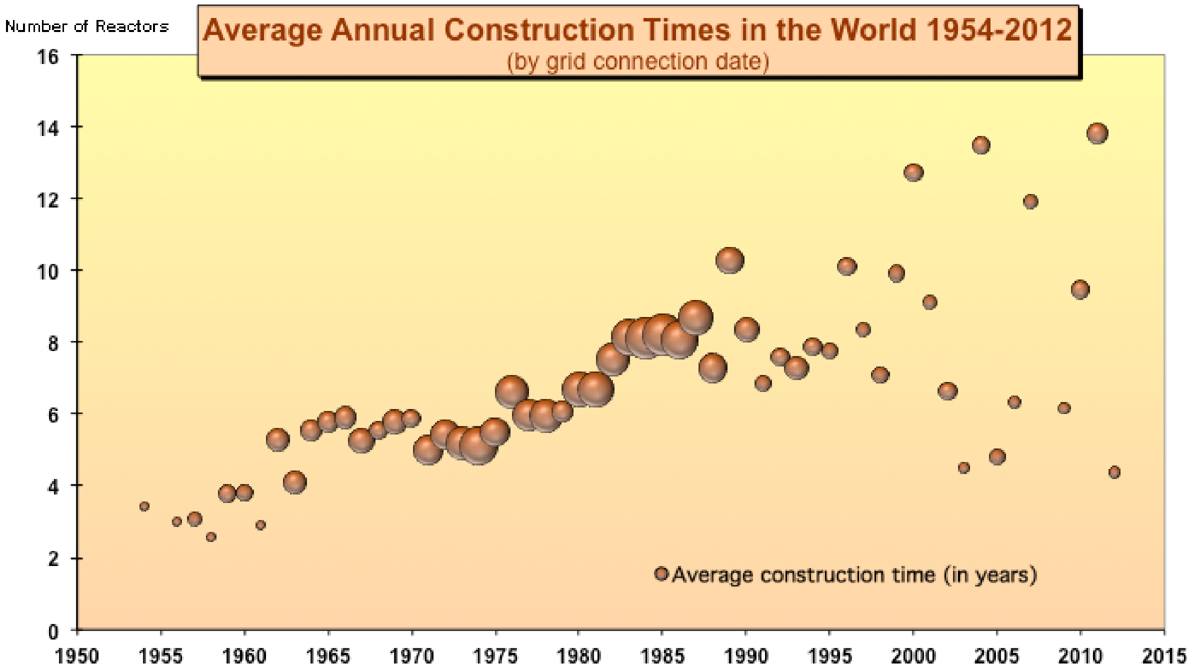

Figure 7: Development of average construction times 1954-2012 (Schneider et al. 2012)

3.2.3 Development of Costs of New Build

Only very new nuclear construction projects are completed during the scheduled cost and time limits – many overrun their planned budgets and construction time many-fold (Greenpeace 2013). In the past decade the construction costs for NPP increased many-fold, sometimes even by a factor five (Böll 2010).

The ***Massachusetts Institute of Technology*** calculated the ***increase of construction costs of 15% per year (MIT 2009 as Update of MIT 2003)***. The overnight costs in the basic scenarios increased in this comparison from ***2,000 to 4,000 US$/kW*** (MIT 2009).

In the past the nuclear industry again and again announced better prices due to ***the learning effects***, however, ***they did not take place*** in reality. Reasons for this are e.g. a continuous increase in safety regulation and strong decrease in the number of nuclear power plants ordered (See Figure 5 and the explanation) (Biermayr/Haas 2008) Therefore it is most likely not the case, that mass production would have economic advantages (Böll 2010, p. 77/7). Rather the contrary – nuclear power is producing a negative learning curve: In the past decade the cost estimates for the new-build of NPP increased five-fold (Thomas 2010, p. 8).

3.2.3.1 Olkiluoto

Around year 2000, when the promotion of this new reactor generation was started for the first time, the cost were ***originally estimated*** to be US$ 1,000/MW, i.e. ***one billion US dollars*** for a 1,000 MW NPP.

An example for the ***extreme overrun in costs and construction time*** is Areva´s EPR reactor construction project in Olkiluoto, Finland. The EPR (European Pressurized Reactor) was one of the first construction projects of Generation III+. Since the project start in 2004 problems kept occurring, e.g. strength of the concrete, welding seam quality, supplier´s lack of expertise and a low quality control over contractors. The problem seems to be never ending – the expected ***completion date*** was already delayed from ***2009 to 2016***[8]***.*** Construction costs have more than doubled since the original estimate from 3.2 billion Euro to 8.5 billion Euro (Status: Dec. 2012[9]).

This price is equal with the price the Confederation of British Industry announced as the price for Hinkley Point with € 16.3 billion for 2 EPR à 1,600 MW - € 5 billion for 1,000 MW[10] in July 2013.

The Finnish NPP Olkiluoto is being built under a so calle turnkey contract of 2003. Turnkey means that Areva committed to having delivered turnkey all work necessary (inclusive not yet foreseeable work) for a price determined already in the beginning resp. having it done at its own expenses. Signing such a contract investors considered as being too risky in most cases, because they are well aware of the possibly enormous cost overruns. (Schneider et al. 2011) TVO and Areva are blaming each other as being responsible for the delays and are already fighting in an arbitration court since 2008: Areva demanded 1.9 billion Euro from TVO in May 2011, TVO then demanded Areva[11]to pay 1.8 billion Euro damage compensation in October 2012.

The French EPR counterpart of Olkiluoto is under construction in Flamanville. The situation there does not seem to be any better – construction started in 2007, should have been completed in 2012, but is delayed meanwhile for several years.

3.3 Benefits for NPP New-build

As Chapter 3.2. explains the precondition of the construction of a nuclear power plant is the availability of an enormous amount of money, which even keeps growing. The argument of nuclear power being more economic than renewable energies can hardly be held up. (Schneider et al. 2011)

A significant contribution to the high is the fact, that financing institutions meanwhile have started rating nuclear power as a risky investment – causing interest rates and overall costs to rise. In all of Europe, current new-build effort is burdened with cost problems. Different benefit for the new-build is an attempt of the nuclear lobby to shift this financing problem on to others. The following chapter is providing an overview over such benefits.

3.3.1 Strike Price: The British example

Current developments under way in U.K. could also have significant impacts on new-build projects in Europe; the so-called „Contract for Difference" (CfD). Behind this term from financial economics hidden is the attempt to gain a guaranteed electricity feed-in-price (Strike Price) under a long-term contract for nuclear investors with the goal to make new-build of NPP profitable.

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[8] http://www.world-nuclear-news.org/NN-TVO_prepares_for_further_Olkiluoto_3_delay-1102134.html, accessed 1 July 2013

[9] http://www.reuters.com/article/2012/12/03/us-edf-nuclear-flamanville-idUSBRE8B214620121203, accessed 1 July 2013

[10] http://www.euractiv.com/energy/uk-cbi-tells-brussels-us-nuclear-news-529006, accessed 5 July 2013

[11] http://www.handelsblatt.com/unternehmen/industrie/finnischer-versorger-tvo-fordert-1-8-milliarden-euro-von-areva/7204410.html, accessed 1 July 2013

Firstly a brief historic outline to explain the background, which led to this development:

- ***2006*** the British government announced the intent to a start ***nuclear new-built program*** with a view to the heavily aging nuclear power plant fleet. This program was to be market driven – ***state aid*** was firmly ***excluded***.
- ***In 2007*** the government initiated the „***Generic Design Assessment***" (GDA) which should conduct comprehensive analysis of certain reactor design to asses non-site specific characteristics for potential reactors for new-build already beforehand. Assessed were Areva´s EPR, the AP1000 by Toshiba/Westinghouse, the ESBWR by Hitachi-GE and the ACR1000 by AECL. The reactor construction was supposed to take place at already existing NPP sites.
- ***In 2010*** the British government announced that an electricity market reform would be necessary to guarantee security of energy supply also in future. The possibility of **subsidizing** nuclear energy was ***not completely excluded*** any more at this point.
- ***In 2011*** the government published a White Paper on the Electricity Market Reform – among other issues it defined a) to determine a ***CO_2 minimum price*** (Carbon Floor Price) and b) long-term contracts (***feed-in-tariffs with contracts of difference***) to attract investors for low-carbon technologies. The White Paper assumes that the CO_2 minimum price will have increased to € 36 per ton until 2020; on the one hand this is exactly the threshold which had been calculated for the economic viability of nuclear energy – on the other hand 2020 had been the year the first new British NPP was to go online. The condition obviously had been tailor-made for the promotion of nuclear energy.
- At the end of ***2011 only one*** of the four potential ***suppliers*** was left over (Areva's EPR reactor). The reactor ACR1000 and ESBWR had been withdrawn. Westinghouse-Toshiba´s reactor AP 1000 however received the Interim Design Acceptance Confirmation (IDAC) from the ONR (Office for Nuclear Regulation) at the end of 2011, but was not prepared to continue working on the project if it would be chosen as the preferred bidder. In such a situation it is not possible to have market driven process.
- ***In 2013*** the Environmental Impact Assessment for the first British new-build project was completed, the construction of two EPR reactors by EDF at the Hinkley Point site. The British state secretary for energy and climate ***decided in favor of the application*** on the NPP Hinkley Point C.

This decision was taken after ***intensive negotiations between EDF and the British government*** concerning the level of the ***Strike Price.*** The mechanism ***Contract for Difference*** (CfD) uses state funds to guarantee the income of nuclear energy suppliers, when the electricity price drops under a certain in advance decided price (Strike Price). In case the electricity market price drops under the agreed Strike Price, the state pays the difference to the electricity generating utility. If however the market price rises above the Strike Price, the electricity generator has to give the excess sum to the state. EDF insisted on the Strike to secure the high investment of project of ca. 14 billion pound. With the CfD in place, the state would guarantee a fixed electricity price to the electricity producer.

The topic of the tough negotiations between EDF and the British government is mainly the level of the Strike Price, which has decisive importance. Because the nuclear power are to go online not earlier than 2020, it is necessary to decide today, which price the state should guarantee in 2020. Such an estimate is extremely difficult to undertake under constantly changing economic conditions (See economic crisis), even though price indexation clauses should cover certain changes like e.g. inflation (the details of the price indexation clauses are the second main point of discussion). It is highly unlikely, that the government would give in to the immense demands raised by EDF: a contract with a validity of almost 40 years and a Strike Price of nearly £ 100/MWh[12].

