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A Renaissance of Nuclear Energy?

Analysis of the conditions regarding a worldwide expansion of nuclear energy according to the plans of the nuclear industry and various scenarios of the Nuclear Energy Agency of the OECD

Commissioned by
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Germany

Matthias Deutsch, PhD
Jens Hobohm
Leonard Krampe
Stefan Mellahn
Vincent Rits
Christian Seidel

Translation: Dörte Müller

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Business Profile

Executive Director
Christian Böllhoff

President of the Administrative Board
Gunter Blickle

Commercial Register Number
Berlin HRB 87447 B

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AG *(Aktiengesellschaft)* according to Swiss Law

Founded
1959, in Basle, Switzerland

Field of Business Activity
European-wide, Prognos develops practical strategies for enterprises, organisations and the public sector on the basis of authorative and objective analyses.

Working Languages
German, English, French

Headquarters
Prognos AG
Henric Petri-Str. 9
CH - 4010 Basle
phone +41 61 32 73-200
fax +41 61 32 73-300
info@prognos.com

Other Locations

Prognos AG
Goethestr. 85
D - 10623 Berlin
phone +49 30 520059-200
fax +49 30 520059-201

Prognos AG
Wilhelm-Herbst-Str. 5
D - 28359 Bremen
phone +49 421 2015-784
fax +49 421 2015-789

Prognos AG
Schwanenmarkt 21
D - 40213 Dusseldorf
phone +49 211 887-3131
fax +49 211 887-3141

Prognos AG
Avenue des Arts 39
B - 1040 Brussels
phone +32 2 51322-27
fax +32 2 50277-03

Prognos AG
Sonnenstraße 14
D - 80331 München
phone +49 89 515146-170
fax +49 89 515146-171

Prognos AG
Werastraße 21-23
D - 70182 Stuttgart
phone +49 711 2194-245
fax +49 711 2194-219

Internet
www.prognos.com

Abstract

Objective: Many countries have recently expressed a growing interest in nuclear energy. This study aims at providing a realistic outlook of the probable worldwide future use of nuclear energy until the year 2030. We answer the question whether nuclear energy is likely to undergo a renaissance in the future.

Methodic approach:
After briefly surveying the current status and the history of the worldwide use of nuclear energy, we present international scenarios of nuclear energy use, as well as announcements of new nuclear reactors. The list of reactors officially rated as ”under construction” by IAEA is critically evaluated. At the core of our analysis is the evaluation of announcements of new reactors in view of challenges with regard to infrastructure, fuel supply, financing and other possible barriers. We assess each country’s announcements by means of an indicator-based method that considers a country’s political stability and its practical experience with reactor-building, its credit rating, the chances of realisation in the context of the respective energy market,the limited global supply of reactor pressure vessels, and the current world economic crisis.

Results:
We do not expect a renaissance of the use of nuclear energy until the year 2030. Instead, shutdowns of aged plants will lead to a decrease in the total number of plants, installed capacity and electricity generation from nuclear power plants. Until the year 2020, the number of reactors in operation worldwide is likely to decrease by 22%; until the year 2030 by about 29% relative to the reference level of March 2009.
In spite of an increase in construction activity compared to construction in the last 10 years, the building boom of the 1970s/80s will not be reached again. Announcements for new reactors are currently increasing. However, ambitious announcements of the past – in particular in the USA, but in other countries as well – have subsequently not materialized. We expect that about 23% of all the projects announced by the German ”International Journal for Nuclear Power” ATW for the time until 2020 will be realised, and that about 35% of the projects announced by the World Nuclear Association (WNA) for the time until 2030 will be realised. The development path we consider to be realistic specifically depends on the chosen assumptions regarding the remaining lifetime of existing nuclear reactors and the extent to which the announcements of China, Russia, the USA, India and Japan will materialize**.**

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Summary

(1) In the public debate regarding the use of nuclear energy, several parties increasingly argue that Germany has chosen a “separate way” with its decision to abandon the use of this type of energy. The reason given is the impression of a current increase in use of nuclear energy worldwide. And in fact, today many countries – similar to the 1960s – show a growing interest in nuclear energy. However, a significant part of the new reactor constructions announced in the past have never materialized. The question is now whether the next 20 years could see a **renaissance** of nuclear energy use. The Federal Office for Radiation Protection has commissioned Prognos AG in March 2009 with the present study in order to find an answer to this question.

(2) In March 2009 worldwide, there was a total of 436 nuclear power plants **in operation** with an installed gross capacity of 390 GW, which means 8 less than the 444 reactors in 2002, the historic peak of nuclear energy use. These 436 nuclear power plants had an **average lifetime** of 24 years. Worldwide 123 reactors have already been decommissioned with an average operating life of 22 years.

- In March 2009, the IAEA lists 45 nuclear power plants as **under construction**, 9 of which are expected to be completed within the next 2 years; and for 8, the construction has come to a standstill. This means that there are actually 37 projects under construction. About 75% of these projects are located in Asia.
- Depending on the source, the number of the **announced nuclear power plants** varies between approximately 210 until 2020 (ATW/International Journal for Nuclear Power) and 380 until 2030 (WNA/World Nuclear Association).
- We assume that until 2020 probably 181 and until 2030 a further 119 aged plants will be **decommissioned**, thus amounting to a total of 300 reactors.

(3) The **new construction of nuclear power plants** faces the following **challenges**:

- Due to the long licensing, construction and refinancing process, nuclear power plants need a long-term **stable general regulatory framework**. And not all countries in the world offer sufficient stability for a commercial development of nuclear energy.

- Nuclear power plants are complex technical systems requiring maximum **reliability of manufacturers, operators and supervisory authorities**. Building up the functioning structures and procedures needs time – particularly in countries that are possible newcomers to nuclear energy use.

- Nuclear power plants are a capital-intensive way of generating electricity. The international **financial crisis** is likely to further complicate the **financing** of such power plant projects.

- Both manufacturers of nuclear power plants and component suppliers have **limited technical and personnel capacities**. A central bottleneck is the manufacturing of ultra-heavy reactor pressure vessels, which are necessary, for example, for the European pressurised-water reactor.

- Regarding electricity generation, **renewable energy sources** are a fast growing competition to nuclear power plants. This is likely to further complicate the refinancing of the new nuclear power plant projects.

- The **final disposal** of high-level radioactive waste is an unsolved problem worldwide.

All this suggests that a significantly **lower number** of nuclear power plants will be constructed and that new constructions will **take more time** than announced.

Within the framework of this study, the announced nuclear power plant projects were put in the context of relevant challenges. We have used an indicator-based method to evaluate the announcements of individual countries. This method takes into account a given country's political stability, its practical experience regarding the construction of reactors, its credit rating, the implementation probability within the context of the given energy market as well as the limited global supply of reactor pressure vessels and the international economic crisis.

The resulting development path is realistic provided that the challenges that we have not quantified do not have an additional negative impact on the result.

(4) Against this background, Prognos considers the following **development path** for the global use of nuclear energy to be **realistic**:

- We expect 86 nuclear power plants to be put into operation until **2020**, including the 37 reactor already under construction in March 2009. Between **2020 und 2030**, another 87 nuclear power plants could be connected to the grid, i.e. a total of 173 new plants between 2009 and 2030.

- Due to the age-related decommissioning of plants, the **number of nuclear power plants** is likely to decrease from 436 (as of March 2009) to 341 in 2020 (-22%). After a slight intermediate increase, the number is expected to drop further to approximately 309 reactors in 2030, i.e. about 29% less than in March 2009.

- In 2020, the **total capacity** of operating nuclear power plants is expected to be about 15% lower than today (as of March 2009). Until 2030, the installed capacity will further decrease und be about 21% lower than 2009 levels. However, there is more insecurity regarding the future capacity development than regarding the number of reactors as the specifications of the announced reactors are usually determined only at a later time; we do not take into account capacity changes of existing reactors either.

- The development path that we consider to be realistic depends in particular on our **assumptions** regarding the **total lifetime** of existing nuclear power plants and the implementation of planned plants in China, Russia, the US, India and Japan. The total of the announcements made by these countries accounts for more than half of all known announcements.

(5) Our **conclusions** regarding the future development of nuclear energy are as follows:

- **Until 2030, we do not expect any renaissance of nuclear energy use**. Age-related decommissioning will rather result in a significant decrease of the number of reactors, installed capacity, and electricity generation in nuclear power plants. Until 2020, the number of nuclear power plants operating worldwide is expected to decrease by 22 %, until the year 2030 by approximately 29%, compared to the reference level in March 2009.

- Despite **increased construction** compared to the last 10 years, new constructions of nuclear power plants will **not reach the levels of the construction boom in the 1970s/80s**.

- There is an **increase in announcements** of nuclear power plants. In the past, however, mainly the US, but also other countries had ambitious expansion plans that did not materialize. We expect that about 23% of the new nuclear power plants announced by ATW until 2020 and about 35% of the projects announced by WNA until 2030 will be built.

- If all announced plants would be realised, the resulting construction activity would outclass the immense increase that occurred in the 1970s. This appears to be highly **unrealistic**.

- Also in relation to the expected large increase in global **electricity demand**, nuclear energy becomes significantly less important until the year 2030. The contribution of nuclear energy to worldwide **electricity generation** is expected to decrease from 14.8% in 2006 to 9.1% in the year 2020 and to 7.1% in 2030, respectively.

- A reduced contribution of nuclear energy to global electricity generation can also be derived from **other scenarios**, e.g. the “low”- scenario of the OECD/Nuclear Energy Agency (NEA) and the reference scenario of the World Energy Outlook 2008 of the International Energy Agency.

- The **capacity** development we expect has the closest correspondence to the current scenario of OECD-NEA “phase out Life Extension”.

1 Tasks and methodology

(1) The Federal Office for Radiation Protection, Salzgitter, Germany, has commissioned Prognos AG, Berlin/Basel, in March 2009 with a **study** on the global development of the nuclear energy use until 2030.

(2) In a number of countries, over the last years there has been an increased interest for using **nuclear energy** for electricity generation. Global climate issues, energy prices that are very volatile and tend to increase as well as the increasing dependency on a few regions in the world regarding the energy supply of coal, oil and natural gas have led several actors to re-evaluate the use of nuclear energy or to announce a “renaissance of the peaceful use of nuclear power”.

(3) The advantages of nuclear power are set off by a number of **disadvantages** or **challenges** that we would have to face if we wanted to pursue a massive expansion of electricity generation based on nuclear energy, e.g. capital intensity, necessity of highly qualified employees, reliable public authorities and the still unsolved issue of permanent repositories, to name just a few. These barriers are likely to be too high for several interested parties and construction projects. Similar to developments in the past, there will be a certain portion of announced nuclear power plant projects that will not result in an actual construction or start of operation. The size of this portion will be examined in the present study. There are two examples for past projects announcements, one from the US and another one from the International Energy Agency.

At the beginning of the 1970s, the US Atomic Energy Commission expected **1,000 nuclear power plants to be built in the US until 2000** (CRS 2007). Eventually, only 132 projects materialized, i.e. about 13% of the originally expected number (IAEA/PRIS 2009a). In 1980 – shortly after the Harrisburg incident – the International Energy Agency assumed that its member countries would have an installed nuclear power capacity of about 485 GW by the year 2000 (Lantzke 1980). Eventually, the actual net capacity of the reactors in the IEA member states was about 283 GW in 2000, which means slightly less than 60% of the capacity predicted 20 years earlier (IEAE/PRIS 2009a). These examples show that there is often a considerable gap between expectations or announced projects and the actual construction of reactors.

(4) The current study has the **goal** to provide a realistic assessment of the probable future global use of nuclear energy. It

will answer the **question** whether a **renaissance** of nuclear energy is likely to occur.

(5) In the following, we will describe the **approach** of the study:

- At first, the study provides a brief overview of the current **status** and the **history** of worldwide nuclear energy use. Here, we look at the question what lessons can be learned from the past regarding the future of new reactor projects. There have been numerous announced projects that never materialized (**Chapter 2**).

- **In Chapter 3**, we will present a comparison of international **scenarios** regarding the use of nuclear energy, without any assessment. Then we will review the **announced** reactor constructions projects worldwide. Finally, we will analyze the nuclear power plant projects that are currently **under construction** and assess how likely a completion is.

- **Chapter 4** describes the already mentioned **challenges** (see section 3 above) that the use of nuclear power will face, especially regarding new construction projects. Some of these challenges are real **bottlenecks**, e.g. manufacturing capacities of special components for nuclear power plants.

- Finally, **Chapter 5** will summarize the results of the analysis und draw conclusions regarding the possible future development of nuclear energy use until the year 2030. The conclusions are based on a comprehensive model-based analysis of all operating and, in particular, known planned nuclear power plants worldwide.

- The **appendix** comprises – in addition to detailed **case studies** regarding the nuclear energy use in individual countries – an analysis of possible **newcomer** countries. The appendix also contains complementing **tables** as well as a description of the **methodology** we have used to model the development path of nuclear energy.

(6) A **nuclear power plant** refers in this study, unless otherwise indicated, always to a single reactor unit. The same applies to the term “reactor”. Unless otherwise stated, all data related to nuclear power plants, such as numbers, capacities etc. are based on a query of IAEA’s **PRIS database** on 18 March 2009 (IAEA/PRIS 2009a). Reactor numbers and capacities in the modelled development path of the nuclear energy use are year-end values of the respective parameter.

This study assumes that the capacities of existing nuclear power plants remain constant. A capacity change of the existing plants due to **retrofits** or other capacity-enhancing measures will not be taken into account. This is one of the reasons why the development path of worldwide nuclear power plant capacity described in Chapter 5 has a higher degree of insecurity than the development path of the reactor numbers. Another reason is that the announced reactors usually are only dimensioned at a later point in time.

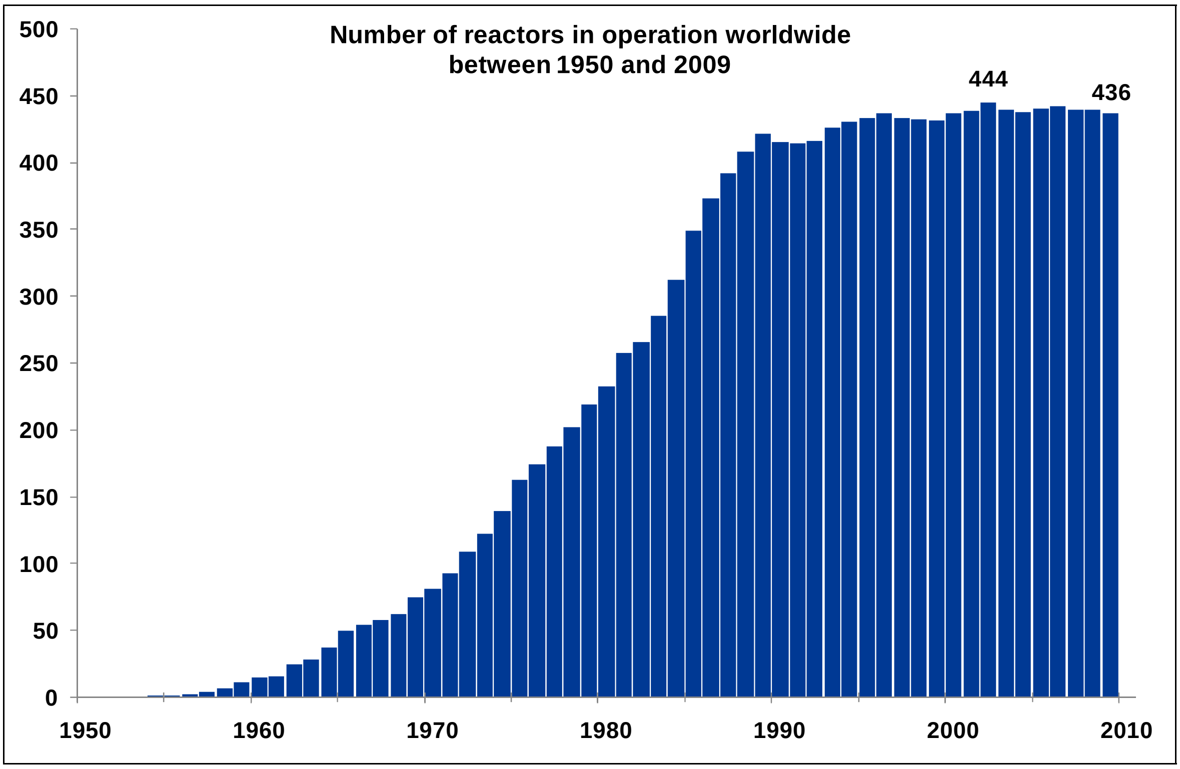
2 Status quo and history of nuclear energy use

This chapter will review the **current status** regarding nuclear energy use. For this reason, we will look at current statistics of operating (2.1) and already decommissioned (2.2) reactors. We will also briefly analyze historical plans for nuclear power expansions (2.3) and past experience regarding construction projects (2.4). The goal is to provide a basis for the assessment of the future development of nuclear energy.

2.1 Development and current status

(1) Retrospectively, the number of nuclear power plants operating worldwide continuously increased between 1956 and 1989. After a period of fluctuations in the 1990s, the **maximum was reached in 2002 with 444 reactors**. Due to decommissioning and less reactors being put into operation, the number decreased after 2002 to a **total of 436 reactors** worldwide in March 2009.

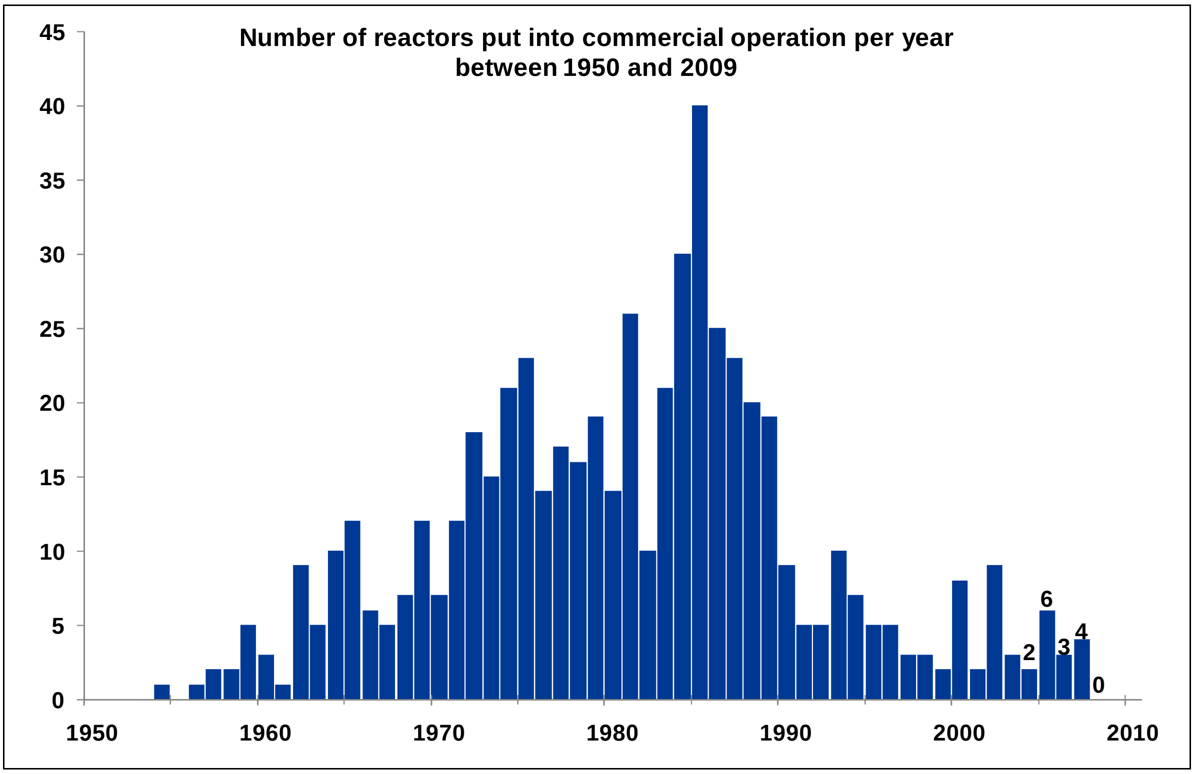
Figure 1: Number of reactors in operation worldwide between 1950 and 2009



Source: IAEA/PRIS 2009a

Whereas in the past each year 40 nuclear power plants were connected to the grid, since 1990, it has been 10 reactors or less per year. In the past five years, a total of only 15 reactors was put into commercial operation; and in 2008 it was not a single one.