If EDF would be granted those demands, which foreseeably would be above market price, EDF would be sure to receive state aid for several decades, which most likely would be higher than those for renewables. Observers assume, that EDF is demanding a Strike Price of 95 £ minimum. [13]

End of ***June 2013*** the British government announced its intention to make available **a state loan guarantee** of up to **10 billion pounds** for the project Hinkley Point.[14]

This loan guarantee enables significantly lower construction interest rates for this project and much decreases the construction costs. To achieve an agreement on the strike price seems much likelier once reduced construction costs have been achieved (See Chapter 3.3.2). This decision confirms the British government´s strong focus on nuclear power. Other countries are awaiting the developments in England and in case of a success they are ready to introduce the same system in their countries. E.g. in April 2013 the Czech Minister of Industry announced that plan of putting the new Temelin units in 2025 into operation will most likely be delayed, because the additional capacity will not be needed until 2030. The current electricity price is too low to make the construction costs for CEZ viable – therefore CEZ keeps waiting.

The European Commission is quite positive towards plans of countries like U.K., Bulgaria, Czech Republic and Finland to give state aid for nuclear energy generation:

In March 2013 the European Commission published the consultation paper on the „Environmental and Energy Aid Guidelines 2014-2020", which among other ideas suggested to allow state aid for nuclear power as a low-carbon technology.[15]

During the consultation phase this paper raised enormous resistance, because potential CO_2 savings are pitted against the most serious problems of nuclear energy, e.g. the unsolved question of a final repository for high level nuclear waste and the residual risk of severe accidents, which still cannot be excluded. As a general rule, state aid for nuclear power should not be possible, because the Treaty on the Functioning of the European Union states in article 107 (1) states, that any aid granted by a Member State or through State resource in any form whatsoever which distorts or threatens to distort competition by favouring certain undertakings or the production of certain goods shall, in so far as it affects trade between Member states, be incompatible with the internal market.

3.3.2 State Guaranteed Loans

An option of decrease the debt capital costs of NPP construction are the state loan guarantees. In case of payment default of the construction company, the state takes over the loan default. With this loan security the loan provider takes on a very low loan default risk only and therefore very low loan interest rates can be agreed. Loan rates being a very significant share of the construction costs, such a

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[12] http://realfeed-intariffs.blogspot.co.uk/2013/06/will-edf-get-inflation-proofed-deal.html, accessed: 21 June 2013

[13] http://www.bloomberg.com/news/2013-06-27/u-k-s-nuclear-plan-advances-with-15-billion-treasury-backing.html, accessed: 2 July 2013

[14] http://www.bloomberg.com/news/2013-06-27/u-k-s-nuclear-plan-advances-with-15-billion-treasury-backing.html, accessed: 2 July 2013

[15] Paragraph 48 of this consultation paper states that some member states consider aid for nuclear power to support energy supply security and possible CO_2 savings. Paragraph 51 adds that this wish of some member states to extend state aid also to other types of low carbon energy generation, justifies a in depth discussion.

state loan guarantees is a key advantage for the construction company. Ultimately this means, that the ***financial risk is shifted to the tax payers*** (Schneider et al. 2011).

The loans for the Finnish NPP ***Olkiluoto***, currently under construction, were partly covered by such state credit guarantees provided by the French and Swedish government, leading to very low credit interest rates (2.6%). This loan guarantee was called unfair state aid – the European Commission however did not support this claim, because the borrower had paid a fee for the loan guarantee. The actual amount of this fee was not made public – therefore it is not possible to determine, whether this fee was so high as to reflect the state´s taking over the credit risk. The lack of transparency concerning the sum of this fee however raises doubts (Schneider et al. 2011).

3.3.3 Tax Reliefs

Another option to grant state aid to nuclear power are tax reliefs. In 2003 for example in the U.S. the suggestion was made to give a tax relief to nuclear power of ***18 US$/MWh*** (0.018 US$/kWh) to make the electricity generated by new NPP competitive with electricity generated from other energy sources (Böll 2010, S. 95).

The effort undertaken until now to initiative nuclear new build in the U.S. carried very little fruit until now: In 2015 over 40% of reactors will have been in operation over 40 years and therefore exceeded their originally planned life time (Schneider et al. 2012). In 2012 only three reactors were under construction – by far not sufficient to equal out upcoming shut-downs. [16] As a cheaper alternative to new build a majority of reactors will undergo life time extension to reach 60 years of operation – the life time extension´s impact on safety is controversial.

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[16] http://www.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=US, accessed: 1 July 2013

4 Costs of Beyond Design Basis Accidents and How They are Covered by Nuclear Liability

The largest accidents of nuclear power plants until now took place in Chernobyl (Ukraine) in 1986 and in Fukushima (Japan) in 2011. Those two Beyond Design Basis Accidents (BDBA) cause a major release of radioactivity from the destroyed reactors and a long-term damage to people and nature and thereby also to the economy and the political system.

This Chapter first describes the potential amount of cost of such severe accidents (BDBA). In the next step those costs will be compared to the currently applied liability sums for the nuclear operators to examine, to which extent they could cover maximum damage.

4.1 Costs of Severe Accidents (BDBA)

4.1.1 Chernobyl

The severe accident at Chernobyl 1986 affected approximately 9 million people of those were 3 million children. The value of human life and the suffering caused cannot be offset with money – the monetary assessment is therefore difficult. The following overview of in part monetarily expressed long-term consequences however gives an impression of how far-reaching the impacts of severe accidents can be.

Ukraine and Belorussia, both back then still belonged to the Soviet Union, had to establish special ministries to manage the disaster. According to WHO[17] data, both states and Russia lost 17843.2 km^2 of their agricultural land and 6942 km^2 of forests with economic use. Agricultural and processing companies as well as factories, whose resources (wood, minerals etc.) had been contaminated needed to be closed down.

The Chernobyl Forum, an initiative of international organizations[18] and of the three mainly affected states Belorussia, Ukraine and Russia devoted one chapter of its final report to the socio-economic consequences (Chernobyl Forum 2006). The range of costs which had occurred in total for two decades **were estimated to one hundred billion US$, for 30 years for Belorussia alone 235 billion US$**[19]. More precise estimates are not possible, because the Chernobyl accident accelerated the break-up of the then Soviet Union, its consequences being years of insecurity and new orientation of the economic and financial system.

Hundred thousands of people needed to re-settle from the contaminated areas, ten thousands of houses and apartments had to be newly build, moreover schools for the children and other infrastructure. For treatment of affected people hundreds of hospitals and outpatient clinics had to be constructed and drugs made available on a long-term basis. This was not possible without

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[17] http://www.who.int/mediacentre/news/releases/2005/pr38/en/index1.html, accessed: 15 April 2013

[18] IAEO, WHO, UNDP, FAO, UNEP, UN-OCHA, UNSCEAR; World Bank Group

[19] For comparison: The current Austrian budget is ca. 73 billion euro = ca. 96 billion US$ (exchange rate April 2013). Belorussia has an area of 207.600 km^2, this is 2,5 times the area of Austria, while the population of 9,5 million is only about 10% higher than in Austria.

international help. e. g. the thyroid centre of the the German radiobiologist Edmund Lengfelder´s Otto Hug Radiation Institute which was opened in Gomel/Belorussia in 1993.[20]

In large parts of the country the demographic situation shifted, young people and children were resettled or migrated, the birth rate sank and mainly old people were left over. This also reduced the workforce and poverty in the affected regions, mainly rural areas, grew steadily.

In the first years after the catastrophe, Belorussia had to spend up to 20% of its annual budget for the minimization of the consequences. The damages in Ukraine and Russia are slightly smaller, because – compared to Belorussia – smaller regions are affected. In 2006, ***i.e. 20 years after the catastrophe, Ukraine still had to dedicate up to 7% of the annual budget for the consequences.*** A large part of the budget needed yearly goes to social support for over seven million people who are affected in the three states (Chernobyl Forum 2006).

4.1.2 Fukushima-Dai-ichi

25 years after the disaster in Chernobyl another accident with large releases occurred: In March 2011, in the Japanese NPP Fukushima-Dai-ichi multiple problems including core melt-down and the release of radioactivity followed a heavy earthquake and a tsunami.

The accident pointed out drastically, that severe accident can occur anytime: When NPP operators state the accident probability being 10^{-6}, it certainly does not mean, that only once in a million years a severe accidents really can take place – the relevant probabilistic value is only an indicator to enable a comparison of the different plants. In addition the probabilistic calculations contain many defects; many factors cannot be taken into account for these calculations, too high the insecurity of the figures taken into account. Severe accidents can never be completely excluded and can occur also at modern reactors. In the following a short overview of consequences of accidents and some early cost estimates will be provided:

From the area surrounding the multiply destroyed NPP (800 km^2 of the „exclusion zone“) about 160,000 people were evacuated, appr. 50,000 more left their homes voluntarily. (Greenpeace 2012, 2013). It is not clear yet, how many of them will be able to return. The costs of buying up of the abandoned land, compensation for the affected people (over 10 years) and the decommissioning of the reactors [21]is supposed to cost between **71 and 250 billion US$** (JCER 2011a). The compensation costs offered be the mean while nationalized operator TEPCO however are far from sufficient according to Greenpeace report (Greenpeace 2012, 2013). Payments for farms and fishing industry are not included. Some of the affected people filed law-suits, their outcome still open. McNeill (Greenpeace 2012, p. 32) bases his cost estimates also on the data provided by the Japan Center for Economic Research (JCER 2011b, p. 3). This source shows a figure on the annual average costs for decommissioning, compensation and recovery of all areas with a level of contamination leading to a dose of over 1 mSv/a in a diagram. McNeill based a calculation of total costs on it resulting in ***520-650 billion US$*** (40-50 trillion yen).

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[20] http://www.ohsi.de/hilfsmassnahmen-in-belarus/diagnostik-therapie/, accessed: 16 April 2013

[21] based on costs of decommissioning the accident reactors in Chernobyl/Ukraine and Three Mile Island/U.S.