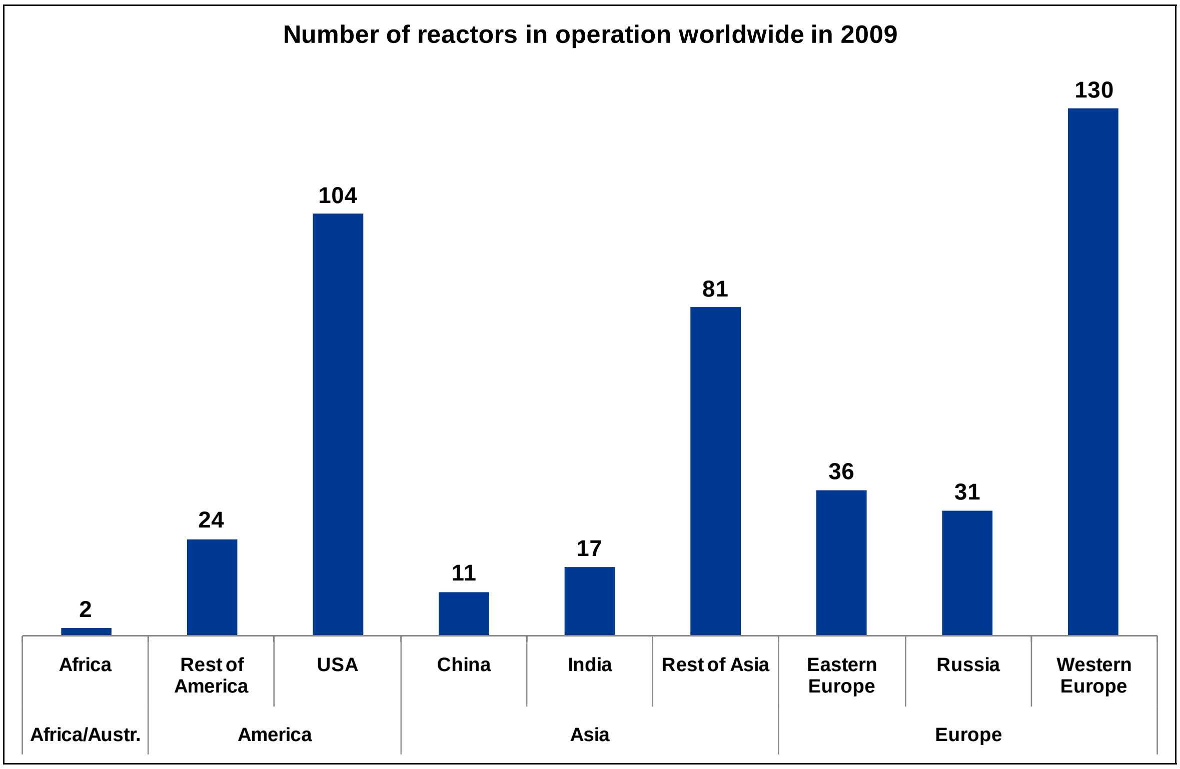
Figure 2: Number of reactors put into commerical operation per year between 1950 and 2009



Source: IAEA/PRIS 2009a

(2) Figure 3 shows the **distribution** of the currently operated 436 reactors by **world regions**. Most reactors are operated in Europe (197). In America, there are currently 128 reactors in operation ; and in Asia, there are currently 109 operating nuclear reactors. For the region Africa/Australia, there are only two reactors operating in South Africa.

Figure 3: Number of reactors in operation worldwide in 2009



Source: IAEA/PRIS 2009a

(3) There are currently **31 countries** that operate nuclear reactors. The US has the largest number of active reactors (104). It is followed by France (59) and Japan (53). This means that almost half of the active reactors (49.5%) are located in these three countries. Table 8 in the appendix shows a detailed compilation of the currently operated reactors according to countries and reactor types.

(4) The 436 reactors currently operated worldwide have a total installed **gross capacity of approximately 390 GW** (net ca. 370 GW). The distribution of the installed gross capacity by world regions (see Table 1) is similar to that of the number of plants. With a total of 179 GW, Europe has the largest nuclear power plant capacities, followed by America (124 GW) and Asia (85 GW). Based on the analyzed statistics, worldwide average installed gross capacity per reactor amounts to about 894 MW. In Asia, the average installed gross capacity (780 MW) is substantially lower than in other world regions. The reactors in the US (969 MW) and Europe (909 MW) are above the international mean capacity.

Table 1: Gross capacity of operating reactors worldwide in 2009

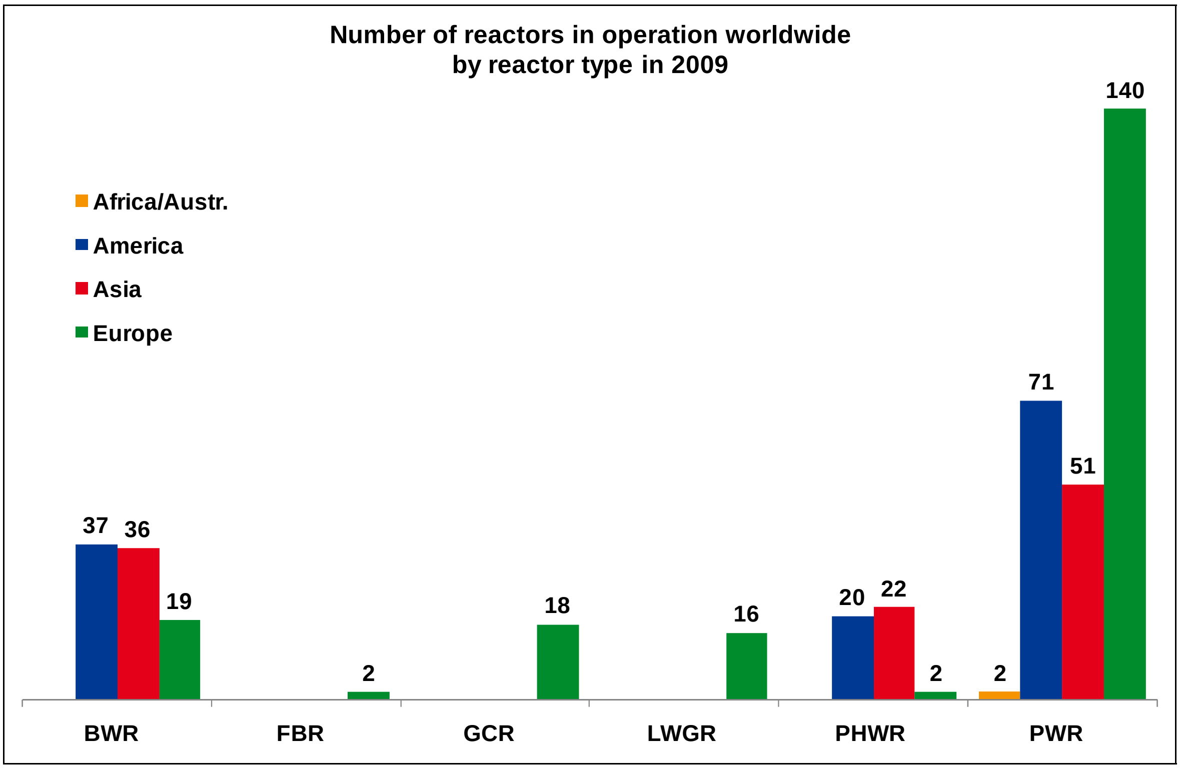
Region	Gross capacity (GW)
Africa/Australia	
Africa	2
America	
Rest of America	18
USA	106
Asia	
China	9
India	4
Rest of Asia	72
Europe	
Eastern Europe	27
Russia	23
Western Europe	129
Total	**390**

Source: IAEA/PRIS 2009a

(5) The **countries** with the largest number of operating nuclear reactors also have the highest installed gross capacities. The US has approximately 106 GW of installed nuclear energy capacity. It is followed by France (66 GW) and Japan (48 GW). These three countries account for approximately 56.3% of the installed capacity. Table 9 in the appendix shows a detailed compilation of the currently installed gross capacity by countries and reactor types.

(6) Regarding **reactor types**, Figure 4 illustrates that pressurised-water reactors are most frequently used. Gas-cooled reactors are only used in the UK. Graphite-moderated light water reactors are a Russian design.

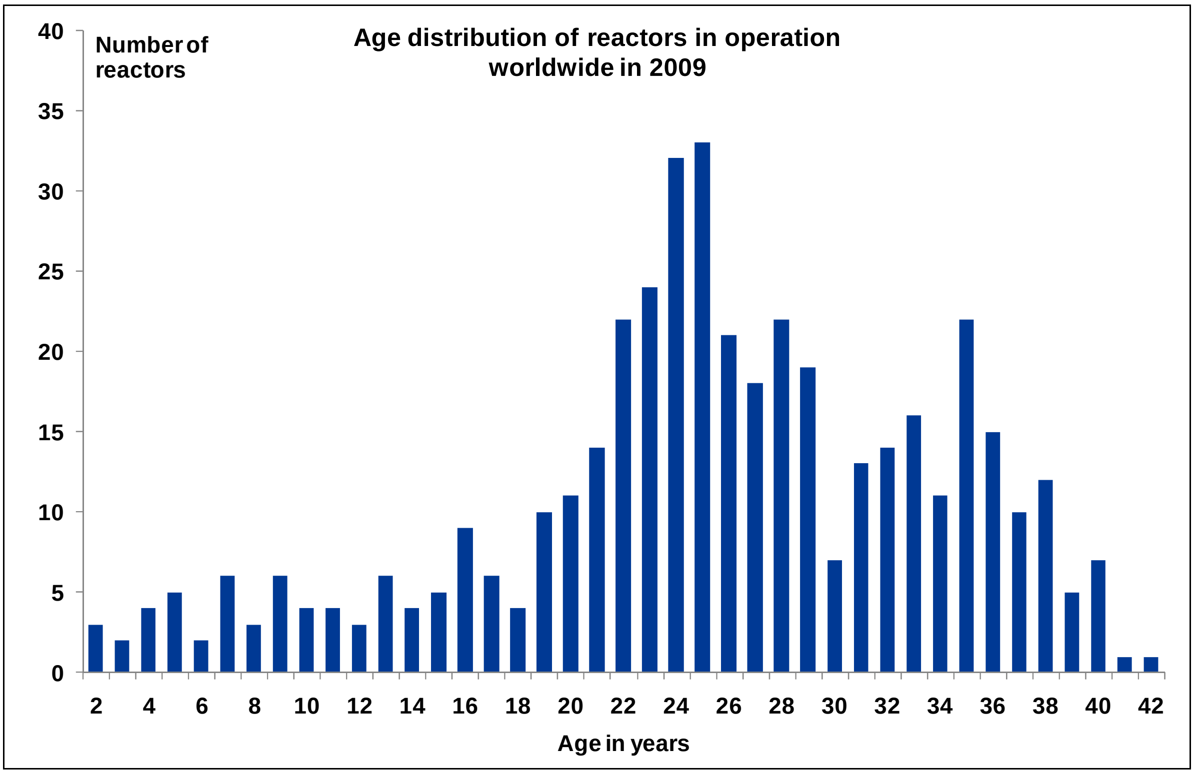
Figure 4: Number of reactors in operation worldwide by reactor type in 2009



BWR Boiling Water Reactor
FBR Fast Breeder Reactor
GCR Gas Cooled Reactor
LWGR Light Water-cooled Graphite-mod. Reactor
PHWR Pressurised Heavy Water Reactor
PWR Pressurised Water Reactor
Source: IAEA/PRIS 2009a

(7) Figure 5 shows the **age of the operating nuclear reactors**. It shows that since 1990 the number of newly constructed reactors has been stagnating at a rather low level (see Figure 2). The majority of the reactors is already older than 20 years. The average age of all reactors is about 24 years.

Figure 5: Age distribution of reactors in operation worldwide in 2009



Source: IAEA/PRIS 2009b

2.2 Historical experience from the lifetime of decommissioned nuclear power plants

(1) In many countries, the State restricts the **operating life** of nuclear power plants. Due to numerous economic and technical factors, the plants are not necessarily operated until the end of their allowed lifetime, though. The manufacturers of nuclear power plants usually specify a design life. For older power plants, this planned operating life is shorter than that of modern plants that were put into operation only in the last few years.

In his analysis of the expected electricity costs of existing and planned power plants from 1983, Hansen (1983) assumes a useful life of 40 years. A prognosis produced by reactor manufacturer Siemens is based on an average useful life of 30 to 35 years (Frewer et. al 1989). As opposed to this, in 1993 the IAEA assumed a planned lifetime of between 25 and 30 years for most reactor designs (IAEA 1993).

In the late **1990s**, the assumption of a lifetime of 40 years can be found more often in the literature: "In general, nuclear power plants are designed for an operating life of 40 years" (Liebholz 1996). Reactors of this design can be found in Sweden and Korea, for instance (Lundgren and Tirén 1996; Kim 1998).

For **future power plants**, manufacturers assume an operating life of up to 60 years. Next-generation Korean reactors – the first of which are expected to be put into operation in 2015 – for instance, have a design life of 60 years (Kim 1998, IAEA/PRIS2009a). The same applies to the European pressurised-water reactor EPR (Areva 2005).

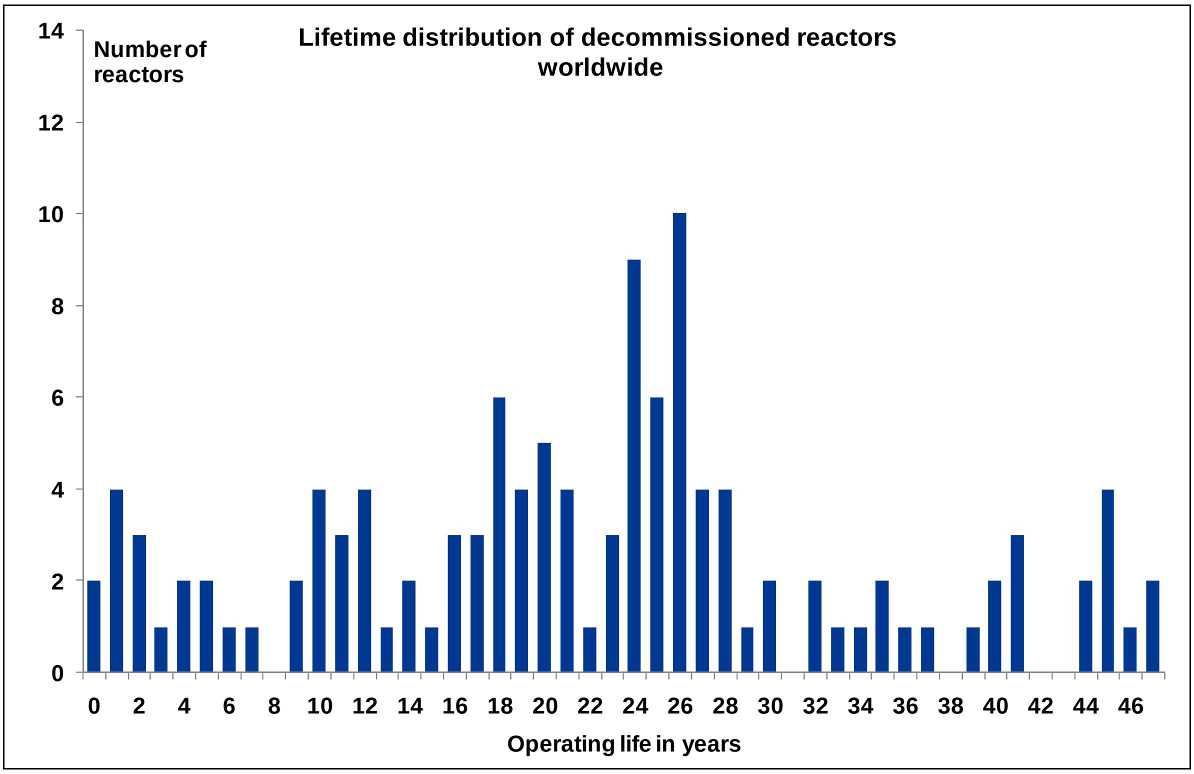
(2) In addition to the issue of the original dimensioning of a power plant, the **possible extension of the lifetime** is also of importance. In general, all nuclear power plant components are subject to aging and thus their conditions will deteriorate over time. This deterioration can reduce the reliability of the entire plant unless the corresponding technical components are serviced, repaired or exchanged in time. Therefore it is necessary to carefully monitor the aging process of a nuclear power plant. In principle, the IAEA considers it technically possible to extend the actual design life if continuous maintenance and thorough checks of the plant are guaranteed. In 1993, the IAEA therefore assumed that the lifetime of most reactor designs – with an originally planned operating life of 25 to 30 years – could be extended to 30 till 40 years (IEAE 1993). However, at the time of writing there was no evaluation available regarding the prognosis of the IAEA on possible lifetime extension.

For currently operating nuclear power plants, the mentioned lifetime data results in an original design **range** of approximately 25 to 40 years. As shown above, we have to take into account that today (as of March 2009) many reactors are older than 25 years, two of them are even older than 40 years (see Figure 5). That means that occasionally, the operating life has already been extended beyond the original design life. In principle, we also assume a lifetime extension to be possible for reactors that have an original design life of 40 years.

(3) However, the discussion regarding a lifetime extension beyond 40 years is rather difficult as – for the majority of the reactors – it cannot be supported by empirical observation. Worldwide, lifetimes of over 40 years are very rare.

Whereas currently operating reactors have an average age of 24 years (see 2.1), the 127 decommissioned reactors had an average lifetime of only 22 years. The following Figure 6 shows the lifetime distribution of decommissioned reactors. We can clearly see the wide spread of the operating lives. About one fourth of all decommissioned reactors were in operation for less than 15 years.

Figure 6: Lifetime distribution of decommissioned reactors worldwide



Source: IAEA/PRIS 2009a. 121 reactors; for 6 reactors, no detailed data was available

In the UK and Russia, individual nuclear reactors have been in operation longer than anywhere else (maximum of 47 years). Mostly, the reactors were very small, though, with a gross capacity of 60 MW each. As opposed to this, there are reactors in various countries that were in operation only a very short time or did not generate any power at all. Tables 10 and 12 in the appendix show a detailed compilation of operating lives of decommissioned and operating reactors on a country level.

In total, out of the 436 operating and 127 decommissioned reactors only 14 have reached an operating life of more than 40 years, i.e. less than 3% of all 563 reactors. This shows that discussions about the extension of the operating life beyond 40 years are to a certain extent speculative because there is no sufficient data available here. The IEA assumes in its World Energy Outlook 2008 an average operating life of 45 years for today's operating reactors (IEA 2008).

For the modelling of the development path (see Chapter 5) we have assumed different categories grouped according to the date when the reactors were put into operation. We assume that older power plants on average will have a shorter operating life than younger ones. For nuclear power plants that became operative before 1980, we assume 40 years; for those that started operations between 1980 and 1985, it is 45 years; and for reactors that started operations after 1985, it is 45 years or more.

The discussion whether and to what extent there will be a lifetime extension beyond 40 years is not relevant within the context of this study as the time horizon ends in 2030, which means before the decisive threshold. A power plant that was put into operation in 1985 will have reached exactly after 45 years the end of the timeframe analyzed in this study.

Exceptions from these lifetimes according to age groups were made if there was WNA data for individual reactors stating a planned or decided shorter lifetime, such as in Germany.

2.3 Past plans for nuclear energy expansion and their outcome

(1) Regarding their member countries, the **International Energy Agency** assumed in 1980 that in 2000 there would be nuclear power plants with an installed capacity of approximately 485 GW (Lantzke 1980). In 2000, the actual net capacity in the IEA member countries amounted to about 283 GW, i.e. slightly less than 60% of the capacity forecasted 20 years earlier (IAEA/PRIS 2009a).

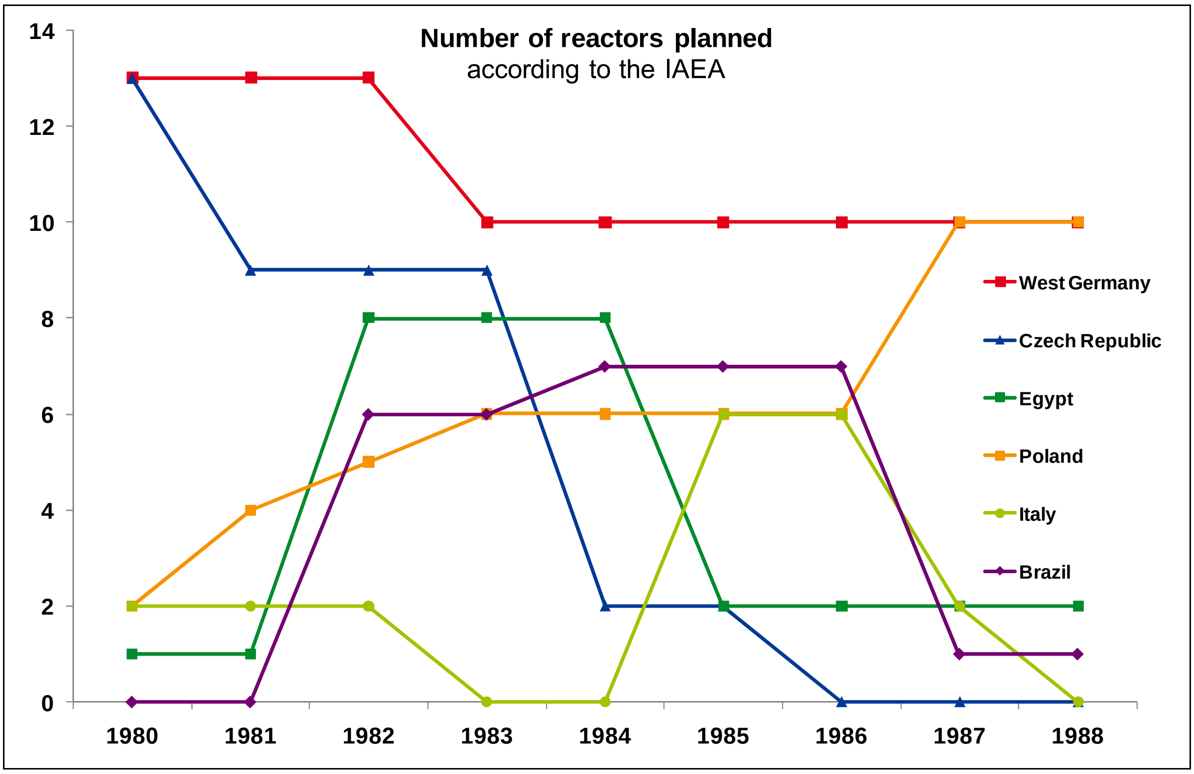
(2) The following Figure 7 shows the **plans made in the 1980s for the new construction of reactors** in the individual countries. These results are based on evaluations of IAEA reports. From 1988 onwards, the annual IAEA reports do not any longer include data regarding further reactor plans.

Figure 7 illustrates that some reactor plans will take a long time to materialize or cannot be carried out at all. In Germany, for instance, there were still 10 nuclear power plants planned in 1983. None of them has been built and – according to current legislation – will not be built in the future either.

For less industrialized countries it becomes obvious that in the process from announcing or planning a nuclear reactor to the actual construction and start of operation, significant obstacles have to be negotiated. In Poland and Egypt, for instance, today there is not a single reactor in operation yet, even though Poland had planned up to ten reactors and Egypt up to eight in the 1980s.

And finally the figure shows that there have occurred sudden changes in the individual countries regarding the planned new construction of reactors. Following the reactor accident in Chernobyl in April 1986, some countries have substantially reduced the number of planned reactors. Italy at this time completely stopped the planning of new reactors.

Figure 7: Number of reactors planned in the 1980s in selected countries



Source: IAEA – Nuclear Power Reactors in the World, Reference Data Series No. 2 (1981 – 1988) and own evaluations

(3) The historical **record of the announced nuclear plant projects in the US** is particularly instructive for the assessment of the future development – especially for the US itself.

According to IAEA data, the US currently operates a total of 104 nuclear power plants. This number contains the story of newly constructed power plants, on the one hand, and the story of announcements, orders and cancellations, on the other hand. Whereas in the 1970s, 59 new reactors were put into operation, it was only 46 in the 1980s and five reactors in the 1990s. The last new nuclear power plant was completed in the US in 1996 (IAEA/PRIS 2009a). That means, that the highest number of operating reactors was reached in 1990; after that the number of operating US reactors has been decreasing (DOE/EIA 2008).

Between 1966 and 1974 a large number of new power plants was ordered; in the following years **orders** decreased substantially, though. In the early 1970s, the US Atomic Energy Commission still expected (see Chapter 1) up to 1,000 new nuclear power plants to be built until the year 2000 (CRS 2007). Since 1978, not a single power plant has been ordered, though. According to the Department of Energy (DOE), this is mainly due to increasing costs: Costly design changes after the Harrisburg accident in 1979; anticipated economies of scales in the production that did not materialize as well as the competition of other energy sources made nuclear power plants less competitive than expected. Due to the disappointment of operators' and investors' expectations, out of the 259 power plant orders since the beginning of nuclear energy use in the US, 124 orders, i.e. almost 48%, were cancelled (DOE/EIA w/o year). Of the originally 1,000 expected reactors in the US only a total of 132 power plants was realised, i.e. about 13% of the originally expected number (IAEA/PRIS 2009a).

In 2001, a working group presented on behalf of the DOE a "**Roadmap 2010**" and concluded that – in principle – it would be possible to build new nuclear power plants until 2010. However, whether this option will materialize depends on sufficient private-sector investments. One of the largest insecurities in a deregulated electricity market is the competitiveness of nuclear power (NTDG 2001). As opposed to this positive assessment regarding the conditions for new construction projects, since 2001 there has been no new reactor project in the US (IAEA/PRIS 2009a).

(4) In 2000, the **Russian reactor expansion plans** comprised a total of over 200 TWh of electricity to be generated in nuclear power plants by the year 2010 (Schneider & Froggatt 2007). In 2000, about 123 TWh of electricity were generated in nuclear power plants (CIA 2002) and in 2007, it was 160 TWh (WNA 2009h). Assuming that the increase continued at the same rate until 2010, the generation would be about 30% lower than the intended expansion goal.

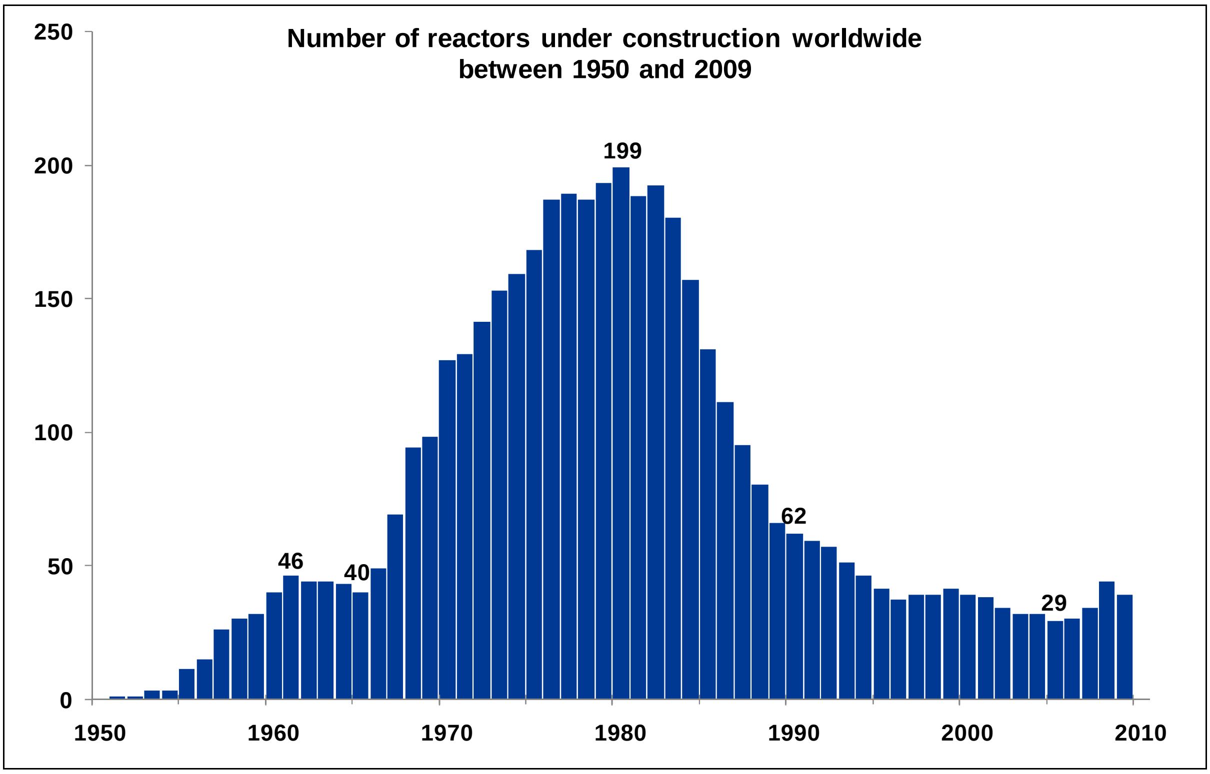
(5) It has become clear that, in the past, plans for the new construction of nuclear power plants often were changed or abandoned and that the originally stated high expectations regarding the future of nuclear power later were frustrated.

2.4 Experience from past construction projects

(1) In the following, we will look at construction projects in the past – both aggregated for the whole world and differentiated by regions. This assessment will form the basis for later assumptions regarding the implementation of current reactor plans.

(2) Figure 8 shows the number of **nuclear reactors currently under construction**. Since the mid-1990s, the number has remained constant at a comparatively low level (about 50). Out of 45 current projects that are officially named as “under construction” eight have come to a standstill (see Chapter 3.4). The current numbers are similar to the levels in the 1960s. Within 15 years, the number of reactors that were simultaneously constructed increased substantially from 40 plants in 1965 to 199 plants in the early 1980s.

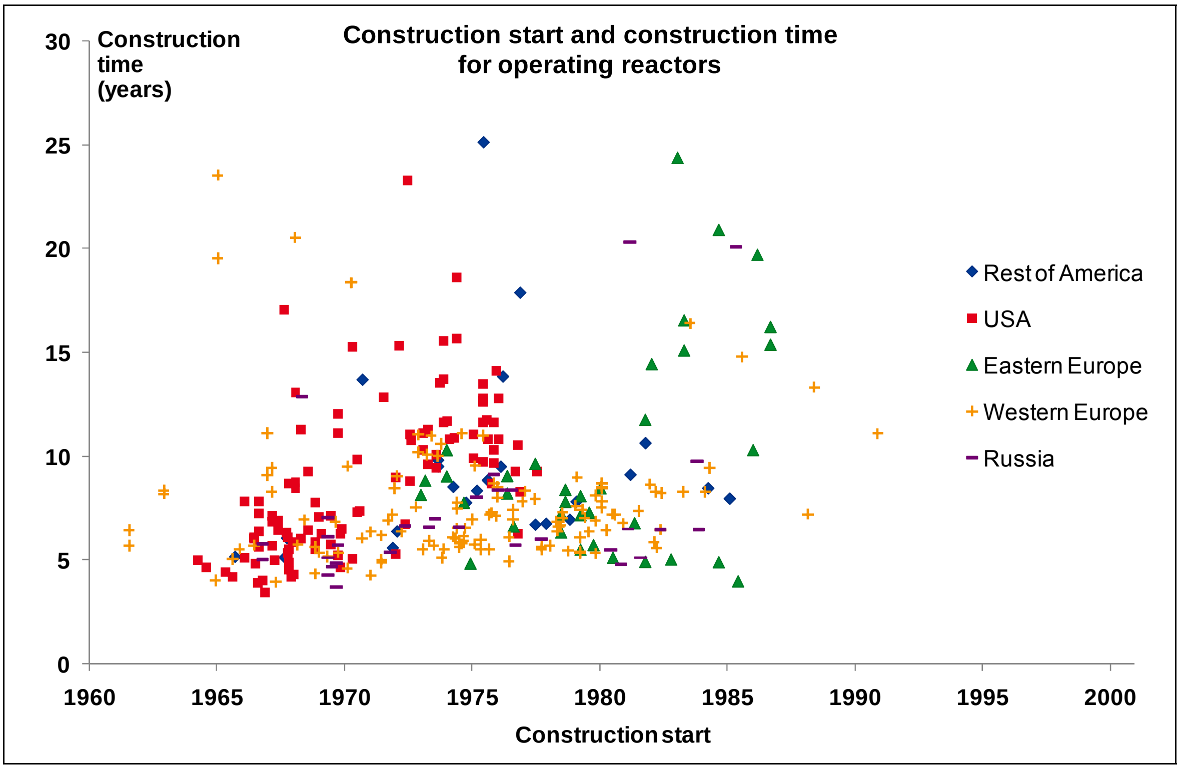
Figure 8: Number of reactors under construction worldwide between 1950 and 2009



Source: IAEA/PRIS 2009a. Includes 436 reactors in operation and 127 decommissioned reactors. Not included are those reactors under construction which were never completed.

(3) The **average construction time** of the 436 currently operating reactors shows a global mean value of approximately eight years. The construction time varies between the world regions. Table 11 in the appendix provides a detailed compilation for the individual countries. The following graphs show the construction times for all reactors currently under construction in Europe and in America (Figure 9) as well as in Asia (Figure 10).

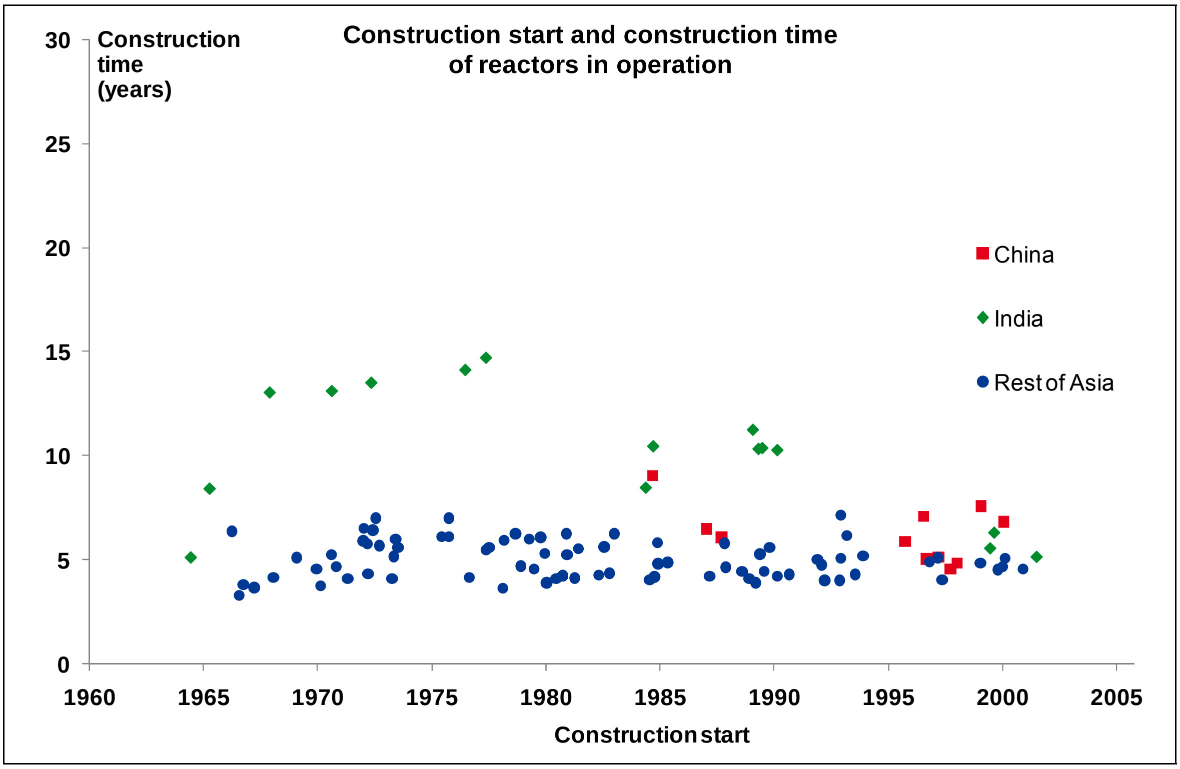
Figure 9: Construction start and construction time for operating reactors in America and Europe



Source: IAEA/PRIS 2009a

(4) Figure 9 shows that particularly in the US and in Eastern Europe, the **construction time** of reactors **has increased** over the years and that the spread between minimum and maximum construction time has become larger. As opposed to this, there is no trend towards longer construction times for nuclear reactors in Asia (Figure 10). In the rest of Asia, construction times remain comparatively stable over the entire period. In India, construction times have significantly decreased since the 1980s.

Figure 10: Construction start and construction time for reactors operating in Asia



Source: IAEA/PRIS 2009a

Comparing the two figures we can clearly see that on average construction times in Asia are significantly shorter than in Europe or in the US (see Table 11 in the appendix).

For the modelling of our development path (see Chapter 5), we therefore assume that construction times in Asia will be shorter than the worldwide long-term average. Based on past construction experience, we assume five years for Japan and South Korea and six years for China and India. For all other countries, we use the worldwide average value of eight years.

3 Comparison of extension scenarios and announcements of nuclear power plants

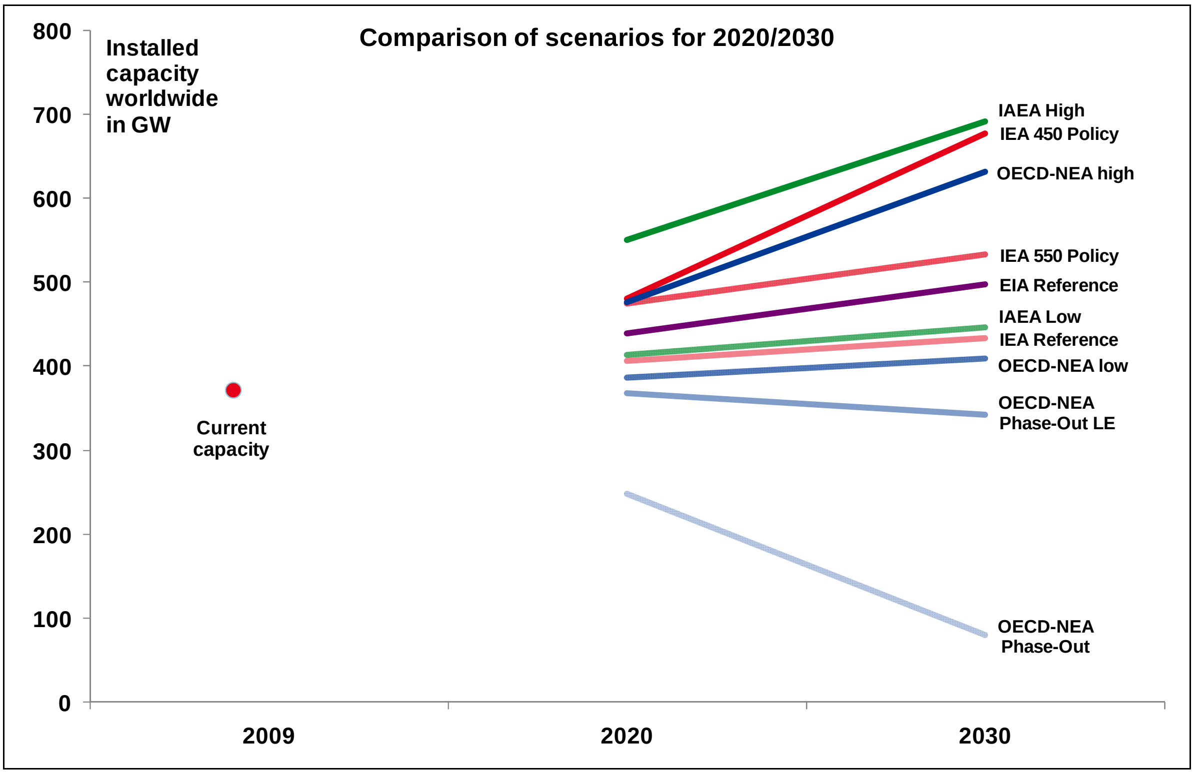
The future of nuclear energy use depends to a large extent on how many new reactors will be built. Some power plants are already under construction or at least in the planning phase. Other reactor projects have only been announced. This chapter will start with an overview of the aggregated, global nuclear energy expansion scenarios (3.1) of OECD-NEA and other institutions. However, these scenarios are not suitable for the modelling of a future development path as they do not contain sufficient details on the level of individual reactors. After this overview, we will look at planned and announced projects and use for this purpose publications of the World Nuclear Association (3.2) and ATW (3.3). Finally we will discuss the IAEA construction statistics and – if necessary – adjust it accordingly (3.4).