4.1.3 France

The French Institute for Radiation Protection and Nuclear Safety IRSN (Institut de Radioprotection et de Sûreté Nucléaire) calculated in several studies the costs, which **France** would have to face in case of a severe or very severe nuclear accident. On its website IRSN published the study which makes estimates on two accidents of differing severity in a French NPP (IRSN 2012). There IRSN listed the following areas, which are relevant for the overall costs:

1. Those costs contain all clean-up costs at the NPP site like decontamination and decommissioning of the plant, but also replacement capacity the electricity, which the plant cannot produce any more.
2. Off-site costs for radiological matters: IRSN includes the costs for emergency measures (e.g. evacuation), health costs, costs for the psychological treatment including the costs for days of sick leave and losses in agricultural production.
3. Image costs: They include consequences like crisis in sales of „clean" products due to a lack of consumer confidence (in particular French wine was mentioned), reduced tourism, reduced export rates.
4. Energy generation costs: This is where assumptions are made, how an accident would impact the future of the nuclear plant fleet in France, e.g. a reduction of reactor operation times.
5. Costs due to contaminated areas (exclusion zones and other areas): These are the costs for people who had to be re-settled and the costs for the zones themselves.
6. Additional follow-up costs like impacts on the national debt level, the stock prices, foreign investments etc. could also occur. The calculations however were not designed to take those into account.

As a beginning a severe accident (INES Level 6[22]) was assumed, based on a meltdown, which however can be controlled more or less. The accident was called "representative"; probably supposed to mean that for the source term and weather conditions no extreme values were assumed. Therefore this is not a Worst Case Scenario. The number of people in need of re-settlement was given with 3,500 people. The authors mention a range of -55% to +100% for a „better" or "worse" case.

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[22] The IAEA INES Scale (International Nuclear Event Scale) has 7 levels, level 7 being a Major Accident. From Level 4 onwards it is not an „incident" anymore, but an „accident", at this level radioactivity is being released also outside the facility.

The occurring costs are the following:

Table 2: Costs of representative accident in France INES 6 (IRSN 2012)

	Billion Euro	Billion US$[23]	Percentage
On-Site Costs	6	8	5%
Off-site Costs	9	13	8%
Image Costs	47	63	40%
Costs of Energy Generation	44	58	37%
Costs due to contaminated areas	11	16	10%
Total Costs	**120**	**158**	**100%**
Range of Total Costs	**50-240**	**66-320**	

For a catastrophic accident (INES Level 7) as it has taken place in Chernobyl or Fukushima, the following costs are estimated. Around 100,000 people are assumed to be in need for re-settlement.

Table 3: Costs of a Large Representative Accident in France INES 7 (IRSN 2012)

	Billion Euro	Billion US$[24]	Percentage
On-Site Costs	8	11	2%
Off-site Costs	53	68	12%
Image Costs	166	221	39%
Costs of Energy Generation	90	119	21%
Costs due to contaminated areas	110	147	26%
Total Costs	**427**	**566**	**100%**
Range of Total Costs	**172-946**	**226-1.242**	

Here, too, the authors offer a range of -60% to +120% of the result. At the upper limit of the range they assume that massive contamination might have affected large urban areas.

After the study was presented to the public in February 2013 and received major media responses, a second IRSN study came to light which had presumably been written in 2007. The French newspaper *Le Journal de Dimanche* published an article on this second study on March 10, 2013. [25] The author of this second study is the same as in the study presented above: Patrick Momal. The 2007 study, which, however, is not accessible, is based on much more catastrophic scenarios. It estimates that 5 million people will have to be evacuated from an area of 87,000 km^2 (for comparison: Austria´s has a territory of 83,855 km^2). 90 million people would be living in an area of 850,000 km^2 contaminated with Cesium-137 (no further details provided on the level of contamination). The scenario uses a weather situation which would result in consequences for Paris. The overall costs which would be incurred reach to **€ 760-5,800 billion (US$ 998-7,615 billion).** The current French budget is € 2,000 billion (US$ 2,600 billion), the follow-up costs would be almost three-fold.

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[23] Exchange rate of 17 April 2013

[24] Exchange rate of 17 April 2013

[25] http://www.lejdd.fr/Economie/Actualite/Exclusif-JDD-le-scenario-noir-du-nucleaire-595593, accessed 17 April 2013

4.1.4 Conclusions

Several different studies have calculated the costs of a major Beyond Design Basis Accident in the range of ***US$* 71 and *5,800 billion.*** This wide range shows how difficult it is to assess the actual costs of such an accident. What does appear certain is that a catastrophic ***accident generates costs*** in the range of ***100's if not 1000's of billions***.

The following factors pose limitations on the considered accidents: 1) the published figures on the Chernobyl accident are questionable because the period following the accident at Chernobyl was impacted by the economic and political break-down in the former Soviet Republic, plus a policy of secrecy and the wish to cover-up the consequences. 2) The Fukushima accident was relatively recent, making it impossible to estimate the costs in necessary detail. 3) The French studies showed how different accident scenarios can have a huge impact on the costs. The worst case scenario in the IRSN studies, which obviously includes a massive contamination of Paris, is very interesting. According to the online tool flexRISK[26], some scenarios show that radioactive emissions from the NPP Dampierre are transferred to Paris. The assumed costs of up to US$ 5,800 billion for this type of accident would by far exceed the several hundred billion US$ reported as the follow-up costs for Chernobyl.

The scenarios used for calculating the consequences of accidents contain a large number of parameters which have an impact on the result. It makes an enormous difference if the complete inventory or only a fraction of the radioactive inventory is released, whether the release lasts hours, days or weeks, and how the weather situation contributes to blowing away or raining down the radioactive particles. The regions impacted can vary greatly in terms of population density and socio-economic structure.

The next logical thought is that someone has to pay for such an accident. Therefore the funds available to cover nuclear liability should be checked to see to what extent they can cover a maximum damage. The low probability of such an accident is not a sufficient argument because, as we saw in Chernobyl and Fukushima, such accidents do occur. The next part of this chapter will examine the question of liability.

4.2 Liability for Nuclear Accidents – Which Costs are Covered and Who Pays?

4.2.1 Current Liability Regimes

Since the 1960s, international agreements have been in place to regulate the question of nuclear liability. The insurance industry has suggested these regimes, in order to achieve better regulation for damages of international dimensions (Schärf 2008). The liability was to be geared towards the operator/owner of a nuclear facility, which provides relief for the suppliers and therefore as a certain level of security for the nuclear industry. Damage to persons, loss of property and financial losses need to be compensated for (Kerschner/Leidenmühler 2012).

All those conventions have in common the definition of damage for which liability is provided, the regulation of who compensates damages, that liability applies also without fault and which courts are competent (Greenpeace 2013, WNA 2013).

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[26] http://flexrisk.boku.ac.at

In 1960, and mainly for the OECD countries, the first agreement, the ***Paris Convention on Nuclear Third Party Liability,*** was concluded**.** The Paris Convention was supplemented in 1963 by the ***Brussels Supplementary Convention*** which was updated in 1982. The ***Protocol to Amend the Brussels Convention Supplementary of 2004*** is not yet in force. According to the Paris Convention, a Paris Convention member state is not liable for an accident which takes place on the territory of a non-convention state, however, other agreements can be made at national level. The Brussels Supplementary Protocol ensures that additional compensation is made from national and international funds, where compensation from the Paris Compensation is insufficient (Schärf 2008).

The ***Vienna Convention on Civil Liability for Nuclear Damage*** was agreed in 1963, revised in 1997, and is open to all states. The ***Protocol to Amend the 1963 Vienna Convention on Civil Liability for Nuclear Damage*** raised the liability limits in 1997.

The ***Protocol Relating to the Application of the Vienna Convention and the Paris Convention - Joint Protocol*** linked these two conventions (agreed in 1988 and entered into force in 1992).

Another agreement, the ***Convention on Supplementary Compensation*** of 1997 is not yet in force.

The following table shows which states have ratified the individual agreements or which they have signed up[27] to, i.e. where the Conventions are already legally valid.

Table 4: Member States to those Conventions which are currently in force (Paris and Vienna Conventions, Brussels Supplementary Protocol and Joint Protocol) (NEA[28], IAEA[29,30], Greenpeace 2013, WNA 2013)

State	Paris Convention 1960	Brussels Supplementary Protocol 1982	Vienna Convention 1963	Protocol on the Vienna Convention 1997	Joint Protocol 1988
Argentina			YES	YES	
Armenia			YES		
Belgium	YES	YES			
Bolivia			YES		
Bosnia and Herzegovina			YES	YES	
Brazil			YES		
Bulgaria			YES		YES
Cameroon			YES		YES
Chile			YES		YES
Croatia			YES		YES
Cuba			YES		
Denmark	YES	YES			YES

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[27] The signing of an agreement only declares that a state is interested. Only ratification makes it legally valid. The agreement enters into force after it has been ratified by a certain number of states.

[28] http://www.oecd-nea.org/law/paris-convention-ratification.html, accessed 18.4.2013)

[29] http://www.iaea.org/Publications/Documents/Conventions/liability_status.pdf#page=1&zoom=auto,0,849, accessed 18.4.2013

[30] http://www.iaea.org/Publications/Documents/Conventions/protamend_status.pdf, accessed 18.4.2013

State	Paris Convention 1960	Brussels Supplementary Protocol 1982	Vienna Convention 1963	Protocol on the Vienna Convention 1997	Joint Protocol 1988
Egypt			YES		YES
Estonia			YES		YES
Finland	YES	YES			YES
France	YES	YES			
Germany	YES	YES			YES
Greece	YES	YES			YES
Italy	YES	YES			YES
Kazakhstan			YES	YES	
Latvia			YES	YES	YES
Lebanon			YES		
Lithuania			YES		YES
Macedonia			YES		
Morocco			YES	YES	
Mexico			YES		
Moldavia			YES		
Montenegro			YES	YES	
Netherlands	YES	YES			YES
Niger			YES		
Nigeria			YES		
UK	YES	YES			
Belorussia			YES	YES	
Czech Republic			YES		YES
Hungary			YES		YES
Norway	YES	YES			YES
Peru			YES		
Philippines			YES		
Poland			YES	YES	YES
Portugal	YES	YES			
Romania			YES	YES	YES
Russia			YES		
Saudi Arabia			YES	YES	
Senegal			YES		
Serbia			YES		
Slovakia			YES		YES
Slovenia	YES	YES			YES
Spain	YES	YES			
Saint Vincent and the Grenadines			YES		YES
Sweden	YES	YES			YES
Switzerland*					

State	Paris Convention 1960	Brussels Supplementary Protocol 1982	Vienna Convention 1963	Protocol on the Vienna Convention 1997	Joint Protocol 1988
Trinidad and Tobago			YES		
Turkey	YES	YES			YES
Ukraine			YES		YES
United Arab Emirates			YES	YES	YES
Uruguay			YES		YES

* Switzerland will ratify the Paris Convention only when the Supplementary Protocol of 2004 has entered into force.