3.1 Comparison of expansion scenarios of nuclear energy

(1) Several institutions have produced development paths for nuclear energy use and mainly put the use in the context of worldwide energy demand. These institutions are **OECD-NEA** (Nuclear Energy Agency), **EIA** (Energy Information Administration, US Department of Energy), **IAEA** (International Atomic Energy Agency) and **IEA** (International Energy Agency).

(2) Whereas the IEA has produced only one reference scenario, the other organisations provide several scenarios. Figure 11 presents an overview of the different scenarios for the future installed capacity of nuclear power plants worldwide. Based on the current status of a net capacity of approximately 370 GW, the scenarios produce a range of between 550 GW (IAEA High) and about 250 GW (NEA Phase-Out) until the year 2020. Until 2030, the range becomes even larger. Then the maximum will be about 700 GW (IAEA High) and the minimum 80 GW (NEA Phase-Out). Overall, nearly all scenarios assume that until 2020 the expected new plants will **compensate the decommissioned power plants**.

Figure 11: Comparison of expansion scenarios of OECD-NEA, EIA, IAEA, and IEA until 2030



2020-2030: interpoliert. Phase-Out LE : Life Extension.
Source: IAEA/PRIS 2009, EIA/DOE 2008, IAEA 2008f, NEA 2008, IEA 2008

3.2 Plans and proposals worldwide according to WNA

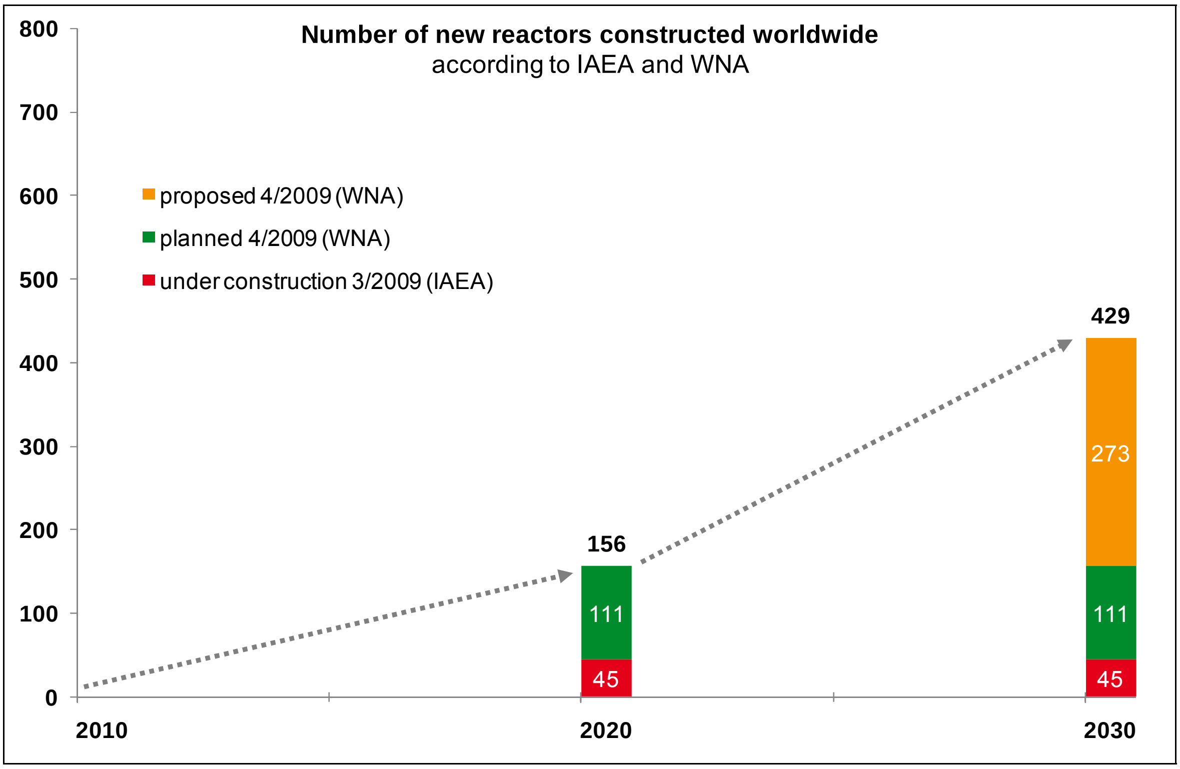
(1) The **World Nuclear Association (WNA)** is an international association of the nuclear power industry with the self-defined goal to promote the peaceful use of nuclear energy as a sustainable energy source for the next centuries. The WNA produces lists with **planned** and **proposed** reactors worldwide. The lists are continuously updated, some of them several times per month.[1]

(2) The following Figure 12 shows the number of reactors that would to be completed until 2020 or 2030 if all reactors that are **planned and proposed** according to WNA were to materialize. In addition, the IAEA currently lists several reactors "under

[1] The WNA uses the following definition to distinguish between "planned" and "proposed" reactors:
Planned are those reactors that already have a high degree of licensing and financing and are expected to be put into operation basically within the next 8 years, or such reactors that have come a long way in the construction process, but whose completion is postponed indefinitely.
Proposed are those reactors for which a specific programme or site has been proposed and which are expected to be put into operation within the next 20 years (WNA 2009a).

construction". Here we assume for the time being that all these reactors will be completed by 2020. Later on, we will critically review and adjust this assumption (see 3.4).

Figure 12: Number of new reactors constructed until 2030 according to IAEA and WNA

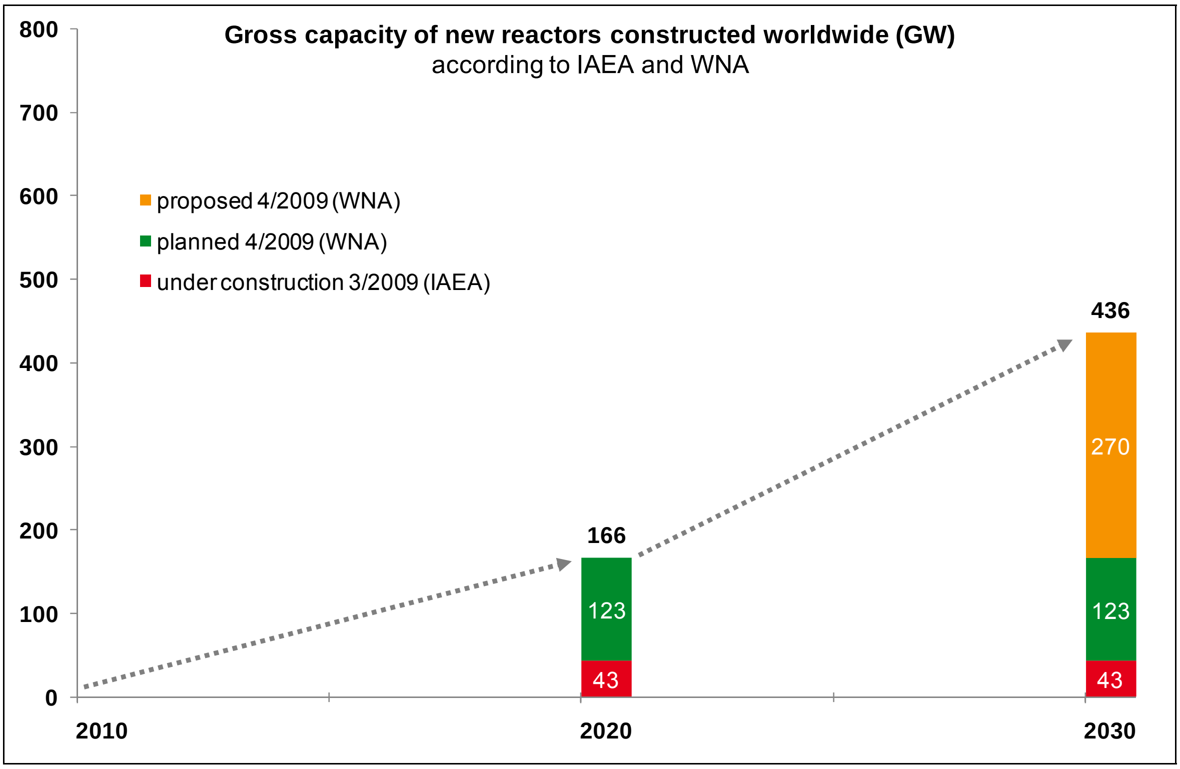


Source: IAEA/PRIS 2009a, WNA 2009g. We assume here that all reactors currently listed "under construction" by the IAEA will be completed by 2020.

This means that 156 new **nuclear power plants** would be constructed until 2020, assuming that all current construction projects would be completed and all plans und proposals would materialize. Until 2030, the number would amount to 429 reactors.

Figure 13 analogously shows the expected installed **gross capacity**. By 2020, 166 GW would be installed, and by 2030 it would be 436 GW.

Figure 13: Gross capacity of new reactors constructed until 2030 according to IAEA and WNA in GW



Source: IAEA/PRIS 2009a, WNA 2009g. We assume here that all reactors currently listed "under construction" by the IAEA will be completed by 2020.

3.3 Plans and preliminary plans according to ATW

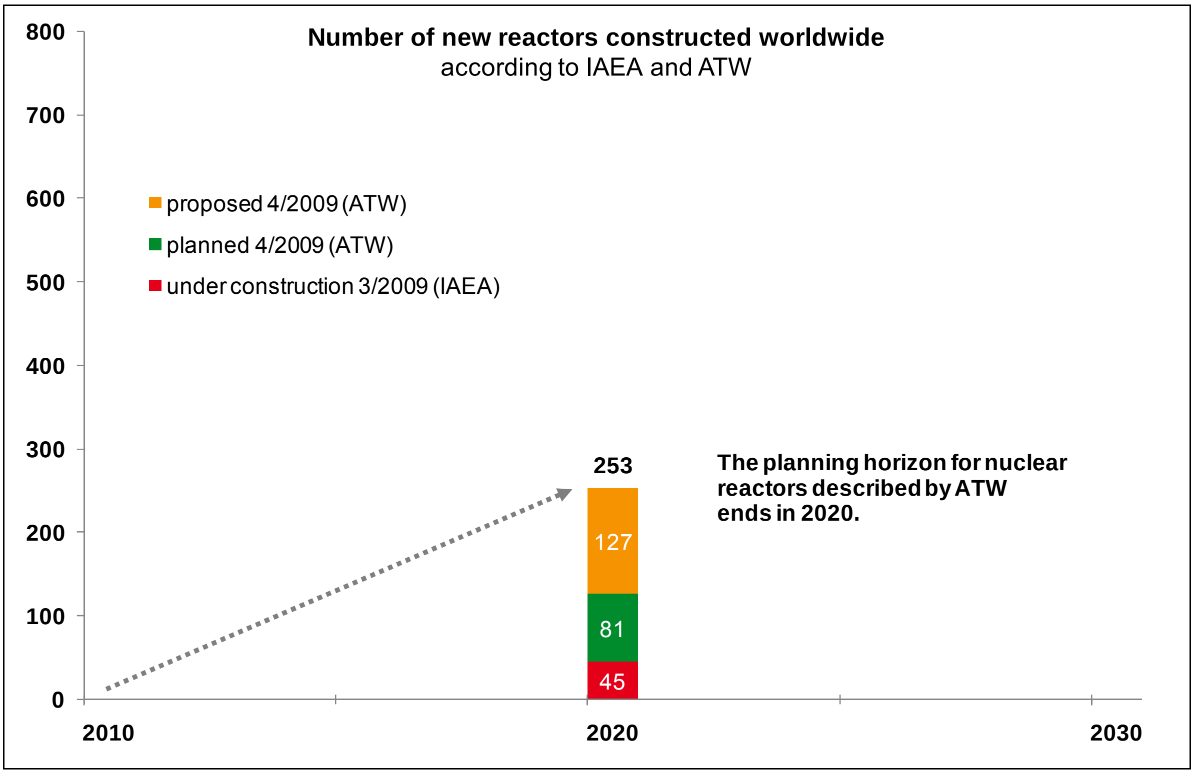
(1) ATW, the "International Journal for Nuclear Power", is institutionally intertwined with the German nuclear energy industry. ATW publishes several times per year a list that is aggregated on the country level and comprises all reactors worldwide that are in the **planning** or **preliminary planning** phase (ATW 2009b)[2].

[2] **Applied for or planned** – according to ATW – are those reactors where there is a "high degree of reliability of the information" and possibly "preparing work (e.g. excavation of building pit) for the construction" already has started. "At least three independent sources" and "at least one from the potential investor" are required as sources for validating this information
Preliminary planning (until 2020) is characterized by the fact, that "information regarding the planning" is available; "at least two independent statements" are required. As opposed to the WNA list (see 3.2), the ATW list of plans and preliminary plans is not continuously updated in order to prevent very short-lived, politically motivated announcement as far as possible from being included. Therefore the ATW list from 2 March 2009 used in this study presents the data status as of 31 December 2008. In addition, the planning horizon for the nuclear power plants included by the ATW ends already in 2020 (Note: All quotations are translations from the original ATW document in German).

(2) Adding up the ATW list of planned projects and the reactors under construction according to IAEA, 253 new **reactors** would be built until 2020 worldwide (Figure 14). This would correspond to an additional installed **gross capacity** of 274 GW (Figure 15).

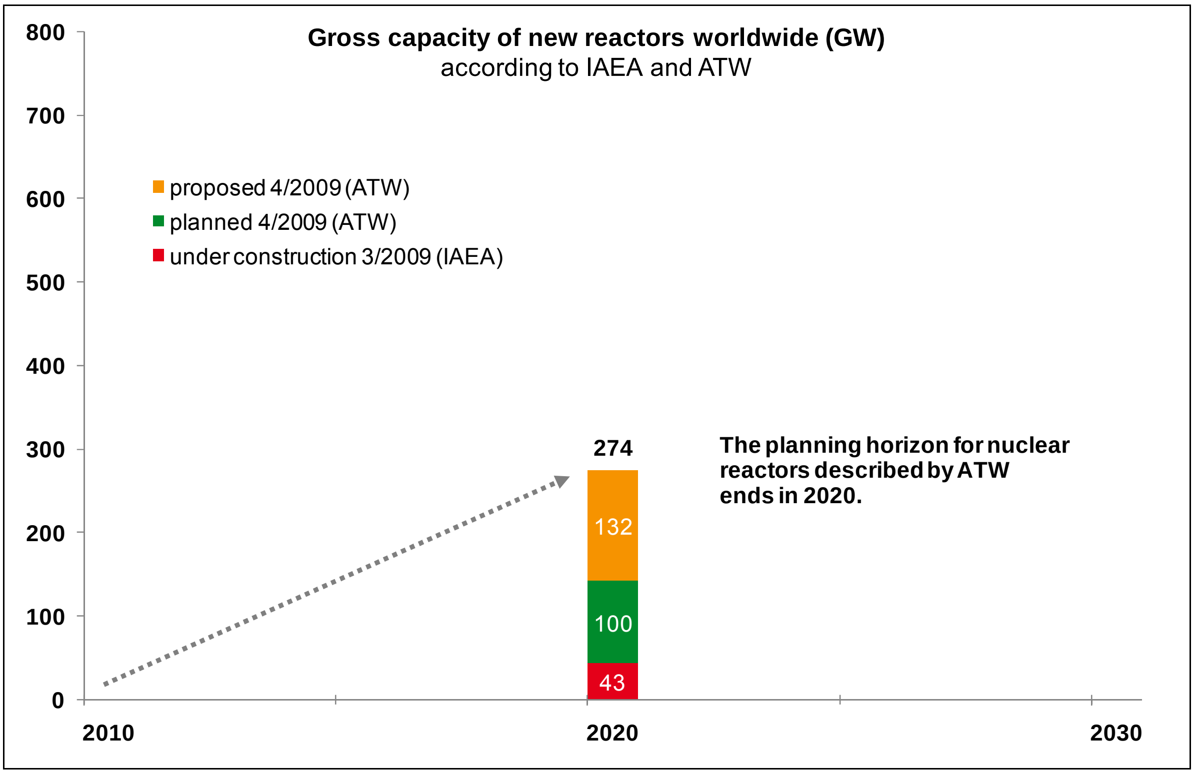
For 2020, the ATW numbers exceed those of the WNA (see 3.2), the latter resulting in 156 new plants with a gross capacity of 166 GW.

Figure 14: Number of reactors in operation until 2020 according to IAEA and ATW



Source: IAEA/PRIS 2009a, ATW 2009b. "Proposed" means "preliminary planning" in ATW's terminology. We assume here that all reactors currently listed "under construction" by the IAEA will be completed by 2020.

Figure 15: Gross capacity of reactors in operation until 2020 according to IAEA and ATW in GW



Source: IAEA/PRIS 2009a, ATW 2009b. "Proposed" means "preliminary planning" in ATW's terminology. We assume here that all reactors currently listed "under construction" by the IAEA will be completed by 2020.

3.4 Analysis of the IAEA construction statistics

(1) The IAEA compiles a list of nuclear power plants under construction that does not include any details regarding the factual status of the construction activity, though. Therefore the construction statistics was matched against other sources in order to group the reactors into three **categories**:

- "construction started" (i.e. completion takes more than two years)
- "construction halted" or
- "completion within the next two years"

Especially the second category is important for the future, as a reactor whose construction has currently come to a standstill possibly may not be completed at all or not as fast as it would be expected according to the average value.

(2) As a **result**, the 45 reactors listed by the IAEA as “under construction” could be categorized as follows (Table 2): In total, the construction of 27 reactors has only currently started; another nine will probably be completed within the next two years. For the remaining eight reactors, the construction has come to a standstill. It is noticeable that seven of them are situated in Europe.

Adjusting the 45 reactors marked by the IAEA as “under construction” for the eight projects that have come to a standstill, actual construction activity is limited to 37 projects; and more than three out of four projects are realised in Asia.

For the modelling of the development path (see Chapter 5), we therefore assume that only 37 reactors will be completed by 2030.

Table 2: Construction statistics of the IAEA and classification of the construction progress in 2009

	total under con-struction (IAEA)	thereof		
		construction started	construction halted	completion within the next two years
America				
Rest of America				
ARGENTINA	**1**	1		
USA*	**1**	1		
Asia				
China	**12**	11		1
India	**6**		1	5
Rest of Asia				
IRAN, ISLAMIC REPUBLIC OF	**1**			1
JAPAN	**2**	1		1
KOREA, REPUBLIC OF	**5**	4		1
PAKISTAN	**1**	1		
TAIWAN, CHINA	**2**	2		
Europe				
Eastern Europe				
BULGARIA	**2**		2	
UKRAINE	**2**		2	
Russia	**8**	5	3	
Western Europe				
FINLAND	**1**	1		
FRANCE	**1**	1		
Total	**45**	**28**	**8**	**9**

*Source: IAEA/PRIS 2009a, WNA, WNN, u. a. * Resumption of construction works of a project originally started in 1972. Table 13 in the appendix provides a detailed compilation of reactors whose construction has come to a halt.*

4 Challenges for nuclear energy use

Regarding the development of nuclear energy use worldwide and especially the new construction of nuclear power plant, we have to take into account several aspects. Firstly, it is necessary that power plant manufacturers and their suppliers have sufficient staff and machine capacity for the simultaneous execution of construction projects worldwide. Secondly, fuel and particularly uranium supply has to be ensured over the planned operating life of the newly constructed plant. Thirdly, also the technological and legislative development on the energy markets can be hindering or beneficial for the expansion as it has an impact on the economic feasibility of the construction and operation of a nuclear power plant. Finally, there should be economically attractive investment and financing conditions for the capital-intensive construction of nuclear power plants. Thus, the new construction of nuclear power plants has to face challenges in the area of **industrial infrastructure** (4.1), **fuel supply** (4.2), **energy market development** (4.3), **financing** (4.4) and **other challenges** (4.5).

4.1 Industrial infrastructure

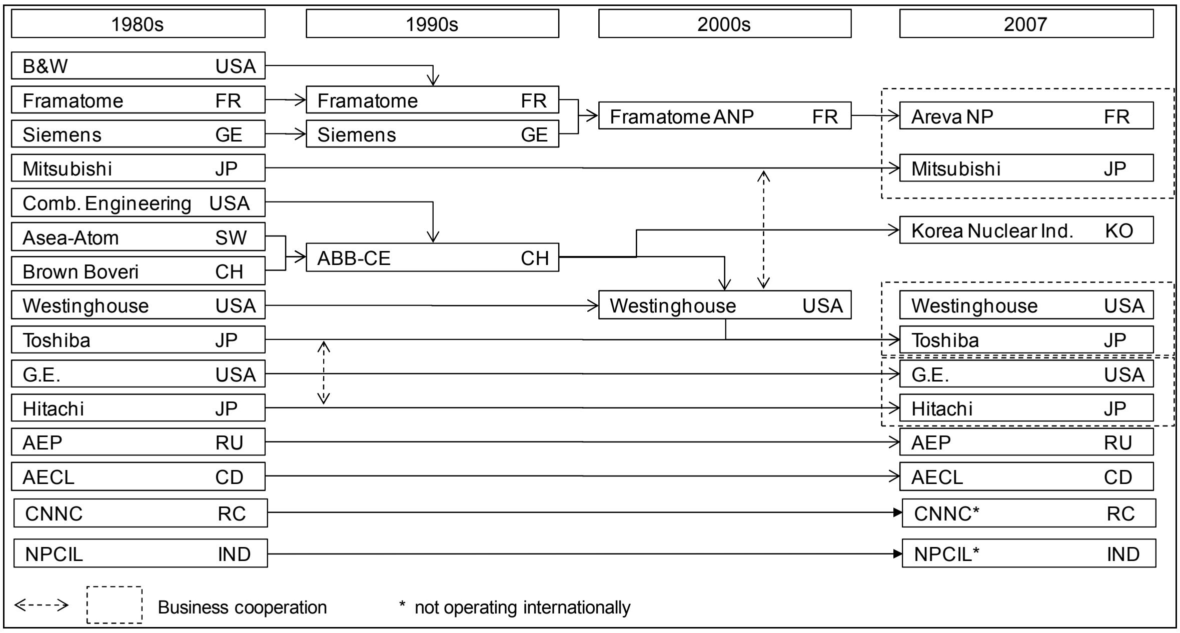
(1) The construction of a nuclear power plant requires a complex industrial infrastructure with an – increasingly international – division of labour between manufacturers and suppliers. Such an infrastructure does exist, but in comparison to the peak in 1979, only a limited number of new nuclear power plants has been built and put into operation during the past twenty years. Therefore, the infrastructure has clearly shrunk in comparison to the 1970s/1980s (IAEA 2008j, p. 17; Freeman 2006). It is necessary to analyse to what extent the existing infrastructure is sufficient for the construction of new power plants and what are the options for a development of the infrastructure. Potential barriers are mainly related to **manufacturer** and **supplier capacities**, **raw material** and **construction prices**, manufacturing requirements (and **safety requirements** in particular) as well as the **personnel situation**.

Capacities of manufacturers and suppliers

(2) The **nuclear power plant** market has an oligopoly structure. Altogether, there are eleven manufacturers with two of them not operating internationally (the Chinese CNNC and the Indian NPCIL). Another six have formed a total of three co-operations (see Figure 16). This means that there are only six companies that compete internationally. We have to take into account, though, that these companies do not offer the same product range, but have specialised in different power plant types. That means that not

every manufacturer can supply every order because the individual countries prefer different power plant types.

Figure 16: Development of the market structure of nuclear power plant manufacturers, as of 2007



Source: IAEA 2008k, Thomas et al. 2007, diagram by authors

(3) Little is known regarding **manufacturer capacity** (see Table 3). According to company information, Areva NP is currently able to build two to three reactor units per year; however, (manufacturing) capacity is currently expanded to five to six units per year (WNA 2009f; Areva 2009a).[3] After recent investments Mitsubishi intends to build up to four reactor units per year in its two manufacturing plants (Areva 2009b, JAIF 2008, WNN 2008, Suga 2008). The capacity of the Russian manufacturing group appears to be two to three reactor units per year (Areva 2009b). There is no capacity data available for the other manufacturers.

[3] It does not become clear from the existing literature whether Areva here means an annual maximum for completing or only processing at the same time two to three or five to three reactor units, respectively.

Table 3: Intended capacities of selected nuclear power plant manufacturers

Company	maximum production capacity (nuclear units/year)
Areva	6
Mitsubishi	4
AEP	3

Source: Areva 2009a, Areva 2009b, JAIF 2008, WNA 2009f

(4) The mentioned numbers already include recent manufacturer investments and expansions that are expected to be completed only in 2011. Note that the estimates are based on manufacturer data and – in the manufacturer's interest - might tend to be too high. We have not taken into account a possible dynamic adjustment reaction of manufacturers to an increased demand, i.e. an expansion of capacity in case of increased demand. The mentioned numbers are therefore to be interpreted as the **intended upper production capacity limit** on the part of the manufacturers.

(5) Bottlenecks from the **suppliers' side** have not been included yet. Each reactor unit of a boiling water or pressurise water reactor requires a very large reactor pressure vessel. Currently there is only one supplier worldwide – Japan Steel Works – that is able to manufacture single-cast reactor pressure vessels of the necessary size and weight of more than 500 tons (Areva 2009a, Morris et al. 2007). Japan Steel Works currently has a maximum annual production capacity of four reactor pressure vessels. Until 2012, an expansion of up to twelve reactor pressure vessels per year is planned (WNA 2009f).

This means that in the near future **worldwide annual production capacity for nuclear power plants** with boiling water or pressurised water reactors will be limited **from the supplier side** to twelve reactor units per years. Even though there is – in principle – the option to manufacture reactor pressure vessels of different sizes from several welded parts, single-cast reactor pressure vessels have become the safety standard because weld seams may constitute a weak point and increase costs and time for control and maintenance. As reactor pressure vessels have to be integrated into the structural construction at a comparatively early phase of the building process, Japan Steel Works will remain for the time being a bottleneck for large boiling water or pressurised water reactor units. Currently, the waiting list of the supplier is (similar to that of Le Creusot, the second-largest manufacturer of heavy casting products) three years (Areva 2009a, Froggatt 2008). Manufacturers have reacted to this situation and have ordered from Japan Steel Works already now reactor pressure vessels for expected, but not yet received reactor orders. The fact that they make down-payments of 100 millions $ confirms the market power of this supplier (Takemoto & Katz 2008).

Reactor pressure vessels for **smaller-type reactors** can also be cast by other suppliers – China First Heavy Industries (China), OMZ Izhora (Russia), Doosan (South Korea) and Le Creusot (France). OMZ Izhora is currently able to produce two reactor pressure vessels per year; and by 2011, it will be four vessels (WNA 2009f). The capacities of the other suppliers are not known. They partially plan to expand their capacity and also their ability to manufacture larger products (Areva 2009b). It will take some time, though, until other suppliers have developed the machines and expertise to produce certified reactor pressure vessels of the specifications and of the quality that Japan Steel Works' products have (Oden 2009, Takemoto & Katz 2008, Morris et al. 2007).

The situation is even made more difficult due to the fact that the manufacturers of nuclear power plants compete with **other sectors** (especially with the petrochemical industry) for production capacities of the manufacturers of ultra-heavy products (Harding 2007). This means that production bottlenecks – price-wise and/or regarding the quantity – will be further aggravated if there is an increased demand in other sectors.

(6) Apart from reactor pressure vessels, there are also production bottlenecks for **other components** likely to occur, among them:

- Steam generators,
- Compressors,
- Reactor cooling pumps,
- Heat exchangers,
- Diesel generators,
- Valves,
- Reactor-fit nickel alloys,
- Special piping systems, and
- Control instruments.

Partially these components have to be tailor-made for each new nuclear power plant (Bubb et al. 2005, NEI 2007a, Froggatt 2008, Harding 2007, Morris et al. 2007). Currently only Creusot Forge, for instance, is able to manufacture piping systems for Generation III+ reactors (Areva 2009a). However, supplier capacities for these components can be adjusted faster than those of ultra-heavy casting products. For these components, too, manufacturers of nuclear power plants compete with other sectors.

(7) We can summarize that on the part of the suppliers – especially regarding ultra-heavy products for reactor pressure vessels – , there are **bottlenecks** that could be a barrier for a faster expansion of the worldwide use of nuclear energy (Bubb et al. 2005; Schlissel & Biewals 2008; NEA 2008, 316; Moody's 2007, 9). In principle, it is possible for manufacturers and especially for suppliers to adjust production capacities; however in that case delays in the construction of new nuclear power plants are to be expected.

Raw materials and construction prices (e.g. steel)

(8) In the past years, **raw material prices** and subsequently prices of those materials directly made of them (such as steel) have **substantially increased**. In general, the main **drivers** of this development are:

- Heavily growing demand, especially due to the growth rate in Asian countries, such as China or India,
- (Geo-)political instabilities,
- Bottlenecks regarding raw material mining and processing as well as
- Monopoly and oligopoly markets in several sectors.

(9) The weak dollar exchange rate additionally forces up the prices that are expressed in US dollars. Price increases are less dramatic if measured in Euro.

(10) The production of steel has considerably increased during the last years. Whereas in 2001, about 800 million tons of steel were produced, the value amounted to about 1,300 million tons in 2007 (Deutsche Industriebank 2008). The **demand** is due to the development of the infrastructure, particularly in Asia's newly industrialized economies; but it is also caused by large traffic and logistics projects in Europe and the US. Another factor is the upswing of the civil engineering and automotive industries in Western Europe (Deutsche Industriebank 2007).

(11) Steel prices were driven by the increased **ore price** which rose from about 30$/t in 2003 to 140$/t in 2008 (Deutsche Industriebank 2007). The reason for this increase is high demand, scarce mining capacities and oligopoly supplier structures in the ore market (Hennes 2006a).

Due to the **financial crisis**, there has been a slight price relaxation. Prices remain at the 2006/2007 levels, though. A structural relaxation of prices is not to be expected in the long term; only for a few markets (Deutsche Industriebank 2007, 2008).

The development of steel prices has affected the construction costs of new nuclear power plants, which the example of Finland shows (Sailer 2007). But also the costs of **competing technologies** have increased. Thus, currently the costs for a coal-fired power plant amount to about 1,800 €/kW, whereas they were 1,100 €/kW only a few years ago. The investment costs for combined cycle gas turbine power plants rose from about 500 to 800-900 €/kW (Prognos 2008a). Increased costs of competing technologies are partially also due to capacity bottlenecks of power plant manufacturers.

Safety aspects

(12) The safety precautions in a nuclear power plant can be active or passive. **Passive safety precautions** are based on mechanisms that – in case of a severe incident – do not require any active control elements or human intervention, but only rely on gravity, natural convection, electric and physical resistance or physical temperature limits (PSI 2005). Generation III and III+ nuclear power plants increasingly apply passive safety elements.

(13) It can be assumed that the safety standards of a new nuclear power plant – in any case in Europe and in the US – are at a high level. New power plants have to comply with IAEA standards and have to have licenses in the individual countries. **High safety standards** are related to high specific investment costs. This becomes obvious if we look at the costs of nuclear power plants in Japan as these have to be additionally protected against possible earthquakes. According to an IEA study in 2005, the investment costs of a new nuclear power plant in Japan were estimated at 2,500 $/kW, whereas the average of 13 selected countries amounted to 1,700 $/kW (IEA 2005).

In deregulated energy markets where nuclear energy competes with other power plants (see 4.3), the connection between safety standards and costs leads to **conflicting priorities**: The more the nuclear power operator has to assert itself in the competition with other energy carries, the larger the incentive to lower the costs even regarding the safety standards. However there is no literature regarding the question to what extent this – in principle – existing incentive has an actual effect.

(14) Nuclear power plants have to guarantee the required safety standards in order to receive an (operating) license. Safety standards and qualified (national and international) control authorities, among others, are needed for this. Despite high safety standards, it is not possible to principally exclude severe incidents (core melting) for the here studied reactor generation III / III+. New safety systems can only reduce the probability of the occurrence of such an event (Sailer 2007; Streffer et al. 2005).

(Qualified) Workforce

(15) The number of employees that are necessary for the construction, commissioning und the continuous operation of a nuclear power plant varies according to reactor type, size and location. In the US, the construction of a Generation III+ reactor unit requires approximately 1,600 employees (Bubb et al. 2005, 3-6f, 6-21ff., see Table 4). Also the construction of the plant needs highly qualified and specialised staff with partially long training periods.

Table 4: Workforce requirements for the construction, commissioning, and operation of a nuclear power plant

Field of activity	Number of employees required per nuclear unit
Construction	1,600
Commissioning	600
Continuous operation, thereof:	200
- Health physicists*	33
- Reactor operators	17
- Senior reactor operators	25
- O&M technicians	125
Total	2,400

*Source: Bubb et al. 2005, 3-6f, 6-21ff. * „Health Physicists“ do not exist in Germany, but their job profile comes closest to that of a German radiation protection officer (“Strahlenschutzbeauftragter”).*

(16) The worldwide simultaneous construction of numerous nuclear power plants would require a multiple of these experts. The 1,600 construction employees are committed to one project

for a period of about five years (The Watt Committee 1984). Peak demand during a simultaneous construction of n reactor units corresponds to – for a slightly chronologically staggered construction start – approximately 0.675*1,600*n (Bubb et al. 2005, 3-5). Several studies underline that the international and regional workforce potential may be insufficient (Morris et al. 2007, 35; Hawkins 2008, 30; Bubb et al. 2005, V, 2-3, 2-5, 6-2; House of Commons 2009, 18; NEI 2007b).

(17) Altogether there are five factors that cause this **tense workforce situation**. In the past twenty years only few new nuclear power plants were built und the existing power plant are operated with an ever increasing efficiency; that means that manufacturers and operators have reduced their staff. In many countries with nuclear technology, there are no qualified construction workers for nuclear power plants, especially boiler constructors, pipe fitters, electricians and steel erectors. There is a scarcity of highly qualified experts for the supervision, commissioning and the operation on the international market. This refers particularly to engineers, nuclear engineers, inspectors, control room operators, and maintenance technicians. That means that the **existing number of required professionals** is not sufficient for the new construction of nuclear power plants worldwide.

Secondly, the major part of the workforce that currently operates and maintains nuclear power plants worldwide started working during the construction boom in the 1970s und will soon retire. In the UK, this will apply over the next ten years to between 18 and 40% of nuclear industry employees (Pagnamenta 2007, 1; House of Commons 2009, 19). Also in the US and in France, the future number of professionals will significantly decrease (Morris et al. 2007, 50; Schneider & Froggatt 2007). There will be an **age-related staff replacement required**, only to be able to keep on operating the existing number of nuclear power plants. This aggravates the workforce situation further.

Thirdly, manufacturers of nuclear power plants **compete with other sectors** for the same expert staff. Engineers with the necessary training are also in demand by the military, civil infrastructure construction and nuclear waste disposal (House of Commons 2009, 19). Qualified construction workers are also required for similar large-scale infrastructure projects.

Fourthly, following low demand and bad job market prospects during the last years also the training capacities for qualified operating staff have shrunk (Schneider & Froggatt 2007). In the US, for instance, the number of training programmes has decreased from 65 to 29, since 1980. Out of 22 training programmes that were available in Germany in 2000, there will be only left five by the year 2010 (Schneider & Froggatt 2007). For Germany, such a development was foreseeable already in the mid-1990s (Knorr 1995). There are not enough power plant simulators for the training of control room operators. As these have to be specifically adjusted to each power plant, the US Department of Energy expects bottlenecks to occur even in this respect (Bubb et al. 2005, 4-2). For a worldwide renaissance of nuclear energy, the **missing training capacities** would have to be rebuilt and updated to the state of the art – both at universities and within companies that operate nuclear power plants. However, the knowledge transfer in the training process will be made more difficult due to the mentioned retirement of experienced employees.

Fifthly, the **long training periods** make it difficult to immediately increase personnel capacities. In 1984, the minimum professional training for a nuclear energy engineer with a minimum experience took five years, for instance (The Watt Committee 1984, 34). Also maintenance technicians that make up the majority of the operating staff (see Table 4) have to complete a special, prolonged training due to the high safety requirements (Bubb et al. 2005, 6-23).

(18) Even though it is difficult to quantify the exact **impact of these five factors** it is reasonable to assume that the workforce situation regarding nuclear energy (construction) technology will slow down the simultaneous construction of new nuclear power plants throughout the world. This coincides with many assessments in the literature (IAEA 2008, 31f.; IEA 2006, 360f.; NEA 2008, 316; Harding 2007, 5; Squassoni 2008; Bruzzano et al. 2008, 89). Not yet included is the fact that the same highly qualified workforce will be required both during the construction phase and the decommissioning of older nuclear power plants and the disposal of nuclear waste. This leads to competition even within the nuclear sector.

It has to be taken into account, though, that workforce bottlenecks will not be the same in all countries. They are due to the high quality requirements and the corresponding long training periods.

In **China**, the fast expansion already results in a scarcity of accordingly trained engineers and scientists; something that may cause safety problems. In order to be able to appropriately staff research institutions and to ensure the operation and monitoring of the planned nuclear power plants, 13,000 specialists would have to be trained in the near future (Sternfeld 2009).

4.2 Fuel supply

(1) The production of fuel elements to be used in a reactor comprises the following four steps: uranium mining, conversion, enrichment and fuel element production. After having been used, the fuel elements can be recycled. However, due to technical and economic problems, this option is hardly used. This process chain will be analysed regarding **possible bottlenecks**.

(2) The **range of uranium resources** can be determined comparing the reserves and other conventional resources with the demand of 66,500 tons in the year 2006. The result is a static range of the uranium reserve of 50 years, of the identified uranium deposits of 82 years and of the conventional uranium resources of 240 years (BGR 2008).[4] For an expansion of nuclear power plant capacities – all other conditions remaining equal – the range would be reduced correspondingly. **No bottleneck** regarding uranium reserves or resources is to be expected, at least short- or medium-term.

(3) Uranium deposits and consequently **uranium mining** is limited to a few countries (oligopoly market). In addition, current mining capacities of 40,000 t uranium per year are not sufficient to meet the demand of 65,000 t. The excess demand is supplied by secondary sources. These consist of previous civil reserves or of strategic (military) reserves, particularly in Russia and the US (BGR 2008). A small part of the demand is supplied by recycled fuel elements. Currently, the secondary sources are gradually depleted. From about 2010-2015 onwards, new **additional mining capacities** will be required to meet uranium demand. It might be possible to develop new mines (which takes about 10 years), to extend existing mining capacities or, in case of increasing prices, to re-open mines that were closed during the last two decades due to low uranium prices. A **bottleneck** is likely to occur by 2020.