This table shows that important nuclear states such as the US, Canada, China, India, Japan etc. have not signed any of these agreements. Overall, liability for half of the world's nuclear power plant fleet is not subject to the regulation of one of the conventions (WNA 2013). Many states, however, have their own regulations for dealing with questions of liability, whether they have ratified one of the Conventions or not.

4.2.2 Current Liability Limits of Different Liability Regimes

The following table contains an overview of the minimum and maximum liability limits as defined by the international conventions. Responsibility for the actual details lies with the contracting countries to the conventions.

Table 5: Overview of the lower and higher liability limits of international conventions currently in force (WNA 2013)

	Liability for operator and state		Collective Liability for all parties to the Convention		Limit	
	In million U.S.$					
	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Paris Convention 1960	7.5	22.5			7.5	22.5
Brussels Supplementary Protocol 1963	7.5	105		75	7.5	180
Vienna Convention 1963	5	open			5	open
Brussels Supplementary Protocol 1982	7.5	262.5		187.5	7.5	450
Protocol of the Vienna Convention 1997	450	open			450	open

General note: Some conventions do not set a maximum amount. However, in Europe it is only Germany, Switzerland and Austria which have introduced unlimited operator liability for nuclear damage. All the other states have national legislation limiting liability (NEA 2011).

The ***Vienna Convention*** does not stipulate a maximum limit for liability however, this can be settled at national level. The lower limit is US$ 5 billion.

The ***Paris Convention*** limits liability to a maximum of SDR 15 million, and a minimum of SDR 5 million[31].

The 1963 ***Brussels supplementary convention*** created a system of three tiers: Firstly, parties of the Brussels convention must also be party to the Paris convention which provides for the first tier of funds via the nuclear operator's liability. Tier two requires the state to pay the difference between the operator's liability (which is set under national law) and SDR 70 million (US$ 105 million). Tier three calls upon all parties to the convention to provide up to SDR 50 million (US$ 75 million). The maximum total amount available for compensation of the 1963 convention is therefore SDR 120 million (US$ 180 million).

Under the 1982 ***amendment to the Brussels Supplementary*** Protocol, the liability limits were revised as follows: the second tier of finance (made available by the country in which the accident occurs) was raised to the difference between the operator's liability and SDR 175 million, while the third tier called upon all contracting countries to contribute up to SDR 125 million so that the total amount currently available is SDR 300 million (US$ 450 million).

The ***Joint Protocol*** relating to the application of both the Vienna Convention and the Paris Convention was negotiated and came into force after the Chernobyl accident. It introduced the regulation that all countries that are party to one of the conventions are also treated as being party to the other convention. Thus if an accident occurs in a country of the Paris Convention, and affecting a country of the Vienna Convention, then the victims are compensated according to the Paris Convention and vice versa.

The 1997 Protocol to the Vienna Convention significantly raised the lower liability limit: Minimum liability now amounts to SDR 300 million (US$ 450 million). However many parties to the Vienna Convention have not yet ratified the Protocol to date.

In ***2004*** another ***Protocol to Amend the Paris Convention*** was adopted, but it is not yet in force as it has not been ratified by a sufficient number of parties. This Protocol will again raise the liability limits; to US$ 916 million for operators, to US$ 654 million for states, and to US$ 392 million for all parties - in total US$ 1.96 billion. In addition, states who do not wish to have maximum limits for the operator´s liability can also become party.

The ***Convention on Supplementary Compensation for Nuclear Damage***, which is also not in force, introduces an additional form of collective liability for states, of SDR 300 per installed 1 MW thermal nuclear capacity.

Since 1957, the ***U.S.*** has had the ***Price Anderson Act*** in place to regulate nuclear liability; US$ 12.5 billion is assigned. The operators are thereby obliged to cover each site with US$ 375 million which is

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[31] SDR (Special Drawing Rights) - SDR is an artificial currency used by the International Monetary Fund for accounting purposes. One SDR had the value of approx. US$ 1.50 as of April 18 2013. Therefore the liability limit is between US$ 7.5 and 22.5 million.

insured with a private insurer´s pool, the American Nuclear Insurers (ANI). A second tier is carried by all operators and reaches up to US$ 112 million per reactor per accident.

Like the US, Japan is not party to any convention. The nuclear liability is regulated by two national laws and contains unlimited operator´s insurance. The operators must set aside up to US$ 1.4 billion. After Fukushima, a special institution for handling the compensation payment was founded; the operator TEPCO has had to ask repeatedly for an increase of funds. Greenpeace (2013), among others, has been examining this thoroughly.

4.2.3 Current Liability Limits in Europe

What is the amount of liability each NPP operator has to make available in each country, and what funds need to be covered by other sources?

The following table provides an excerpt of the different liability limits for nuclear power plants in Europe (NEA 2011):

Table 6: Limits of Nuclear Liability in Europe, in excerpts:

Country	Operator´s Liability	Additional Compensation Provided by the State	Additional Compensation Provided by International Agreements
Belgium	€ 297.4 Million	~ € 136.2 Million (SDR 125 Million)	~ € 136.2 Million (SDR 125 Million)
Bulgaria	~ € 49.1 Million (BGN 96 Million)	-	-
Czech Republic	~ € 306.2 Million (CZK 8 billion)	-	-
Finland	unlimited for damages in Finland and € 700 Million for damages outside Finland	~ € 136.2 Million (SDR 125 Million)	~ € 136.2 Million (SDR 125 Million)
France	€ 91.5 Million	€ 99.3 Million	-
Germany	unlimited	up to € 2.5 billion	~ € 136.2 Million (SDR 125 Million)
Hungary	~ € 109 Million (SDR 100 Million)	~ € 217.9 Million (SDR 200 Million)	-
Netherlands	€ 340 Million	€ 1.93 billion.	~ € 136.2 Million (SDR 125 Million)
Romania	~ € 163.5 Million (SDR 150 Million)	~ € 163.5 Million (SDR 150 Million)	-
Slovakia	€ 75 Million	-	-
Slovenia	~ € 163.5 Million (SDR 150 Million)	~ € 27.2 Million (SDR 150 Million)	~ € 136.2 Million (SDR 125 Million)

Spain	€ 700 Million + € 700 for environmental damages in Spain		~ € 136.2 Million (SDR 125 Million)
Sweden	~ € 326.9 Million (SDR 300 Million)	-	~ € 136.2 Million (SDR 125 Million)
Switzerland	unlimited	-	-
United Kingdom	~ € 156.7 Million (GBP 140 Million)	~ € 34.2 Million (SDR 31.4 Million)	~ € 136.2 Million (SDR 125 Million)

4.2.4 Conclusion 1: Massive Underinsurance

To sum up: the valid amounts for nuclear liability are way too low. A very conservative estimate of the Fukushima costs have already shown that at least US$ 71 billion in costs can be expected, however, this sum is likely to be much higher. Compared to the worst case data issued by IRSN for France, of over US$ 7,000 billion, the existing liability amounts are ridiculously low. The question arises - who is going to pay the difference?

Even where we assume nuclear liability coverage of US$ 450 million (an amount most states do not guarantee) – then compared to the accident costs outlined earlier, the following levels of coverage would result:

Table 7: Costs of Accidents Covered by the Nuclear Liability

		Costs of Accident	Assumption of liability	Coverage
Chernobyl, only Costs in Belorussia acc. to Chernobyl Forum (2006)		$ 235,000,000,000	$ 450,000,000	**0.19%**
Fukushima acc. to JCER (2011a)	from	$ 71,000,000,000	$ 450,000,000	**0.63%**
	to	$ 250,000,000,000	$ 450,000,000	**0.18%**
Fukushima acc. to JCER (2011b)	from	$ 520,000,000,000	$ 450,000,000	**0.09%**
	to	$ 650,000,000,000	$ 450,000,000	**0.07%**
France acc. to IRSN (2012)	from	$ 226,000,000,000	$ 450,000,000	**0.20%**
	to	$ 1,242,000,000,000	$ 450,000,000	**0.04%**
France (Scénario noir)	from	$ 460,000,000,000	$ 450,000,000	**0.10%**
	to	$ 5,800,000,000,000	$ 450,000,000	**0.008%**

For all the assumed cases, coverage is less than – in some cases way under – 1 %. In addition, unclear situations arise when it comes to asserting claims for compensation, in particular if affecting a state which is not party to any of the above convention, for example, Austria.

Moreover, legally speaking the nuclear states are walking on thin ice: as Kerschner and Leidenmühler note in their 2012 study, operators of non-nuclear power plants in Europe do not have a maximum liability limit. They regard the limited liability for nuclear power plants as set out in the international conventions as a violation of the ***Polluter Pays Principle.***

The limited liability and the states' assumption of liability lead to savings on insurance premiums for the NPP operators. This constitutes ***preferential treatment by the state*** for which the NPP operator does not deliver a sufficient service in return.

4.2.5 Conclusion 2: Impact of Full Insurance on the Electricity Price

The *Versicherungsforen Leipzig* insurance forum (Gunther et al. 2011) conducted a comprehensive study into the issue of a sufficient financial coverage of nuclear accidents.

The authors arrived at the following conclusions:

"If the costs for clean-up caused by such an occurrence of damage would have to be paid by the consumers of nuclear generated power (internalization of external effects), by spreading the costs of the insurance premium based on it over the availability period of 100 years, then the consequence would be an increase in the price of nuclear generated power (net value) for the period of ***100 years*** *in the range of* ***€ 0.139 per kWh up to € 2.36 per kWh.*** *For a period of availability of* ***10 years,*** *the range would be* ***€ 3.96 per kWh up to € 67.3 per kWh****."*

"Looking at the overview of kWh costs for the individual scenarios it becomes clear that, with regards to the situation in Germany, there is ***no possibility of fully covering the risk*** *resulting from the operation of NPP.* ***Only with an accumulation phase of 100 years*** *of a surcharge on the electricity price will a pool covering all NPP risk reach an order of magnitude which at first glance seems payable. In light of the residual lifetimes of German NPPs, and normal lifetimes of 25 to 40 years,* ***much shorter accumulation phases would have to be realized to guarantee the availability of the funds before the risk ceases to exist because of nuclear phase-out.*** However, ***no realistic financing method*** exists for this scenario. At the same time this underlines the problem of the immediately risk which is present when starting operations, and before sufficient funds are available to compensate for damages occurring when the risk materializes."

This is summarized by following conclusions:

- Even if nuclear industry would be granted the period of ***100 years*** to accumulate the funds needed in case of a possible nuclear accident, the consumer would have to pay ***extra costs*** of ***0.139 – 2.36 €/kWh.***

  For comparison: Current power generation costs are around 0.018 – 0.079 €/kWh (1.8 – 7.9 €-Cent/kWh) (Thomas et al. 2007, p. 35): Over 100 years the power generation costs than would increase to 0.157 – 2.439 €/kWh– i.e. by ***3 to 50-fold***[32]***!***

It is practically impossible to finance full insurance for a nuclear accident during the lifetime of a NPP: If appropriate funds are to be made available over a period of ***10 years***, the additional costs would amount to at ***3.96 – 67.3 €/kWh***.

In turn, the impact on power generation costs would be to increase them, to 4.1 – 67.4 €/kWh, i.e. by ***80 – 1,300-fold!***

In both scenarios nuclear power becomes completely economically unviable.

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[32] referring to average power generation costs of 0.05 €/kWh

5 Other Cost Components/Externalised Costs

5.1 External Costs of the Nuclear Fuel Chain

In order to assess the health and environmental impact of technologies it is critically important to examine their complete lifecycle. In the case of nuclear power, aspects including demand for resources and energy, waste generation and ***emissions*** into the environment must be considered not only for operating the NPP, but also for the ***complete nuclear fuel chain***, starting with uranium mining, enrichment of the fuel, and through to the decommissioning of the nuclear power plant and the final waste disposal.

This is extremely significant for nuclear power, because only a fraction of the total emissions are released during the actual operation of the NPP – the majority of the emissions are emitted during other steps in the nuclear fuel chain. Figure 8 provides an overview over:

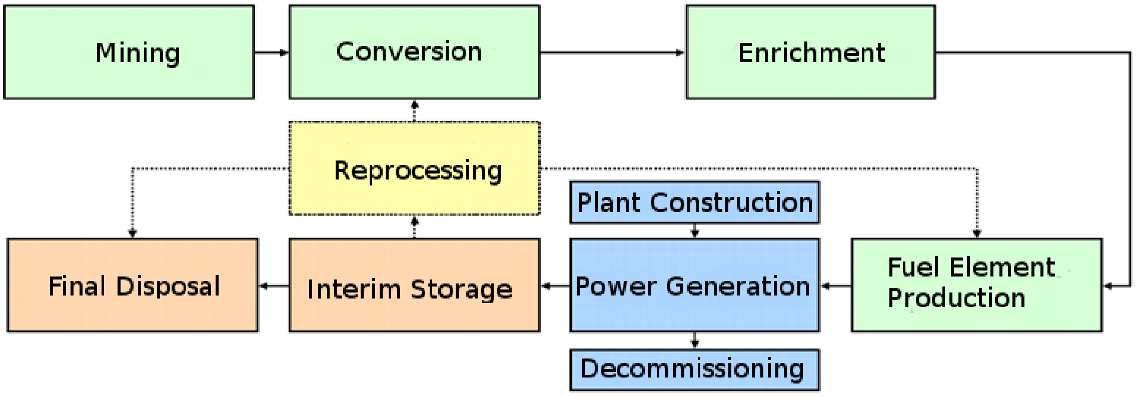


Figure 8: Nuclear Fuel Chain (Wallner et al. 2011)

Emissions are produced during all stages of the nuclear fuel chain – some radioactive – and waste is generated.

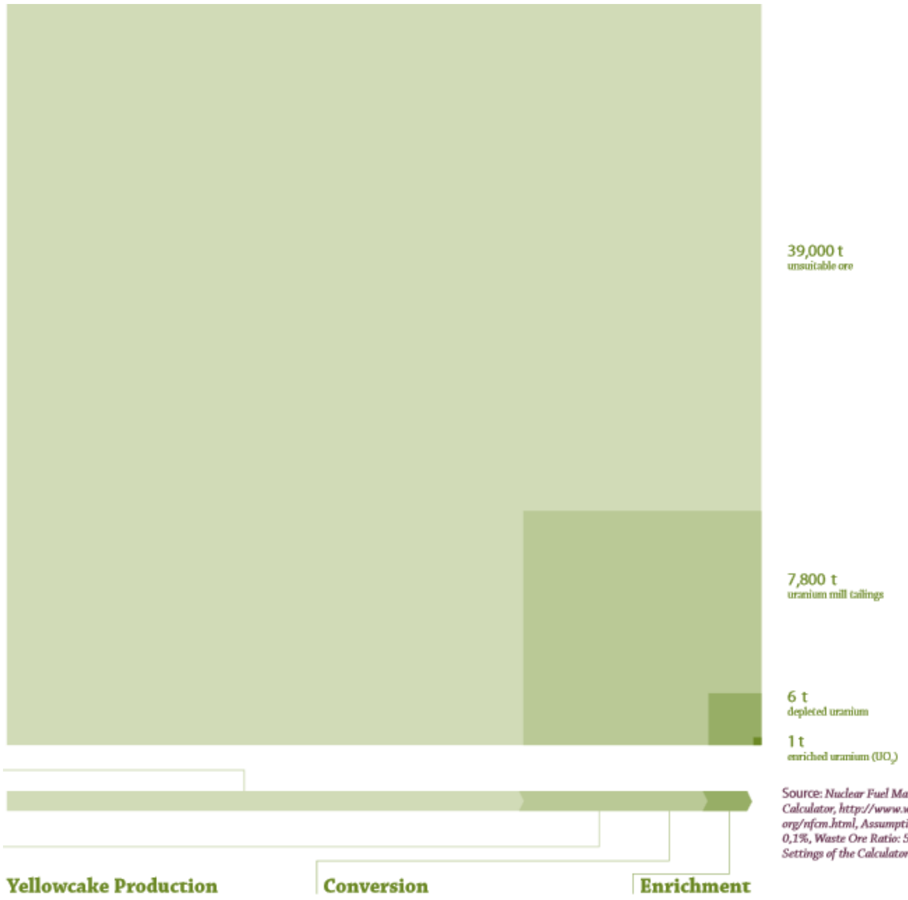
The ***impact on the environment and health*** of a large part of these emissions are not included in the total costs. However, they are borne by society, i.e. the injured party. These are the so-called "external" or "externalised" costs.

The monetization of those costs is very difficult and assessing attempts to do so, e.g. the ExternE study, is far beyond the scope of this present study. An additional problem is that, for the assessment of impacts on health and environment, some discounting is applied – making future damages to the health and environment "less expensive" than if they happened today. For example, ExternE (1995) applies a discount of 3% per year – making long-term health damages relatively cheap...

ExternE compares this with undiscounted sums: According to ExternE, undiscounted external costs account for 2.5 ECU million (mECU) per kWh = ***0.25 €-Cent/kWh*** (ExternE 1995 in NRC 2012, p. 134). However, the fact remains that costs for health and environmental damage are passed on to others.

Particularly large are the ***environmental damages and externalized costs connected with uranium mining***[33]. Uranium dust particles and the resulting decay product Radon are inhaled and can cause lung cancer. The wind blows away the fine particles, thereby affecting people living kilometres away from the mine dumps. (Wallner et al. 2011). Very often the mining takes place in countries with very low environmental and health protection standards. In Niger, for example, over the past 40 years of uranium mining 270 billion liters of water have been used and released into the surrounding bodies of water - contaminated. Mine dumps with partly radioactive rocks are used for repairing the streets and in house construction. (Greenpeace 2010)

Moreover, waste is generated along the entire fuel chain. Again in uranium mining, the waste volume and the resulting impact on health and environment is very high. The following figure provides an overview of the volume of waste generated:



Source: *Nuclear Fuel Material Balance Calculator, http://www.wise-uranium.org/nfcm.html, Assumption: Ore Grade 0,1%, Waste Ore Ratio: 5; Rest: Default Settings of the Calculator*

Figure 9: Waste Volume Generated by the Nuclear Fuel Chain (Wallner et al. 2012) – Large Square: Waste from Uranium Mining

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[33]: Examples of damages resulting from uranium mining have been published in *Uranium Mining in and for Europe*: http://www.ecology.at/files/pr801_2.pdf - commissioned by the Vienna Ombuds Office for Environmental Protection

5.2 Fuel Costs

5.2.1 Development of Nuclear Fuel Costs

The Öko-Institut (1998, p. 33) stated that the development of fuel prices has a strong influence on electricity generation costs. They are dependent on inflation and on the relationship between demand and supply on the world markets. Currently fuel costs make up 20% of the overall costs (See TABLE 1) and, together with the Operational and Maintenance costs, are the biggest variable cost components.

Among other factors, fuel supply is dependent on uranium supply. When increasing or stagnating fuel demand encounters decreasing uranium supply, this influences fuel prices. A decrease in uranium supply can have the following causes (Wallner et al. 2011):

1. Gradual depletion of uranium resources
    a. Values in literature point to a seriously limited range of uranium resources, in particular if an increase in nuclear capacity is assumed.
2. Amount of mined uranium falls below demand due to insufficient mine exploration activity
    a. e.g. due to the forecasted decrease in secondary resources, time delay during exploration of new nuclear uranium mines, or a low success ratio for mine exploration due to gradual depletion of resources.

Another factor is the decreasing ore grade of the uranium, whereby more uranium ore has to be mined in order to produce the same amount of fuel. The energy used per unit of fuel increases – of course impacting the price.

This can reach the point at which as much, or even more, energy is used in mining extremely low grade ores as is generated by the nuclear power plant itself. In this case the nuclear fuel chain would use up more energy than it produces (Wallner et al. 2011).

5.2.2 Costs of Nuclear Fuel Disposal

The disposal of radioactive waste consists of several steps, depending on the waste category: High Level Waste (HLW) (mostly spent fuel) as well as Low and Medium Level Waste require interim storage as well as a final repository.