(4) The **conversion of uranium** is necessary in order to produce – from the mined uranium – compounds that can be further processed. Over 90% of worldwide conversion capacities are located in Canada, France, Russia, the US and UK (IAEA 2009). A significant part of the existing conversion plants has to be replaced within the foreseeable future (IAEA 2008j). The

[4] "Identified uranium deposits" are derived from feasibility studies for mines and from less explored deposits. "Conventional resources" are those resources that can be inferred due to the geological knowledge of uranium deposits and known regional geological structures as well as such resources that are presumed to exist in areas with geological formations that contain uranium (Prasser 2009).

construction of new or extended capacities of such chemicals plants can be carried out comparatively fast and will therefore **not create a significant bottleneck.**

(5) The conversion is followed by uranium **enrichment** which is provided by suppliers in only a few countries (France, Russia, Germany, the UK, the Netherlands, the US, China, Japan). Current enrichment capacities are limited, similar to uranium mining capacities (Combs 2006; Neff 2006b). Even though gas centrifuges for enriching uranium can be erected comparatively fast and Areva and Urenco are planning new capacities, among others, in the US, enrichment capacity **bottlenecks** are to be expected in Europe and the US around the year 2015 (Combs 2006; Neff 2006b).

(6) The **production of fuel elements** to be used in power plants requires massive technical resources. The largest production capacities are located in France, Germany, Russia and the US. At least seven other countries produce fuel elements, mostly under the license of power plant manufacturers (IAEA 2008f). Currently, there are **no capacity bottlenecks** regarding the production of fuel elements. There was no data found indicating bottlenecks in the near future.

(7) The **fuel costs** of nuclear power plants are mainly determined by two components (see Prognos 2008), the cost of supply (including use) and of disposal. We will look at the latter in Section 4.4. The uranium price usually accounts for less than 25% of **total fuel costs**. About 20% of the electricity generating costs can be allocated to fuel costs (PSI 2005; Prognos 2008; NEA & IEA 2005). If uranium prices are doubled, generating prices thus will increase by about 5%. Changes in uranium prices therefore have little (though not a negligible) impact on fuel costs. As opposed to this, for combined-cycle power plants, fuel costs constitute over 70% of electricity generating costs and for coal- and lignite-fired power plant about 50% or 25%, respectively (excluding prices of CO_2 certificates).

For the supply side, uranium prices play an important part. Between 1990 and 2003, uranium prices were at a low level due to the supply from secondary sources (see above). Unprofitable mines were closed because of the low prices. As secondary reserves will fast deplete, **additional mining capacities** will be required from 2015 onwards. However, mines will only become profitable again if uranium prices increase. This could be a reason for bottlenecks. Before new mines are able to start operations, demand may already have largely exceeded supply with the corresponding consequences for the price, i.e. volatility and possible peak prices (see Neff 2004, 2006a/b, 2007; Combs 2004, 2006).

Uranium prices have recently increased; and also the fluctuation range of the prices has grown. Available data shows between 20$ and 250$ per kilogram of uranium (MIT 2003; IEA 2004; Morris et al. 2007). Supply bottlenecks and the subsequent volatile prices are likely to characterize the situation on the uranium market until 2020 (Neff 2006a). According to studies by Combs (2006) and Neff (2006a), uranium prices can be expected to lie at the level of the actual mining costs from about the year 2030 onwards. In comparison to the use of natural uranium, the recycling of nuclear fuels is more expensive and therefore it is of comparatively little importance.

The **result** is that fuel supply bottlenecks could cause higher and more volatile prices in the period between 2015 and 2030. However, as uranium prices play a comparatively small role regarding the economic feasibility of nuclear power plants, we assess that they affect the decision in favour or against the new construction of a nuclear power plant only to a small extent.

4.3 Developments in the energy markets

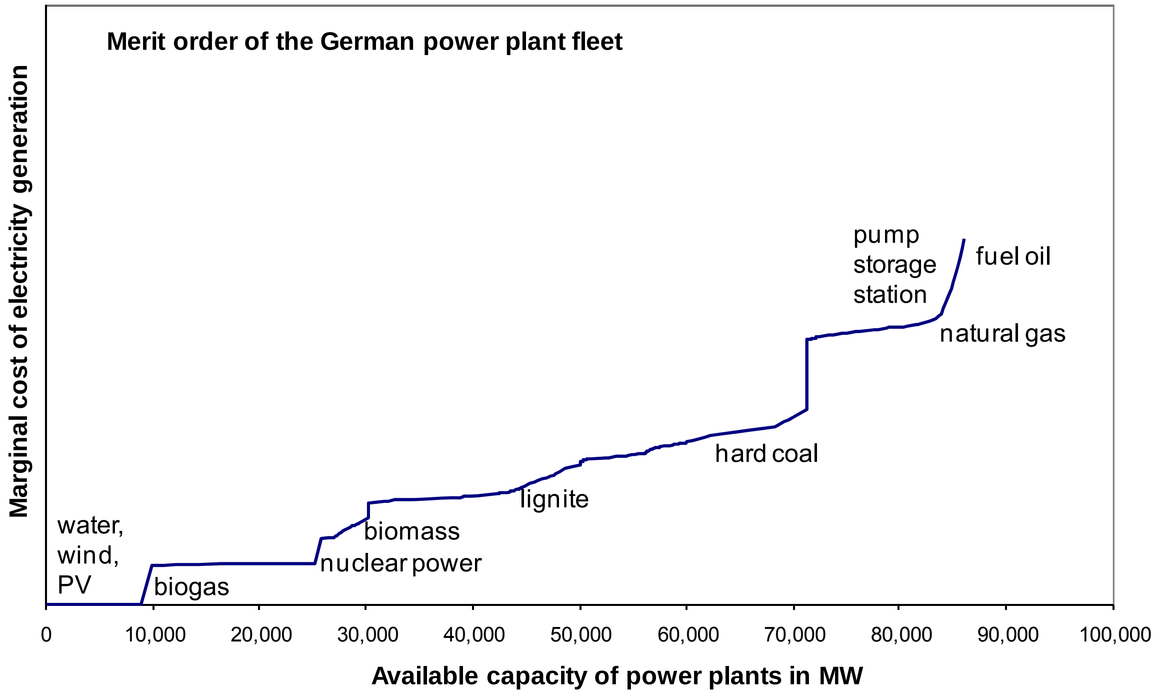
(1) In **regulated markets**, the price is determined by the full costs of a power plant (if applicable the purchase price of electricity). In this case higher generating costs can usually be passed on to the final customer. Final customers cannot avoid price increases as they are not able to change the supplier.

(2) However, in many Western countries, energy markets were deregulated during the last decade. This means that supply and demand of electricity determine the price. Electricity generating plants compete with each other.

In many **deregulated markets**, the use of power plants follows the merit order. The power plant with the lowest marginal costs operates the most; all other power plants are ranked according to their marginal costs until the load for the entire year is covered. Here, it is the power plant that operated last (i.e. the one with the highest marginal costs) that determines the price that is paid for the electricity generated by different power plant types even if these partially have lower generation costs. This price, in turn, determines the revenues of a power plant in the corresponding regional market.

Figure 17 shows the example of the merit order of the German power plant fleet. The more a power plant lies to the left, the lower its marginal costs are and the more hours per year it will be used for generating electricity.

Figure 17: Merit order of the German power plant fleet



Source: Prognos AG. PV = photovoltaic

(3) In the **base-load range**, nuclear power plants compete with other base-load power plants, such as lignite-fired power plants. The CO_2 certificate price should benefit nuclear energy in this case. Operators of coal- or lignite-fired power plants will include the CO_2 costs in the price. (Future) coal- or lignite-fired power plant with CCS (Carbon Capture and Storage) will have to pay very little – or nothing at all – for CO_2 certificates and consequently these costs will not be included in the price. However, power plants with CCS will have higher fuel costs because of the lower efficiency.

Due to the comparatively low marginal costs of a nuclear power plant, it will reach high annual full-load hours. As long as nuclear energy is only a small portion of the required base-load capacity, nuclear power plants will not determine the price, but act as a price taker. The profitability of a nuclear power plant thus depends on the marginal costs of the last operated power plant as this determines to what extend fixed costs (capital and fixed operating costs) can be covered. In other words: The profitability of a nuclear power plant partially depends on the power plant portfolio of the individual country. As nuclear power plants are especially capital-intensive, they have to be able to generate revenues over a long period of time.

(4) Electricity generation from **renewable energies** (such as wind power) has hardly any marginal costs, which means that renewable generators take top positions in the merit order and thus compete with nuclear power. In addition, there are legal preference regulations in the grid, i.e. “must-run” stipulations. With a strong **expansion of renewable energies**, nuclear power plants increasingly will be pushed to the right in the merit order and will operate less frequently. This may lead to a situation where – during times when lots of renewable energy is available – nuclear power plants have to be down-regulated as there is no demand for their power. Due to safety and technical reasons, however, nuclear power plants are not suitable for frequent and short-term changes in output.

Eon apparently is aware of such a conflict of interests between renewable energies and nuclear power. In March 2009, it became public that during a hearing in the UK, Eon has warned against the unrestricted promotion of renewable energies as this would force Eon to abandon its plans for the construction of new nuclear power plants in the UK (Macalister 2009).

(5) On the **free market**, price risks can be mitigated through (long-term) futures contracts. The investment risks of the generation company are shared with the price risks of the purchaser. For nuclear power plants with high investment costs, such **long-term contracts** can ensure the necessary long-term security (see the financing of the nuclear power plant under construction in Finland).

4.4 Financing issues

(1) The construction of a nuclear power plant is very capital-intensive (Gawlicki 2008, 23). The **capital costs** to be raised for the construction typically correspond to over 60% of the total generating cost of nuclear energy (IAEA 2008j, 27; NEA & IEA 2005). Therefore, the profitability of a nuclear power plant depends mainly on the financing conditions that the operator can achieve for the construction of the nuclear power plant.

The **range** of investment costs or capital costs of a nuclear power plant stated in the specialist literature is very **wide**. The examples of selected nuclear power plants in Table 5 show that the information varies considerably for individual countries. The specific costs, i.e. the costs per kilowatt of installed capacity, are between 670 €/kW and 5,500 €/kW.

Table 5: Expected construction costs of nuclear power plants in the planning or construction phase

Region	Country	Power plant	Specific cost min. (€/kW)	Specific cost max. (€/kW)	Total cost min. (billion €)	Total cost max. (billion €)	Comment
America	**USA**	Turkey Point	1,660	5,500	n/a	n/a	Minimum represents mere construction cost. Maximum contains additional costs of financing and of infrastructure.
		"green field"-Standort	2,350	4,300	5.20	9.52	Minimum represents development and construction cost. Maximum contains additional costs regarding real estate, development and financing.
		Bellefonte 3 & 4	1,700	5,300	3.81	11.90	Minimum represents combined construction cost. Maximum represents "total cost of ownership", according to operator.
Asia	**China**	Yang-jiang 1	1,000	1,380	6.87	9.00	Total costs refer to all 6 units to be erected at the Yangjiang site.
		Hong-yanhe 1	1,100	1,200	4.80	5.10	Total costs refer to all 4 units to be erected at the Hongyanhe site.
	India	Kudan-kulam	1,000	2,400	2.00	4.76	Total costs refer to the 2 units to be erected at the Kudankulam site.
	Japan	Shimane 3	n/a	3,300	n/a	4.50	
		Tomari 3	2,200	n/a	2.00	n/a	
Europe	**Russia**	Lenin-grad 2-1	670	1,900	1.56	4.50	Total costs refer to the 2 units to be erected at the Leningrad 2 site.
		Severo-dvinsk 1 & 2	3,500	3,800	0.25	0.27	Each unit's capacity amounts to 35 MW. Therefore, in comparison to other nuclear power plants, the figures for specific cost are decisive.
	Fin-land	Olkiluoto-3	1,740	3,080	3.00	5.30	Unclear whether costs will rise further.
	France	Flaman-ville 3	2,000	2,400	3.30	4.00	Unclear whether costs will rise further.

Source: ATW 2000, ATW 2007b, ATW 2009a,WNA 2008, WNA 2009b, WNA 2009h, HB 2008, Thomas et al. 2007, Verivox 2009b, Asia Times 2002, NPCIL 2008, PowerTech 2009, Rosatom 2008, Spiegel 2006, FT 2009. All cost figures are rounded.

For cost information regarding nuclear power plants, there is often only little data available and a large insecurity about what costs are actually included. This is particularly true for the cost data of **US nuclear power plants**. The data regarding specific costs vary between 1,600 €/kW and 5,500 €/kW. This is, among others, due to different calculation methods. The power plant operators partially only state the development and construction costs or they include infrastructure and financing cost. The latter heavily depends on the interest rate and the construction time. Delays in the construction, as examples in Finland and France show, lead to higher investment and financing costs.[5]

In addition, some information is based on manufacturer data and the contractually agreed sum (example China). Or the information refers to – as is the case in India – to the planned costs. For past nuclear power plant projects in India, the planned costs often were exceeded and finally were about 170% and even up to almost 400% of the original budget (Thomas et al. 2007).

Also the capacity of a plant generally is important for the actual amount of specific costs. “Floating” nuclear power plants (Severodvinsk 1 & 2), for instance, with a capacity of 35 MW each have higher specific costs than large plants with over 1,000 MW. For cost reasons, larger plants are usually preferred. It is also often unclear whether the data already contain costs for decommissioning and disposal.

The cost data presented here for the construction of nuclear power plants have to be compared to the costs of **competing technologies**. The specific investment costs for coal-fired power plants currently amount to approximately 1,800 €/kW, those of a combined-cycle gas turbine power plant to about 800 to 900 €/kW (Prognos 2008a). The comparison shows that above all combined-cycle gas turbine power plants have much lower specific costs than nuclear power plants. But also coal-fired power plants usually have specific costs that are lower than those of nuclear power plants.

(2) Since the 1980s, the **financing conditions** for the construction of nuclear power plants have substantially changed (IAEA 2008i). The major part of today’s worldwide operating nuclear power plants were constructed in regulated electricity markets. This meant a secure customer base and sufficiently high electricity prices to cover the costs. The investments were politically encouraged by State loans and/or State guarantees. Additional costs caused by construction delays could be allocated to the electricity price and eventually passed on to the customer. The operator was guaranteed a profitable investment.

(3) Today, countries increasingly rely on **deregulated electricity markets**. In addition, an **international capital market** has emerged in the wake of globalization. This has two

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[5] Only after one year of construction activities, Areva had to increase the budgeted costs for the European pressurised water reactor (EPR) in Flamanville from 3.3 billion € to 4 billion € (Verivox 2009b). For the Finish EPR which also is built by Areva, the current cost increase after four years of construction already amounts to 2.3 billion €. Thus the originally budgeted total investment increases from 3 to 5.3 billion € (FT 2009).

consequences: Firstly, nuclear power plant operators do not have a long-time guarantee of an electricity price and customer base. Nuclear power plants must assert themselves in the price competition with other energy conversion technologies.

Secondly, operators now must increasingly finance the construction of their plants with **equity** or with debt capital provided by the (international) capital market as the State only rarely adopts the role of a sponsor any longer (Geusau 2006, 6). And private investors compare the expected profit of different energy conversion technologies against each other. In national economies without a planned-economy organisation of the energy sector, operators of nuclear power plants compete with other energy conversion technologies not only regarding electricity sales, but also regarding the financing of their investment.

(4) For instance, 80% of the reactor unit **Olkiluoto** 3 in Finland that is currently constructed by Areva NP is **debt financed**. (Geusau 2006, 20f.) According to Moody's assessment, the debt-to-equity ratio of future construction projects is expected to be 50% (Moody's 2007, 20). Assuming that this portion is prototypical for future construction projects in deregulated electricity markets and taking into account the high capital intensity of nuclear power plants, the need of external financing will correspond to several billion US dollars per reactor unit. The economic **payback period** depends on the individual project and has increased during the last years due to higher raw material prices (see 4.1). Because of regular consulting projects for electricity utilities regarding power plant investments in the European context, Prognos has the necessary experience to estimate the current revenue situation. We estimate that currently in Western Europe the economic payback period (that includes a market interest rate) for combined-cycle gas turbine power plants usually is 10 to 15 years and for coal/lignite-fired power plants 15 to 20 years, respectively. It is even longer for nuclear power plants. Investing into nuclear power plants has the disadvantage that a true return is only to be expected in a comparatively distant future.

Due to the high capital intensity of nuclear power plants, operators face challenges both regarding equity and debt capital. On the one hand, financing has to include a high portion of equity in order to underline the credibility of the construction project and to attract outside capital (IAEA 2008i, 2f). On the other hand, equity-financed construction costs constitute a substantial part of the operator company's market capitalization (Gawlicki 2008, 23). This means that unexpected cost increases during the construction of the power plant or a completely failed construction project may threaten the existence of the operator as equity is used up fast.

From the lender's perspective, this means – reversely – a **credit default risk**. This is aggravated by substantial insecurities regarding the calculation of **construction costs** and **times** (IAEA 2008i, 6f). In the US, for instance, the actual costs for the construction of the first generation of nuclear power plants exceeded the originally budgeted costs by 219% (Aston 2006). There is no noticeable learning curve in the US regarding cost estimations; and even for construction projects that have come comparatively far, final total costs often have been massively underestimated (Gielecki & Hewlett 1994). Quite recently, the construction of the EPR plant (European Pressurised Water Reactor) Olkiluoto 3 in Finland has shown the insecurities that investors face. Already today, the costs exceed the original budget by 2.3 billion € (or 76%; FT 2009). The plant is expected to be put into operation in 2012 – three years after the planned date (WNN 2009c).[6] Delays in the planning, licensing and construction phases cause considerable costs as during this time, credit interest has to be paid; and thus the power plant becomes profitable at a later point in time. Even stricter safety requirements, the above mentioned workforce bottlenecks or increased steel prices can force up capital costs substantially (CBO 2008; Hultman et al. 2007). Consequently, profitability and competitiveness of nuclear power decrease.

(5) Nuclear power plants need a **guaranteed long operating life** and a guaranteed **high full-load operation**, i.e. the guaranteed purchase of the generated output, in order to be able to refinance the high capital costs. The proof of a guaranteed long-term demand is an essential prerequisite for stable financing conditions. Here, we can identify **further risks** for nuclear power plant operators.

(6) In addition to investment costs, the operator also incurs **running costs** for plant operation and maintenance as well as for the fuel uranium (Chernoff & Friedman 1990, p. 3). Over the entire fuel cycle, **fuel costs** make up about 15% of total electricity generating costs of nuclear power (NEA & IEA 2005). A doubling of uranium prices increases generation costs by 5 to 10% (IAEA 2008i, p. 1). Against the background of a possible worldwide expansion of nuclear energy use and bottlenecks in uranium mining, increased and more volatile prices are not an unrealistic assumption (see Section 4.2). However, the impact on the competitiveness of nuclear power depends largely on the further

[6] In the case of Olkiluoto 3, the buyer consortium led by the Finish power plant operator TVO is said to claim compensation and penalties amounting to 2.4 billion € from Areva and its present partner Siemens. The manufacturers, in turn, claimed a compensation amounting to 1 billion € and applied for arbitration to the International Chamber of Commerce (ICC) in Paris in December 2008 (Welt 2009).

price development of the competing energy sources coal, lignite and natural gas (see 4.3).

(7) The competitiveness of nuclear energy is heavily affected by the **policy** and **regulatory framework**. In an international emission trading system, an increasing CO_2 price should constitute a relative advantage for nuclear energy. All State measures taken to increase planning security for investors and to minimize risks will be beneficial to the construction of new nuclear power plants. This includes legally guaranteed minimum feed-in prices for nuclear energy as well as the stability of the pursued energy policy. To reduce investment costs even in deregulated markets, the State can act as a direct of indirect lender through equity supply (as in France where the State holds the majority of the shares of market leader EdF), funds for the promotion of low-CO_2 technologies, State guarantees, State bad debt insurance or tax incentives (Moody's 2007, 18; Gawlicki 2008; IAEA 2008i, 4f.).

According to Gawlicki (2008), in the US it would not be possible to construct the current new nuclear power plants without such State support (Gawlicki 2008) (see 7.1.2). Legislation plays an important role regarding the question whether the operator – in case of exceeding construction budgets – may pass on part of the unexpected construction costs via the electricity price to final consumers. Without this option, the effective construction costs of the operator may be substantially higher. In the US, a planned nuclear power plant has been stopped due to this reason (Platt 2009).