Final repositories for highly active waste are a particularly serious issue. This is technically difficult, because safe storage needs to be guaranteed for thousands of years[34]. It is also almost impossible to make cost estimates for such long periods of time. To conduct a proper cost estimate of the cost of final repository of High Level Waste is additionally difficult because worldwide no such final repository for High Level Waste is in operation. This leads to a wide range of cost estimates for the final repository:

- According to WNA (2013b), costs of the back-end of the nuclear fuel chain are up to 10 % of the total cost per kWh
- The Swiss Nuclear Safety Authority ENSI provides absolute costs of fuel disposal according to Table 8 (ENSI 2012) for the whole nuclear disposal process (incl. costs already incurred during operation of the NPP and the post-operation phase)
    - from CHF 2,153 million for NPP Muehleberg (373 MW net) = **€ 1,763 million**

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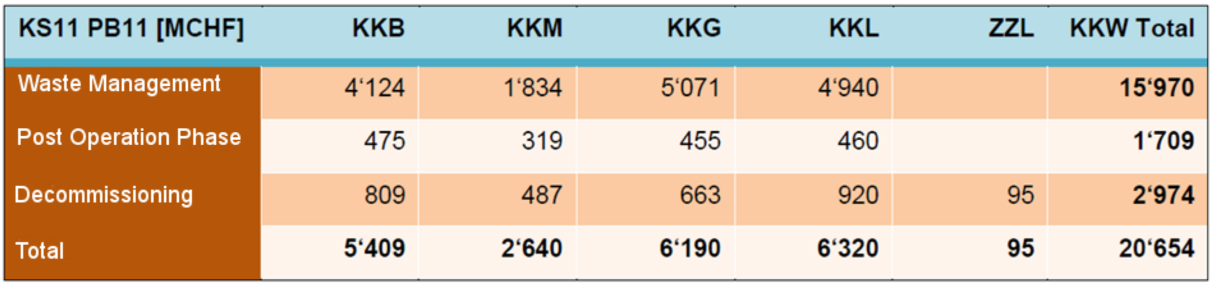
[34] Greenpeace (2013) considers the necessary storage time to be 250,000 years.

- to CHF 5,400 million for NPP Leibstadt (1190 MW net) = **€ 4,422 million**

TABLE 8: Estimate of Overall Costs in Swiss Francs by KS11, based on the Price Level of 2011 – Data in Million Swiss Francs (ENSI 2012, p. 26)



KS11 PB11 [MCHF]	KKB	KKM	KKG	KKL	ZZL	KKW Total
Waste Management	4‘124	1‘834	5‘071	4‘940		**15‘970**
Post Operation Phase	475	319	455	460		**1‘709**
Decommissioning	809	487	663	920	95	**2‘974**
Total	**5‘409**	**2‘640**	**6‘190**	**6‘320**	**95**	**20‘654**

While **Final Disposal of HLW** is a worldwide problem, current estimates of the cost of nuclear energy appear to consider that it represents a negligble share of the costs (See Figure 1).

When the economic assessment for the construction of a nuclear power plant is undertaken, compared to other cost components, the issue of final disposal of radioactive waste and the costs incurred by it are hardly taken into account.

The reason is the calculation method usually applied when taking investment decisions - the discounted cash-flow method:

Costs incurred at different points in time are calculated using the discounted cash-flow method for a set moment in time, e.g. the start-up of the NPP. This is done using “discounting”. Future costs are calculated at a lower sum, which is calculated using the annual discounting rate. This method is based on the usually reasonable assumption that current income and expenditure weigh more heavily than future ones – funds which only need to be spent in the future should (at least theoretically) have already generated interest – this interest could be used to contribute to repaying the sum. (Böll 2010, Thomas 2010)

While this is the method usually applied for investment decisions, results with discount rates over long periods need be interpreted carefully: For example, costs of €1,000 discounted over 100 years, even if the discount rate was only 3%, would have a net present value of only €52. At highly discount rates, costs or benefits more than 15 years in the future have a negligible current value in a normal economic analysis (Böll 2010, Thomas 2010).

The choice of discounting rate is essential for the calculated costs of capital, and operators of nuclear power plants usually apply higher rates than the real interest rates.[35] Using this method, the costs of final disposal can be made to look even smaller. Additionally, the assumed point in time at which the costs are to be incurred is significant. Thus the French capital value of the costs for final disposal is approximately the same as the German, although the real costs in France are around 68% higher. The reason is that the assumed payment time is set later. (Drasdo 2001, p. 20)

Because the investment for the final disposal of radioactive waste is due only many decades into the future, final disposal hardly receives any attention as a cost factor during the investment decision. The ***cash-flow discount*** method is a valid way for the investor to compare different investment options,

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[35] Real interest rates are, in this case, those interest rates which are deducted from long-term interest rates of the almost risk-free securities of the individual states

however, to call final disposal costs insignificant easily leads to wrong conclusions, and can consciously be ***used to incorrectly imply that final disposal is "cheap".***

Not only the method of calculation, but also the method of funding the disposal costs is highly speculative. The operators of the facility are obliged ***to set aside yearly provision*** for the final disposal. However, if the cash-flow discount method is used then the amount is reduced significantly due to discounting. Whether ***the costs will be covered at a future point*** in time is ***uncertain***. (Biermayr/Haas 2008, S. 34)

5.3 Decommissioning Costs

It is very difficult to estimate the costs for decommissioning (shutting-down) a nuclear power plant, because there is ***very little expertise in decommissioning large nuclear power plants available worldwide.*** However, some cost estimates assume that the decommissioning costs reach the level of the construction costs – i.e. in the range of several billion euros for a large NPP. (Schneider et al. 2011)

Here several estimates of the costs of decommissioning as quoted by different sources:

- The Swiss Nuclear Authority *Eidgenössische Nuklearsicherheitsinspektorat* ENSI gives the following costs for decommissioning in absolute terms as shown in Table 8 (ENSI 2012)
  - CHF 487 million for NPP Muehleberg (373 MW net) = **€ 399 million**
  - up to CHF 920 million for NPP Leibstadt (1190 MW net) = **€ 754 million**
- Maine Yankee, 790 MW_{el}: **US$ 616 million** in 2002 (Storm/Smith 2007, Part F, p. 49)
- Storm/Smith (2007) calculate costs of decommissioning reaching 100-400 % of construction costs (Part F, Table F.28) – based on the assumption that average construction costs of US$ 6,500 million for a 1,000 MW_{el} reactor (Storm/Smith 2007, Part F, p. 9) average costs of decommissioning of US$ 6,500 million – 26,000 million = approx. **€ 5 - € 20 billion**
- According to NEA estimates, the costs of decommissioning make up 10-15 % of the overnight capital costs
- El-Bassioni et al. (1980), whose results are the basis for EcoInvent (2009), calculate the energy used in demolishing a 1,000 MW light water reactor as ***75 % of the energy used in construction.***
  Energy usage does not enable us to directly deduce the costs, but the figures give an idea of the dimensions.

It is clearly that even cost estimates more conservative than those calculated by Storm/Smith (2007) do not regard decommissioning as a small or negligible cost factor.

In contrast however, investment calculations often regard the cost of decommissioning as an almost insignificant small cost factor (approx. 1%, See Figure 1). However, the rules for the costs of fuel disposal (Chapter 5.2.2) apply equally to the costs of decommissioning:

As the costs of decommissioning are incurred only decades after start-up, the investment costs which need to be calculated are much lower than the sum which needs to be finally paid (See Figure 1) - therefore the figures are misleading when it comes to the absolute values.

Assuming that decommissioning will have been completed 150 years after start-up, and has been discounted at 3 %, then real term overall costs of ***€ 1 billion*** will cost ***only € 12 million***. (Schneider et al. 2011)

An additional obstacle is that the real costs of decommissioning are very hard to foresee. All that is certain is that they will increase in time. At first glance, the current solution of paying into to a ***decommissioning fund*** seems to be a good one. However, the situation looks completely different when it becomes clear that the calculated payments were too low, or the fund's rate of return (interest) was lower than expected, or the operator went bankrupt before the end of the NPP's lifetime. All of these problems have occurred in the past years in the UK, and now a significant share of the decommissioning costs must be ***borne by the taxpayer***. In the end, British Energy only had to pay £20 million per year, which is only 0.03 p/kWh (according to current exchange rate 0.035 Cent/kWh) (Thomas 2005, Böll 2010).

Other states use different systems for financing decommissioning costs: Some charge annual, non-discounted instalments of the final sum, and in Sweden and Finland the full, undiscounted amount has to be guaranteed at reactor start-up. (Wuppertal 2007)

An adequate estimate of decommissioning costs and the availability of the funds needed is extremely important: the European Commission has estimated that up to 48 reactors need to be decommissioned by 2025. (Wuppertal 2007)

Sample calculation

When, in 100 years' time, the costs of decommissioning a nuclear power plant reach **€ 700,000,000,** then, if discounted at 5%[36], this gives a calculated value of **€ 5,323,143 – only 0.8% of the real sum!**[37]

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[36] Note: In Drasdo (2001, p. 26) real interest rates of 1% p.a. to 13% p.a. are used.

[37] Calculations according to: http://www.zinsen-berechnen.de/renditerechner.php and own calculations using the discounting formula:
$K_0 = K_n * (1/(1+i)^n)$ simplified calculation, not including inflation; for comparison: discounting over 50 years at 5% would mean a final value of € 61,042,609, i.e. 9% of the real value.

6 Overall Costs of Nuclear Energy

The previous chapters have discussed the individual cost components of nuclear energy, especially those that have to be covered by the operator only in part, or not at all. For comparison, this chapter presents the overall costs of nuclear energy. It explains the impact that integrating the cost components which are currently shifted onto the taxpayer would have on the operator's overall costs and on the electricity price for end consumers.

Relevant definitions of overall costs of nuclear energy are explained in Chapter 2.2.

6.1 Level of Current Electricity Generation Costs

As Chapter 3 has already described, cost calculations and cost forecasts are ***difficult to compare*** and differ significantly from one another depending on the assumptions and factors on which they are based***.*** The costs are influenced, amongst others, by the assumed interest rate, the lifetime of the NPP, and the load factor.

However, in order to convey an idea of the power generation costs, we have listed several sources of data provided by a variety of studies, without implying that the figures are directly comparable:

- Thomas et al. (2007) compared the results of ten studies on the generation costs of nuclear power, and examined why the results differed. Thomas came up with a range of study results between 18-79 €/MWh (***1.8 to 7.9 €-Cent/kWh***).
- Hiesl (2012) examined the generation costs of the Olkiluoto 3, Flamanville 3, Shin Kori 3, Sanmen 1 and Leningrad II/1 nuclear power plants, and the factors influencing these costs. He concluded that the generation costs of those plants lie between ***2.47 and 6.54 €-Cent/kWh*** , excluding external costs and nuclear accident insurance.
- According to IEA/NEA/OECD (2010), nuclear generation costs are between 29.82 and 136.5 USD/MWh = 2.92 – 13.65 US-Cent/kWh = ***3.5 – 13.4 €-Cent/kWh***[38]. These figures depend greatly on the country and the capital interest rate (See Figure 10).

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[38] Calculated with the rounded average exchange rate of 1.2 in 2010.

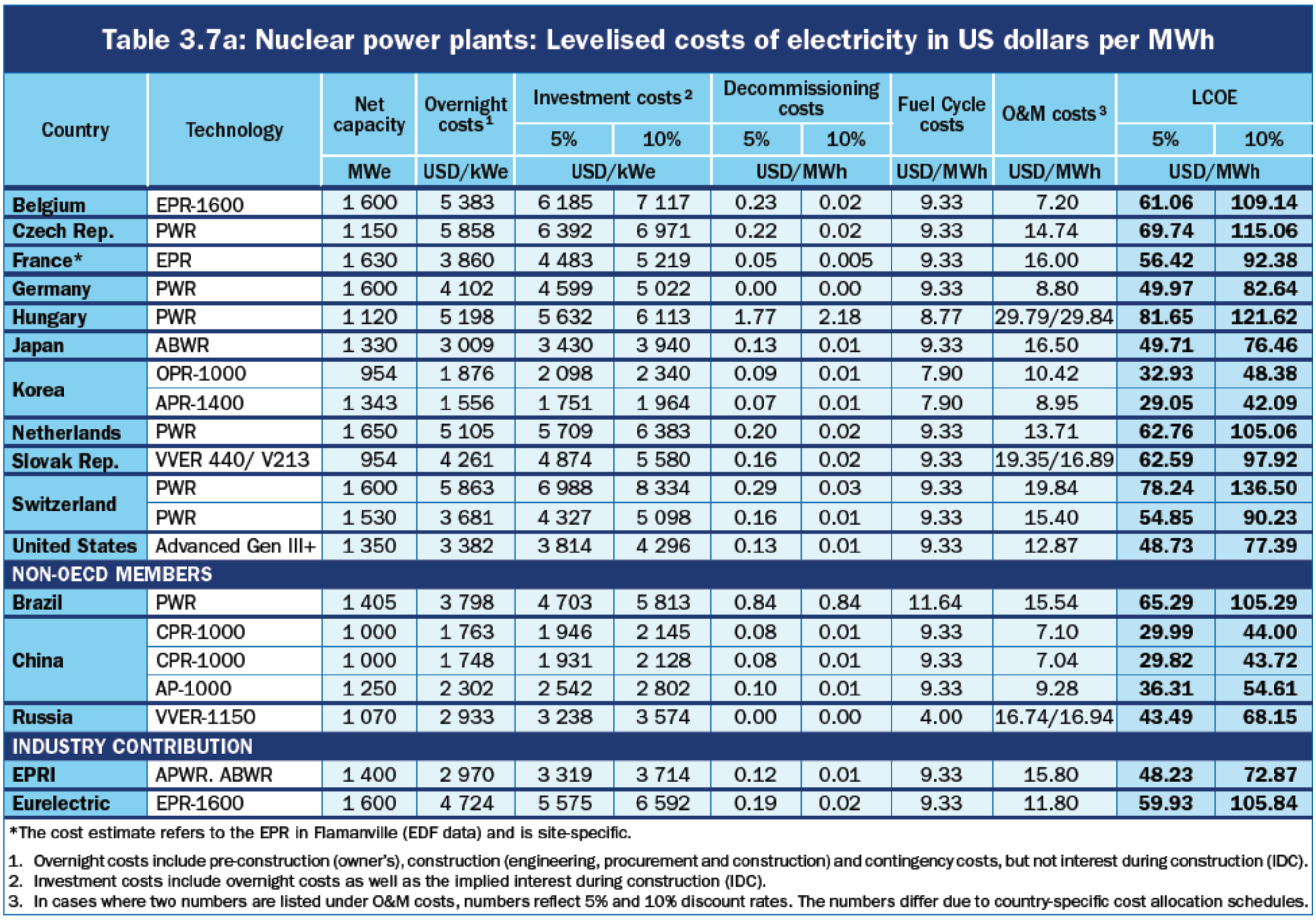

Table 3.7a: Nuclear power plants: Levelised costs of electricity in US dollars per MWh

Country	Technology	Net capacity	Overnight costs¹	Investment costs²		Decommissioning costs		Fuel Cycle costs	O&M costs³	LCOE	
				5%	10%	5%	10%			5%	10%
		MWe	USD/kWe	USD/kWe		USD/MWh		USD/MWh	USD/MWh	USD/MWh	
Belgium	EPR-1600	1 600	5 383	6 185	7 117	0.23	0.02	9.33	7.20	**61.06**	**109.14**
Czech Rep.	PWR	1 150	5 858	6 392	6 971	0.22	0.02	9.33	14.74	**69.74**	**115.06**
France*	EPR	1 630	3 860	4 483	5 219	0.05	0.005	9.33	16.00	**56.42**	**92.38**
Germany	PWR	1 600	4 102	4 599	5 022	0.00	0.00	9.33	8.80	**49.97**	**82.64**
Hungary	PWR	1 120	5 198	5 632	6 113	1.77	2.18	8.77	29.79/29.84	**81.65**	**121.62**
Japan	ABWR	1 330	3 009	3 430	3 940	0.13	0.01	9.33	16.50	**49.71**	**76.46**
Korea	OPR-1000	954	1 876	2 098	2 340	0.09	0.01	7.90	10.42	**32.93**	**48.38**
	APR-1400	1 343	1 556	1 751	1 964	0.07	0.01	7.90	8.95	**29.05**	**42.09**
Netherlands	PWR	1 650	5 105	5 709	6 383	0.20	0.02	9.33	13.71	**62.76**	**105.06**
Slovak Rep.	VVER 440/ V213	954	4 261	4 874	5 580	0.16	0.02	9.33	19.35/16.89	**62.59**	**97.92**
Switzerland	PWR	1 600	5 863	6 988	8 334	0.29	0.03	9.33	19.84	**78.24**	**136.50**
	PWR	1 530	3 681	4 327	5 098	0.16	0.01	9.33	15.40	**54.85**	**90.23**
United States	Advanced Gen III+	1 350	3 382	3 814	4 296	0.13	0.01	9.33	12.87	**48.73**	**77.39**
NON-OECD MEMBERS											
Brazil	PWR	1 405	3 798	4 703	5 813	0.84	0.84	11.64	15.54	**65.29**	**105.29**
China	CPR-1000	1 000	1 763	1 946	2 145	0.08	0.01	9.33	7.10	**29.99**	**44.00**
	CPR-1000	1 000	1 748	1 931	2 128	0.08	0.01	9.33	7.04	**29.82**	**43.72**
	AP-1000	1 250	2 302	2 542	2 802	0.10	0.01	9.33	9.28	**36.31**	**54.61**
Russia	VVER-1150	1 070	2 933	3 238	3 574	0.00	0.00	4.00	16.74/16.94	**43.49**	**68.15**
INDUSTRY CONTRIBUTION											
EPRI	APWR. ABWR	1 400	2 970	3 319	3 714	0.12	0.01	9.33	15.80	**48.23**	**72.87**
Eurelectric	EPR-1600	1 600	4 724	5 575	6 592	0.19	0.02	9.33	11.80	**59.93**	**105.84**

*The cost estimate refers to the EPR in Flamanville (EDF data) and is site-specific.

1. Overnight costs include pre-construction (owner's), construction (engineering, procurement and construction) and contingency costs, but not interest during construction (IDC).
2. Investment costs include overnight costs as well as the implied interest during construction (IDC).
3. In cases where two numbers are listed under O&M costs, numbers reflect 5% and 10% discount rates. The numbers differ due to country-specific cost allocation schedules.

Figure 10: Electricity Generation Costs of NPP in Different Countries (IEA/NEA/OECD 2010)

6.2 Conclusions: True Costs of Nuclear Power

6.2.1 Impact of Construction Costs

Du/Parsons (2009) (Update of MIT 2003) calculated the average ***electricity generation*** (LCOE[39]) ***costs*** with a focus on the ***increase in construction costs:*** The authors reached the result of 8.4 US-Cent/kWh (in 2007 US$) = approx. ***11.8 €-Cent/kWh***[40] (0.118 €/kWh).[41]

Compared to the MIT (2003) LCOE results of 6.7 US-Cent/kWh, the ***LCOE increased by 25 % between 2003 and 2009.*** New build projects including the NPP in Olkiluoto, Finland confirm this trend of increasing construction costs.

Considering this rapid increase in construction costs, and their impact on the overall cost of nuclear energy, it is not surprising that nuclear investors are trying to secure state subsidies, in the form of

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[39] Definition of LCOE in MIT (2003): "The levelized cost is the constant, real wholesale price of electricity that meets a private investor's financing cost, debt repayment, income tax, and associated cash flow constraints."

[40] Du/Parsons (2009) used an exchange rate of 1.4 for €/US-$

[41] Assumptions: 1,000 MW NPP, capacity factor of 85%, lifetime of 40 years. Construction costs (overnight costs) of US$ 4,000 million, US$ 700 million for decommissioning, inflation rate of 3%, increase in fuel costs of 0.5%, increase in operation and maintenance costs without fuel: 1%, 10% WACC (weighted capital costs – equity and debt capital), tax rate: 37%

long-term, guaranteed feed-in prices, as in the UK (See Chapter 3.3. Benefits for NPP New-Build), as these investments would not otherwise be lucrative.