(8) On the other hand, the legislator could **aggravate the conditions** for the new construction of nuclear power plants by phasing out nuclear energy or increasing the minimum indemnity insurance premium. There is also the risk of the low social acceptance of nuclear power to be taken into account. A serious incident at any place can fast destroy the confidence in nuclear energy use. The subsequent likely shorter operating life of nuclear power plants would make many investments unprofitable. This is what happened after the Chernobyl incident (IAEA 2008j, 17).

(9) Finally, the operating company also has to take into account the costs for **decommissioning** the plant and **disposing** of the nuclear waste. Worldwide, there is no solution yet regarding the disposal of high-level radioactive waste. The IAEA assumes that decommissioning and disposal costs make up 10% and 15%, respectively, of the capital costs of a plant (IAEA 2008j, p. 30). There are also estimates that assume higher numbers.

Regarding the **decommissioning of reactors**, cost estimates vary between 200 million and 2 billion € per 1,000 MW plant (Geusau 2006, p.9; Prognos 2008). The costs for the current dismantling of the two decommissioned German nuclear power plants Stade and Obrigheim are estimated at approximately 500 million € which corresponds to 0.7 - 1.4 billion € per 1,000 MW (SZ 2003; Reuters 2008, IAEA/PRIS 2009a). These numbers suggest that decommissioning costs could reach the same size as the investment costs.

The costs for **final disposal** are hard to estimate. A distinction has to be made between low-level and intermediate-level radioactive waste, on the one hand, and high-level radioactive waste, on the other hand. The former originates from the dismantling of the nuclear power plant, for instance, and the latter are the fuel elements to be disposed or the residuals from recycling spent fuel elements. For short-lived low-level or intermediate-level radioactive waste, near-surface permanent repositories have become the international standard (BfS 2009b). The budgeted construction costs for completing the German permanent repository for low-level and intermediate-level radioactive waste in the Konrad mine by the year 2013 amount to 1.8 billion € (Kleemann 2007). Total costs until the end of the operating period between 2040 and 2080 are budgeted with an amount of approximately 5 billion € (BfS 2009a). In comparison, the US pilot project for the permanent disposal of long-lived intermediate-level radioactive waste that produces only little heat are estimated at over 10 billion US$ until the year 2070 (Rempe 2007).

There are no similar numbers available for the **final disposal of high-level radioactive waste**. The challenge consists in that this waste contains long-lived radionuclides and generates heat. Internationally the disposal in deep geological formations of the Earth's crust is assumed to be safest. Even though this issue has been the subject of scientific research for about 50 years, there is still no operative permanent repository for spent fuel elements that are not to be recycled, but are to be disposed of permanently. Existing international planning approaches for permanent repositories range from conceptual considerations to specific plans (BfS 2009b).

No final clarification has been reached regarding who will pay for the possible **additional costs** related to the renewal and maintenance of permanent repositories. According to the current financing model in Germany, nuclear power plant operators have to make provisions for future permanent repositories. In other countries, there are other regulations or even no regulations at all. It is unclear whether the State will be able to make additional claims when provisions do not cover actual disposal costs (and whether the operating company has to pay these additional claims at all) – or whether society has to bear the additional costs. This means that operators and investors have a financial risk regarding the amount of actual costs and payment liabilities not only before and during, but also after the operation of the plant.

(10) Due to such risks that are difficult to calculate, **investors are rather hesitant** to finance nuclear power plants (Aston 2006; Macalister 2008). The rating agency Moody's (2007) arrives at the conclusion that the investor risks related to the construction of future plants will increase even further. Thus the already high risk premium on the capital markets (3 to 5 % point in comparison to other electricity generating technologies, IAEA 2008i) is unlikely to decrease in the future. According to IAEA statements the biggest challenge for the new construction of nuclear power plants therefore consists in attracting investors with sufficient debt capital for adequate conditions (IAEA 2008l; IAEA 2008i). Many experts coincide with this assessment (Aston 2006; Moody's 2007; Geusau 2006; Macalister 2008).

(11) The **current international economic situation** – at least temporarily – further complicates the financing conditions for the construction of new nuclear power plants. Firstly, in 2009 for the first time after World War II global **electricity demand** has decreased. This decrease appears to occur both in OECD and non-OECD countries such as China. The decrease eases the direct pressure to build new power plants (IEA 2009). Secondly, the **financial crisis** has reduced the risk willingness of investors. Due to the presented risk profile of nuclear power plant construction and given the current market conditions, it should be difficult for operators to attract debt capital. Thirdly, the **priorities** of some governments have changed. Political efforts mainly focus on mastering the economic crisis; and it is currently difficult to put issues such as climate protection on the agenda given the (media) dominance of the economic crisis. On the other hand, following the international economic down-turn, raw material and steel prices have recovered from the peak values in mid-2008 which has a positive effect on construction costs.

4.5 Other challenges

(1) For some countries, the **integration of nuclear power plants into the high-voltage grid** constitutes a challenge. The integration of a nuclear power plant into the power plant fleet has to take into account grid capacity, quality and stability. A nuclear power plant should not provide more than 10% of total grid capacity in order to guarantee grid stability in case of failures (IAEA 2008i).

Several countries that have implied that they will operate nuclear power plants in the future have a grid capacity of less than 10 GW. Most commercially available nuclear power plant types have a minimum capacity of 1 GW. This means that they could not comply with the 10 % standard (IAEA 2008i). Grid extension or smaller nuclear power plants would be necessary. This aspect could not be analysed within the framework of this study, though.

(2) The construction of a nuclear power plant poses large **logistics challenges**. Capacities of over 1,000 MW require large and heavy components of a power plant to be transported to the power plant site. This means that roads have to be **suitable for heavy transports** and that obstacle such as bridges and gradient have to be avoided.

(3) Another challenge of nuclear energy use is to minimize the **risk of proliferation** of nuclear weapons. In order to guarantee international security, the distribution of nuclear technology, nuclear material or related knowledge for military purposes has to be minimized.

The **new construction of nuclear power plants** can increase several proliferation risks as the existence of nuclear power plants in more countries in principle increases the possibility of gaining access to nuclear material. There are three specific risks: Firstly, each country with civil nuclear power plants always needs scientists and technicians with **basic nuclear knowledge** that later on generally also could be used for the development of a nuclear weapons programme. The latter requires substantial additional knowledge, though. Secondly, countries can install **uranium enrichment and recycling plants** in order to supply their civil nuclear power plants with fuel. These can – in principal – also be used for the production of weapons-grade material. The construction of such plants does not fall under the Nuclear Non-Proliferation Treaty. Currently, there are only a few countries that enrich uranium (see 4.2). From the operators' perspective, it may be beneficial to produce the required fuel elements themselves in order to be independent of other countries. The current example of

Iran shows how the presented intention for a civil use of nuclear power is connected with the demand for an own uranium enrichment plant. Thirdly, terrorists can get a hold of nuclear material and use it for the construction of so called "**dirty bombs**", i.e. bombs with conventional explosives combined with radioactive substances that release radioactivity when exploding (Kerzel & Thränert 2009).

The four most important politicy instruments against the proliferation are the Nuclear Non-Proliferation Treaty and the Additional Protocol to the Nuclear Non-Proliferation Treaty, the Statute of the International Nuclear Energy Organisation as well as the Treaty for the Foundation of the European Nuclear Community (ECN 2008). Several initiatives, among others the Proliferation Security Initiative, have been started to strengthen these instruments (ECN 2007).

Due to the risk of proliferation, the building of an infrastructure for the civil use of nuclear energy involves security policy risks. However it is difficult to evaluate how possible newcomer countries evaluate these challenges within the context of their own nuclear ambitions and whether they would constitute a serious obstacle, or whether – on the contrary – the possibility of proliferation for some countries constitutes an incentive to start nuclear energy utilization..

4.6 Preliminary conclusions

(1) The infrastructural and other challenges presented in this chapter can be summarized in the following way (Figure 18).

Figure 18: Summary of the challenges regarding the new construction of nuclear power plants

- Infrastructure
  - Capacities of reactor manufacturers
  - Capacities of suppliers
  - Qualified workforce
- Fuel supply
  - Uranium mining capacities
  - Uranium enrichment capacities
- Deregulated markets
  - Customer base
  - Electricity prices
  - Passing on cost increases to consumers
  - Competition of renewable energy and other energy sources
- Financing
  - Payback periods
  - Acquisition of loan capital (amount and conditions)
  - Risk that failing project may use up equity
  - Construction time
  - Expensive debt capital
  - Policy and regulatory framework (security)
  - Decommissioning and permanent disposal
  - Social acceptance (risk of an incident)
  - World economic crisis: delayed increase in electricity demand
- Other challenges
  - Integration into the high-voltage grid
  - Logistics challenges (e.g. heavy transports)
  - Risk of proliferation

Source: Prognos AG

(2) Taking into account the aspects described in this chapter it has to be analysed how realistic the WNA announcements of new constructions really are (see 3.2).

5 Discussion of a realistic development path for nuclear energy and conclusions

(1) **Experience** from the past shows that the number of announcements often is larger than the number of reactors eventually built (see 2.3).

In addition to the empirical data, it is a fact that particularly those reactors announced until 2020 already today would need to show visible progress regarding **planning and licensing** in order to be completed by 2020 after 5 to 8 years of construction.

For many of today's announced reactors, however, there is not even a specific site known yet, not to speak of any order.

Finally, the large number of announced project completions would require **capacities of manufacturers** – which during the past 15 years have hardly built more than 50 nuclear power plants simultaneously worldwide – to rise significantly. It has taken 15 years, though (between 1966 and 1980) during the nuclear energy boom for the construction activity to reach its peak.

Against this background, it appears adequate to **critically assess** current announcements and thus arrive at more realistic future estimates regarding the start of operation of new nuclear power plants. Several existing scenarios of OECD-NEA and other institutions are not suitable as data basis for such an evaluation as they do not contain sufficiently detailed data on the level of individual reactors.

(2) We have used the lists of **planned** and **proposed** projects of the Wold Nuclear Association (WNA) and the International Journal for Nuclear Power (ATW) to describe the plans or proposals for new reactors. As the ATW lists only have a time horizon until 2020, we will limit the remaining discussion to the WNA data. According to WNA, about 110 new reactors have to be considered until 2020 and a total of over 380 new plants until 2030. These data provide a comprehensive overview over the possible **demand** for reactors. This has to be put into the context of the probable development of the **supply** of reactors and, in particular, of reactor pressure vessels as well as into relation to the other challenges described in Chapter 4.

5.1 Realisation of announced projects

(1) Based on the challenges in the areas infrastructure, fuel supply, energy markets, financing etc, the following section will determine what part of the projects listed by the WNA will actually be started or completed, respectively. We will **evaluate** the announcements of a country by using a multi-step procedure to assign an indicator-based **coefficient** to the individual expansion plans. The derived realistic development path is subject to the provision that the challenges that have not been quantified here (see 4.6) will not have an additional negative impact on the result.

(2) Initially, we will use three **indicators** that are individually weighted and included in the total evaluation. In the following, the used indicators are listed with the indicator's weight in brackets:

- **practical experience** with the construction of new reactors in relation to the planned size of the new power plant (40%),
- **political stability** (20%), and
- **credit rating** of the country (40%).

(3) The weighted average of these three values constitutes the **result of the indicator evaluation**. Due to the importance that deregulated energy markets have for the actions of potential power plant investors (see 4.3) we attach special importance to a fourth factor. It is individually identified including its impact on the total result:

- **implementation probability** of new reactor construction within the framework and the competitive environment of an individual energy market.

The result of the indicator evaluation and the implementation probability provide a **degree of realisation**. Further on, we assume that the international economic crisis and the bottlenecks regarding the supply of reactor pressure vessels will cause a **delay** in the realisation of reactor projects. This delay and the above mentioned degree of realisation will be used to arrive at a **final result**.

In the following, we will describe the **procedure** that was used to operationalise these indicators and consolidate them to a total evaluation of the announced projects.

1st indicator: Experience with new construction

(4) The **new construction activity** over the last years can be retrieved from the IAEA's reactor database (IAEA/PRIS 2009a). As the historical period we will analyse the time after 1990 because it is similar to the time frame of the prognosis horizon, i.e. approximately twenty years. This approach prevents the inclusion of possible excessive incentives for new construction projects due to the competition of the systems in East and West until the late 1980s. The number of new construction projects since 1990 can be interpreted as an indication of to what extent a country is able to successfully start and complete reactor projects. A given country's ability depends on the interaction of its (energy) industry, policy, administration and civil society. To the contrary, it appears very unlikely that a country without much experience regarding the new construction will be able to implement extensive plans in the short term. Experience with new construction projects since 1990 ranges from no experience at all[7] to the construction of 19 reactors in Japan. Japan is followed by France and several Asian countries (see Table 6, column 1).

In order to **evaluate the practical experience** with new construction projects, we compare the projects of the past with future project plans (column 2). The larger the experience in relation to the planned projects, the higher the number of points that the country receives. The following formula is used to calculate the points:

*Points = (number of completed) / (number of planned) * 100*

Here it applies that however large the construction experience is, it is not possible to get more than 100 points (column 3). Japan, for instance, reaches the maximum of 100 points with 19 nuclear power plants having been built since 1990 and 14 new power plants being planned according to WNA (19/14*100).[8] The indicator Experience with new construction receives a weight of 40%.

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[7] Experience shows that countries need at least 10 to 15 years to build their first reactor (IAEA 2007e; Kerzel & Thränert 2009). The appendix (7.2) comprises a detailed analysis of possible newcomer countries.

[8] In the case of China, this evaluation leads to a very low score (11) because China intends to build until 2030 ten times as many power plants as it has constructed during the last 20 years. On the one hand, there might be objections as China has shown enormous growth rates in many areas during the last few years; and the procedure used here may not apply to the Chinese economic dynamics. On the other hand, the positive experience of the last years may also lead to excessive ambitions for new construction projects and announcements on the part of Chinese planners. The very large number of 103 planned reactors in China until 2030 seems to express such expectations. Due to this reasoning, we do not give China a special treatment; we will apply our procedure also to China and treat it consistent with all other countries.

2nd indicator: Political stability of a country

(5) The second indicator, the political stability in a country (column 4), originates from the indicator set of the Worldwide Governance Indicators of the World Bank. It measures violence in a country and the risk of a possible government destabilization by unconstitutional, politically motivated violence and terrorism. Also here, a positive evaluation by the World Bank corresponds to 100 points. We assume that regarding the new construction of reactors especially in newcomer countries, the construction of a sufficient infrastructure requires a high degree of political stability. However, some of the countries that are assessed to be less politically stable, such as Russia (23 points) and China (32 points) have substantial experience regarding the use of nuclear energy; with 20%, this indicator affects the total evaluation less than the two other indicators.

3rd indicator: Credit rating

(6) The **credit rating** of a country as the third indicator has large importance for newcomers, but also in general for economically less developed countries. The data used here originate from the OECD (Country Risk Classification). As before, the best evaluation corresponds to 100 points.

As the construction of a new power plant requires substantial investments and consequently capital, the financing is significantly affected by the credit rating of a country. The lower the credit rating of a country, the higher the probability for an investor in this country to make losses. This increases the costs for raising capital; and the financing of large-scale projects, such as nuclear power plants, becomes more difficult.

As Table 6, column 5 shows, credit rating is high (= 100) in most economically developed countries. In less developed countries, however, diverse risk premiums on the investment are to be expected. The Credit rating indicator is **weighted** at 40%.

Result of the indicator evaluation

(7) The result of the indicator evaluation is calculated as the weighted average of the three indicators Experience with new construction (40%), Political stability (20%), and Credit rating (40%), and is shown in column 6 of the following table. The following formula was used:

$$\begin{aligned}&(Points_{Experience\ with\ new\ construction} &&* 40\ \%\\ +\ &Points_{Political\ Stability} &&* 20\ \%\\ +\ &Points_{Credit\ rating} &&* 40\ \%)\quad /\ 100\end{aligned}$$

Japan has reached 97% and is the country with the highest indicator evaluation; Bangladesh has the last position with 8%. The calculated result is used to evaluate and accordingly reduce the number of new construction projects planned or announced by the country until the year 2030 (column 2).

4th indicator: Implementation probability in the individual energy market

(8) The mentioned three indicators, however, do not sufficiently take into account the importance of the specific competitive environment.

In general, it is more difficult for power plant operators in deregulated energy markets to pass on the incurred costs to the customer (see 4.3). This increases insecurity. The larger the insecurity, the lower the probability that a potential power plant manufacturer will decide in favour of a difficult-to-finance nuclear power plant if there are several other alternatives. This insecurity has to be included in our evaluation.

Here we distinguish between electricity markets that are already largely deregulated or are in the process of deregulation and those that are not liberalised according to our assessment. Experience with deregulation in Germany shows that especially during the initial phase of the deregulation process, power plant manufacturers and operators face particularly large insecurities.

It follows for our evaluation that: If the literature (see Table 6) states for a country that its electricity market is largely deregulated or that it is in the process of deregulation, we assume that three in four projects (75%) will be implemented. For all other countries, we assume a complete implementation of the projects in the intermediate result (100%). Column 7 shows the implementation probability. The resulting degree of realisation can be seen in column 8.

Time delay

(9) After we have evaluated the number of reactors, we need to look at possible time **delays** regarding new reactor projects. Although the WNA data in many cases includes planned construction periods, we assume a time delay of the construction due to the **international economic crisis**. In this context, the IEA expects global electricity demand to decrease and – subsequently – the pressure to build new power plants to be released (IEA 2009). In order to adequately reflect this economic issue in the modelling of the development path of nuclear energy, we postpone the construction start of all planned and proposed project by an average of two years.

(10) In addition to the country-specific degrees of realisation and a possible time delay due to the economic crisis – which mainly affect the demand for reactors –, we also include the **supply side**. The supply of reactors is mainly restricted by one component: pressure vessels. This raises the question of how many **reactor pressure vessels** can be simultaneously manufactured per year and in total during the analysed period. We assume that in the next years the capacities of Japan Steel Works continue to be an important restriction (see Chapter 4.1). We have to add capacities in China and Russia that cannot be quantified in detail. As a result we expect a total of about 130 pressure vessels to be manufactured until 2020. A part of these vessels will be integrated into reactors that will be put into operation only after 2020.

Given the assumed degrees of realisation and the construction delays (see above), demand for reactor pressure vessels is likely to be very large during the first years and could not be covered immediately according to our assessment. In order to include this restriction in our model, we will postpone the construction of the planned reactors another year.

(11) The here assumed average time delays due to the international economic crisis and the reactor pressure vessels have different impacts in the individual countries. The closer to the year 2030 the expected start of operation of a reactor is, the more likely the assumed delay will move the reactor out of the analysed period and it will not be included in the result (see 7.4.4).

Final result

(12) Regarding the construction projects that were not started yet in March 2009, the **final result** is as follows: Until 2020, a total of 49 reactors will be constructed (column 9), until 2030, it will be 136 reactors worldwide (column 10). These totals represent the central result of our evaluation. We do not claim to be able to provide specific reactor numbers for each country for the years 2020 or 2030. However, we have arrived – on the level of individual countries – at a certain probability of that projects will be realised. Therefore, **on the level of individual countries** reactor numbers may show values with decimal points that may be lower than one. This does not mean that a country with a value of 0.5, for instance, will build half a nuclear power plant. It rather specifies that we evaluate the probability of a new reactor to be built at about 50%. In other words: If two countries have a value of 0.5 each, we expect in a joint evaluation of both countries, that these two countries will build only one reactor in total. This reasoning applies to the totals of all countries.