The nuclear electricity generation cost of 11.8 €-Cent/kWh includes only increased construction costs – other subsidies to nuclear power are not taken into account. However, other forms of energy production deliver better results:

- Onshore wind power plants have better electricity generation costs than nuclear power (6-8 €-Cent/kWh vs. 11.8 €-Cent/kWh) (Fraunhofer 2012). This does not take into account the prices increases for nuclear energy between 2009 and 2012.
- The MIT study concludes that the LCOE of coal (6.2 US-Cent/kWh, 8.7 €-Cent/kWh) and gas (6.5 US-Cent/kWh, 9.1 €-Cent/kWh) have lower costs than nuclear energy (8.4 US-Cent/kWh, 11.8 €-Cent/kWh) (MIT 2009)

6.2.2 Impact of Full Insurance for Nuclear

As described in Chapter 4.2.5, a comprehensive study by the *Versicherungsforen Leipzig* (Gunther et al. 2011) into sufficient financial insurance for nuclear accidents concludes that it is not possible to finance full insurance for nuclear: this would incur additional costs of 0.139 – 2.36 €/kWh over an accumulation period of 100 years. For an accumulation period of only 10 years, these additional costs would rise to 3.96 – 67.3 €/kWh. The ***current*** electricity generating costs are around ***0.018 – 0.079 €/kWh*** (1.8 – 7.9 €-Cent/kWh) (Thomas et al. 2007, p. 35):

If these amounts are added to the electricity generating costs of ***0.118 €/kWh*** *(11.8 €-cent/kWh, 118 €/MWh),* as calculated by MIT (2009), and which already account for increasing building costs, then the following applies (see Table 9 and Figure 11).

Table 9: Level of Electricity Generation Costs with different assumptions

	Electricity Generation Costs [€/kWh]	**Source**
Range of construction costs until today	0.018 – 0.079	Thomas et al. (2007)
incl. increase in new build costs	0.118	MIT (2009)
Additional costs due to insurance – lowest value of the range of results for 100 years of accumulation phase: + 0.139 €/kWh	0.26	Gunther et al. (2011)
Additional costs due to insurance – highest value of the range of results for 100 years of accumulation phase: + 2.36 €/kWh	2.48	Gunther et al. (2011)
Additional costs due to insurance – lowest value of the range of results for 10 years of accumulation phase: +3.96 €/kWh	4.08	Gunther et al. (2011)
Additional costs due to insurance – highest value of the range of results for 10 years of accumulation phase: + 67.3 €/kWh	67.4	Gunther et al. (2011)

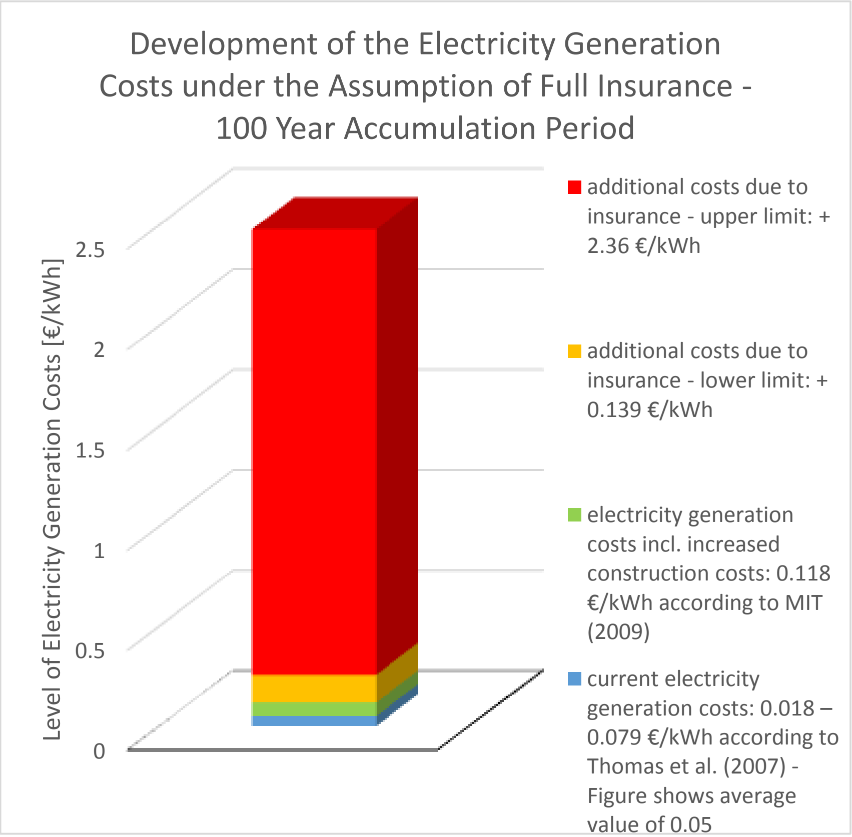

Figure 11: Development of the Electricity Generation Costs under the Assumption of Full Insurance – 100 Year Accumulation Period

6.2.3 Impact of other Factors

In addition to liability and an increase in construction costs, there are more factors which would cause an increase in the electricity price if they were taken into account. For example, the external costs of the nuclear fuel chain are significant:

- **External Costs of the Nuclear Fuel Chain** (See Chapter 5.1)
  Average electricity generation costs of 5 €-Cent/kWh would increase by 0.25 €-Cent/kWh, i.e. 5% according to the ExternE results. However, it seems doubtful that these 5 % of additional costs can actually cover the damages to environment and health which are caused by uranium mining and the storage of High Level Waste, for example.

Other factors not included in the price of nuclear electricity:

- **Too low reserves for decommissioning and final disposal** (See Chapter 5.2.2 and Chapter 5.3)
- **Nuclear energy research (EURATOM)**
- **Institutional framework of nuclear power use (IAEA, state nuclear authorities...)**

6.2.4 Comparison with Electricity Prices/ Electricity Prices Increase

The electricity price is the price the end customers pay for their electricity. The end customer´s electricity price is composed of the price of electricity generation, net usage charges, and taxes.

Compared to other countries, current net ***household electricity prices*** in Austria of ***14.3 €-Cent/kWh*** are in the middle range. The tax burden of 5.5 €-Cent/kWh, however, is above average. The electricity price charged to average ***industrial companies is 9.1 €-Cent/kWh***. [42]

Compared to a price of ***11.8 €-Cent/kWh*** as calculated in MIT (2009), and which already includes the ***increased construction costs*** of nuclear energy, it is clear that with such high construction costs, the cost price for NPP operators is already higher than the price at which electricity is supplied to industry. The current costs for households are only 17% higher than the NPP operators´ cost price.

Figure 11 and the sample calculation demonstrate the consequences of integrating the costs of full insurance into the electricity price:

Sample calculation:

The Mayer family live in a three-person household and consume 4,000 kWh (4 MWh) of electricity each year. They currently pay € 700 per year for electricity, including fixed costs. They pay variable costs of 14.3 cent/kWh.

10% of the electricity delivered to the Mayer family is generated by nuclear power.

Full insurance for nuclear energy would increase the per kWh costs by anything from 13.9 cent/kWh to 6,730 cent/kWh. As a result, the 400 kWh nuclear electricity used by this family would cause their annual electricity bill to increase by anywhere from € 56 (+8%) to € 26,920 (+3845%!).

However, where this increase is only 8%, then only after 100 years would sufficient funds have accumulated to actually cover citizens in the event of an accident – the Mayer family would benefit very little from their additional payments.

6.2.5 Conclusions

New nuclear power plants can only be realized with the help of state benefits – in addition to the wide range of benefits and special regulations which nuclear power already enjoys. Moreover, even the latest reactor technologies cannot exclude the possibility of a severe accident. Full insurance for severe accidents (Beyond Design Basis Accidents) would drive the electricity price to absurd heights, and therefore the environmental and health damages caused by accidents and the nuclear fuel chain will continue to be paid for by society into the future. The taxpayer is also required to pay for the state benefits enjoyed by nuclear power.

Thus investments in new nuclear power plants, and in nuclear power in general, are neither economically nor socially justifiable. Investments into a sustainable energy future make better economic sense.

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[42] http://oesterreichsenergie.at/daten-fakten/statistik/Strompreis.html, accessed: 24 June 2013

7 Glossary

Billion: 10E9 = 1,000,000,000

Decommissioning: Demolition of shut-down nuclear power plants and other nuclear facilities

FAO: Food and Agriculture Organization of the UN

IAEO, IAEA: International Atomic Energy Agency IAEA of the UN

Generating costs: Electricity Generating Costs are the costs incurred for transforming energy into electricity. Usually they are given in € per MWh. Possible calculation method: Operator´s total annual operational costs compared to annual amount of electricity produced (e.g. in MW).

Levelized Energy Costs, Levelized Cost of Electricity
To compare the generation costs between different power plants, it is useful to calculate the average generation costs for the complete operational life time of a power plant: the ÖkoInstitut (1998) describes the following calculation method for average electricity generation costs, and helps understand this term better:

> *"The average generation cost is determined in two steps: in a first step, the cash value of all costs is determined by discounting the costs of each operational year from the time of the plant start-up. In a second step, this cash value is levelled, i.e. transformed into an annual constant payment over the observation period. The average annual cost of operation is determined using this financial method of calculation. The generation costs of electricity are derived from the relationship between these annual average costs and annual levels of electricity generation."*

SDR: Special Drawing Rights, SDR is an artificial currency used by the International Monetary Fund for accounting purposes, used by the international conventions on nuclear liability.

Strike Price: is a pre-agreed, fixed price per MWh which the electricity producer is guaranteed for a contract period. When the electricity price falls below the Strike Price, then the state pays the electricity producer the difference; where the opposite occurs, the electricity producer pays the difference to the state.

SUPER MCA: Maximum Credible Accident or Beyond Design Basis Accident. Worldwide there have been two Super MCAs to date - the catastrophe in Chernobyl/Ukraine in 1986, and in Fukushima-Dai-ichi/Japan in 2011.

UNDP: United Nations Development Programme, the World Development Organization

UNEP: United Nations Environment Programme, the World Environment Organization

UNO: United Nations Organizations, an intergovernmental organization consisting 193 states

UN-OCHA: United Nations Office for the Coordination of Humanitarian Affairs

UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation, a UN body dedicated to assessing the impacts of radioactive radiation; it regularly published reports on this issue (UNSCEAR-Reports).

US$, USD: US American Dollar

WHO: World Health Organization, a UN organization

Y: Japanese Yen

8 Directories

8.1 List of Tables

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8.3 References

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