Table 6: *Indicator evaluation of the planned expansion in individual countries*

Indicator-based assessment of construction plans			(1) Number of reactors brought into service since 1990	(2) Number of reactors planned/ proposed to be built until 2030 according to WNA	(3) Experience with construction since 1990 compared to plans (0 = low, 100 = high)	(4) Political stability 2007 (0 = low, 100 = high)	(5) Credit rating 2006-2009, transformed (0 = bad, 100 = excellent)	(6) Indicator assess-ment from columns (3) to (5) (%)	(7) Chance of implementation, given a country's energy market (%)	(8) Degree of realization from columns (6) and (7) (%)	(9) Final result including delay * Number of reactos in 2020	(10) 2030
Africa/ Austr.	Africa	SOUTH AFRICA		27	0	51	57	33	100	33	2,0	8,6
		EGYPT		2	0	22	43	22	100	22	0,2	0,2
Amerika	Rest of America	ARGENTINA		2	0	50	0	10	75	7	0,1	0,1
		BRAZIL	1	5	20	31	48	34	100	34	0,3	1,3
		CANADA	4	9	44	85	100	75	100	75	0,7	6,7
		MEXICO	2	2	100	25	71	74	100	74	0,0	0,7
	USA	UNITED STATES OF AMERICA	5	31	16	56	100	58	75	43	7,8	13,0
Asia	China	CHINA	11	103	11	32	71	39	100	39	18,4	39,6
	India	INDIA	11	25	44	18	57	44	100	44	3,5	10,6
	Rest of Asia	BANGLADESH		2	0	9	14	8	100	8	0,0	0,1
		INDONESIA		6	0	15	29	14	100	14	0,3	0,7
		IRAN, ISLAMIC REPUBLIC OF		3	0	11	22	11	100	11	0,1	0,3
		ISRAEL		1	0	13	57	25	100	25	0,0	0,3
		JAPAN	19	14	100	85	100	97	75	73	5,1	9,5
		KAZAKHSTAN		4	0	58	43	29	100	29	0,6	0,9
		KOREA, DEM. P. REP. OF		1	0	57	0	11	100	11	0,1	0,1
		KOREA, REPUBLIC OF	11	7	100	62	100	92	100	92	2,8	6,5
		PAKISTAN	1	4	25	1	13	16	100	16	0,3	0,5
		THAILAND		6	0	17	57	26	100	26	0,5	1,3
		TURKEY		3	0	21	34	18	75	13	0,3	0,3
		UAE		14	0	73	71	43	100	43	1,3	5,6
		VIETNAM		10	0	56	37	26	100	26	0,5	2,3
Europe	Eastern Europe	ARMENIA		1	0	42	13	14	100	14	0,0	0,1
		BELARUS		4	0	53	0	11	100	11	0,2	0,3
		BULGARIA	1	2	50	61	51	53	75	39	0,8	0,8
		CZECH REPUBLIC	2	2	100	77	90	92	75	69	0,0	0,7
		HUNGARY		2	0	68	60	38	75	28	0,0	0,3
		LITHUANIA, REPUBLIC OF		2	0	75	70	43	75	32	0,0	0,3
		POLAND		5	0	67	71	42	75	31	0,0	1,3
		ROMANIA	2	3	67	51	52	58	75	43	0,9	0,9
		SLOVAK REPUBLIC	2	1	100	80	87	91	75	68	0,0	0,7
		SLOVENIA		1	0	84	94	55	75	41	0,0	0,4
		UKRAINE	3	12	25	50	21	29	100	29	0,6	2,0
	Russia	RUSSIAN FEDERATION	4	36	11	23	52	30	100	30	0,9	10,5
	Western Europe	FINLAND		1	0	99	100	60	75	45	0,0	0,4
		FRANCE	10	2	100	65	100	93	75	70	0,0	0,7
		ITALY		10	0	62	100	52	75	39	0,0	3,5
		SWITZERLAND		3	0	99	100	60	100	60	0,0	1,2
		UNITED KINGDOM	1	6	17	66	100	60	75	45	0,9	2,7
Total			**90**	**374 ****							**49**	**136**
Weighting					40%	20%	40%					

Source: IAEA 2007f, von Hirschhausen 2007, CEER 2008, Weltbank 2008, IAEA/PRIS 2009a, OECD 2009a, Oshima 2009, WNA 2009g

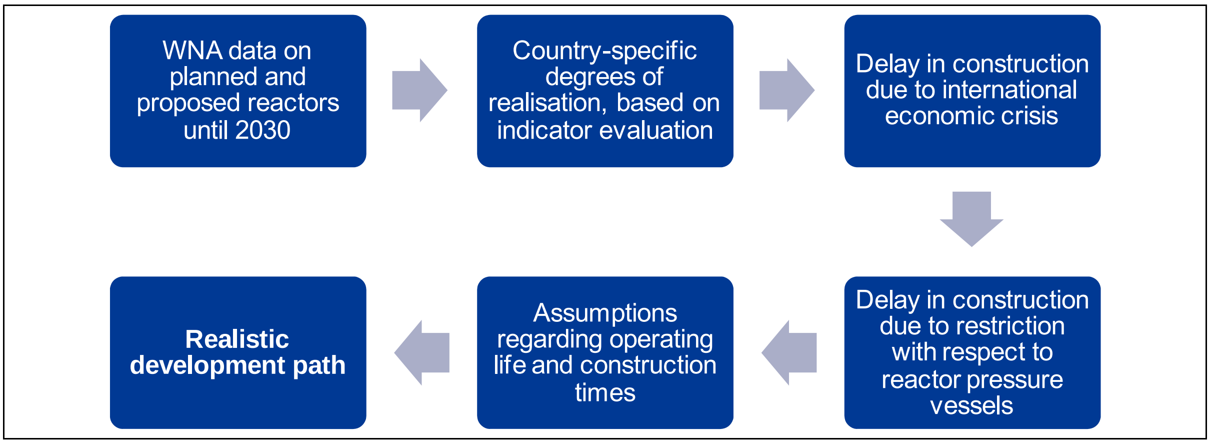
** Delay due to world economic crisis and bottleneck of few reactor pressure vessels, which varies by country. The closer a reactor's realization is originally expected to be to 2030, the more likely it is that it is delayed until after 2030 (see 7.4.4). The number of reactors has to be interpreted as a probability. In some countries, it has fractional digits and is smaller than one, for example 0.5. In such a country, we see a chance of realization that amounts to 50 %. If two countries have a chance of realization of 50 % each, we expect that only one reactor will be erected in total.*

*** Deviation from aggregated WNA data (384 reactors; see chapter 3.2) because of ten reactors which are announced for the time after 2030, according to the more detailed WNA data at the nuclear unit level (see 7.4.4)*

5.2 Development path

(1) From the WNA data on planned and announced projects, the country-specific degrees of realisation, the time delay due to the international economic crisis, the pressure vessel restrictions and the assumptions regarding operating life and construction times (see below), we derive a **development path for the use of nuclear energy** that we consider to be realistic (Figure 19).

Figure 19: Derivation of a realistic development path of nuclear power use



Source: Prognos AG

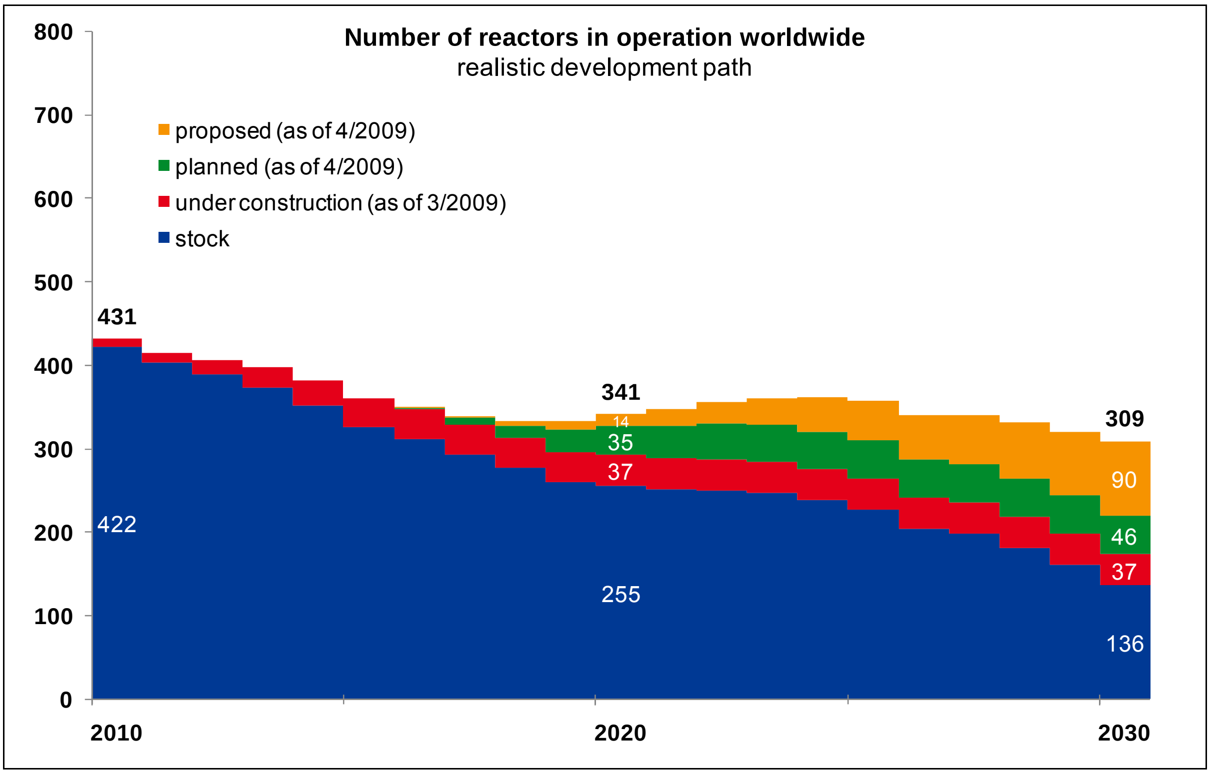
(2) For the **currently operating reactors**, we assumed mean operating lives that are differentiated according to age groups. For nuclear power plants that were put into operation in 1980, we assume an operating life of 40 years, for those put into operation between 1980 and 1985, it will be 45 years; and for the plants put into operation since 1986, we assume 45 or more years. The discussion of whether and to what extent the operating life of reactors can be extended beyond 45 years is irrelevant in the context of this study as the analyzed period ends prior to the decisive threshold in 2030 (see 2.1). Exceptions were made for the operating lives of such reactors for which according to the WNA list, a shorter operating life has already been planned or determined, such as in Germany.

In addition to the existing plants, the development of the reactors that are currently **under construction** is relevant, too. The official IAEA construction statistics has been adjusted for construction projects that have been halted (see 3.4). It is possible of course that some of the momentarily halted construction projects will be resumed at a later time. On the other hand, some of the currently active projects can come to a standstill at a later time. Considering these two factors, we expect 37 of the current construction projects to be completed by 2020.

Regarding the construction times of **planned** and **announced** reactors, two cases have to be distinguished. If the construction time stated in the original WNA data is longer than the country-specific average, we will use the further. Otherwise – or for data without construction time –, we will use our own assumptions regarding construction times. Based on past construction experience (see 2.4), we assume five years for Japan and South Korea and six years for China and India; for all other countries we assume an average construction time of eight years.

(3) Figure 20 shows the number of reactors that are expected according to the realistic development path. Figure 21 illustrates the development path of gross capacity.

Figure 20: Realistic development path of nuclear energy use worldwide until 2030 – Number of reactors



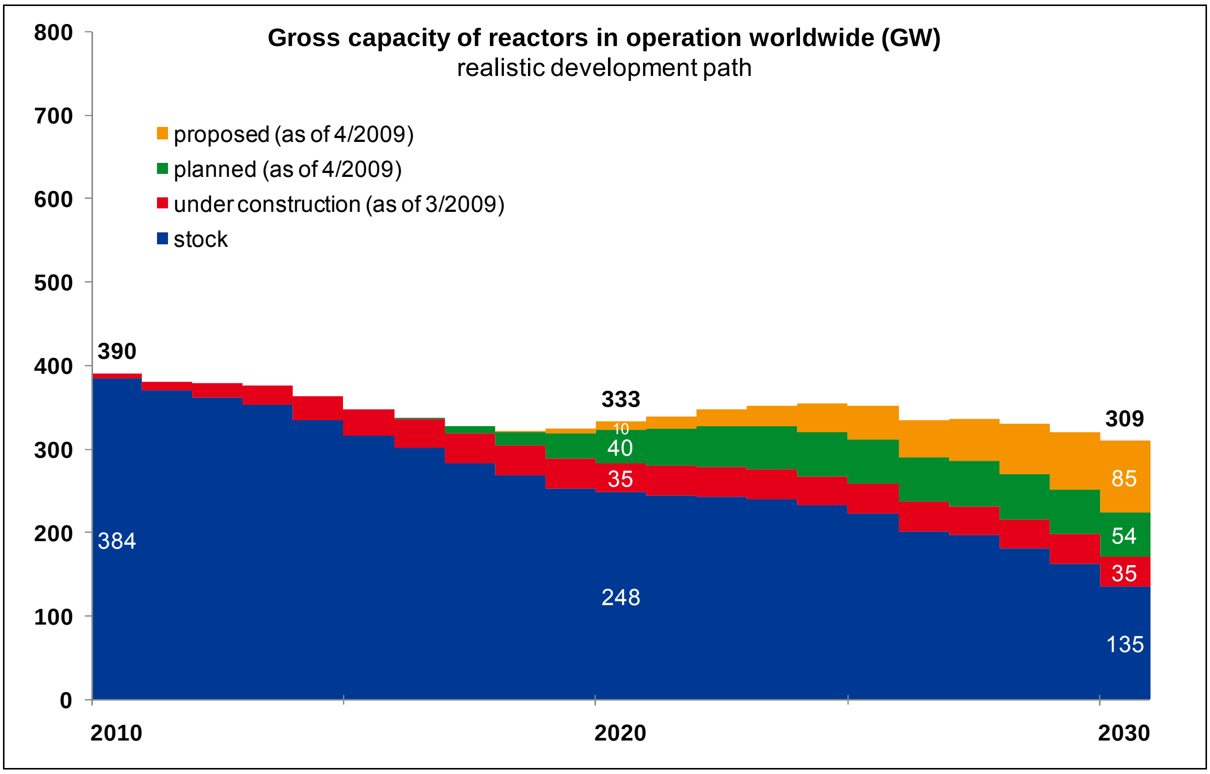
Source: Prognos AG. In March 2009, a total of 436 reactors were in operation worldwide. For future years, the diagram has to be interpreted as follows: Out of the total number of reactors proposed in April 2009 (orange), about 14 will be in operation by 2020, and about 90 will be in operation by 2030. The figures for planned reactors and reactors under construction have to be interpreted similarly.

(4) Until the year 2020, the **number** of nuclear power plants initially decreases to 341. Following a slight intermediate increase, it will probably decline again and reach a level of 309 reactors in 2030. This is clearly lower than the 2009 level (436 reactors). The decrease until 2020 corresponds to about 22% and until 2030 to about 29%.

The here presented numbers of reactors is used to arrive at a development path for gross capacity (see also Chapter 7.4). In total, this development path has a higher degree of insecurity as the specific size of an announced reactor usually only is specified at a later time and because we do not take into account capacity-enhancing measures for existing reactors (see Chapter 1).

The **gross capacity**, too, decreases until 2020 and following a short intermediate growth, it will further decline until 2030. In 2030, it will reach 309 GW; that means it will be substantially lower than 2009 gross capacity (390 GW). Gross capacity will decrease until 2020 by about 15% and until 2030 by approximately 21%.

Figure 21: Realistic development path of nuclear energy use worldwide until 2030 – Gross capacity

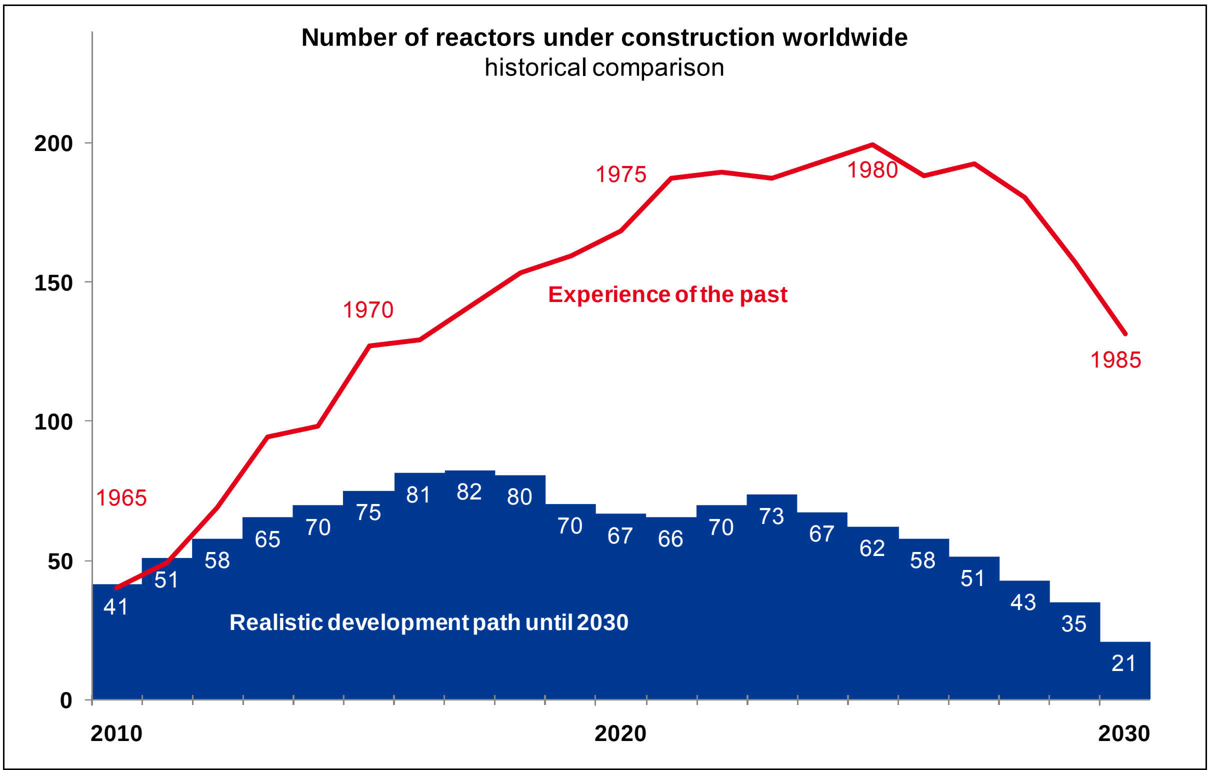


Source: Prognos AG. In March 2009, the total installed capacity amounted to 390 GW. For future years, the diagram has to be interpreted as follows: Out of the total number of reactors proposed in April 2009 (orange), reactors with a total capacity of about 10 GW will be in operation by 2020, and reactors with a capacity of about 85 GW will be in operation by 2030. The figures for planned reactors and reactors under construction have to be interpreted similarly.

The development path presented here is related to the **construction activity** that may be compared – at least during the first two or three years – with the reactor construction phase during the 1960s (see Figure 22). At that time, many new construction projects were initiated from a similar base level. The absolute number of reactors worldwide under construction reached its peak in 1980 with approximately 200 projects. For the period until 2030 though, we do not expect to reach a construction activity level that corresponds to that in the 1970s and 1980s.

The (not evaluated) list with WNA and ATW announcements presented in Chapter 3.2 would result in a nuclear power expansion that would, especially regarding the first years, largely exceed the expansion rate of the 1970s.

Figure 22: Realistic development path of nuclear energy use worldwide until 2030 – Reactors under construction



Source: Prognos AG. The historical experience comprises 436 reactors in operation and 127 decommissioned reactors. This does not include those reactors whose construction was never completed.

(5) The development path that we assess to be realistic is subject to the provision that all used indicators adequately capture the essential challenges and that the challenges that are not quantified here will not have an additional negative impact on the result (see 4.6).

Sensitivity of the results

(6) The development path described here is particularly affected by two assumptions. Firstly, for the **operating lives** of currently operating reactors we have made general assumption based on the age group (see Chapter 3.2). If we assumed, for instance, for all US nuclear power plants an average operating life of 60 years, the 2020 and 2030 numbers of reactors would be much higher, but still lower than the reference level of 436 reactors (as of 2009).

However, we need to evaluate the plausibility of this assumption: US nuclear power plants that have been decommissioned until now have had an average age of 16 years and a maximum age of 34 years. Even though the US has been utilizing nuclear energy for 49 years, not a single power plant has reached the 40 year threshold – the current maximum is 39 years. The average lifetime of the currently operated US reactors is 29 years (see Table 10 in the appendix). An average age of 60 years would correspond to a doubling of the current average lifetime. Even if the approved operating life of some nuclear power plants currently is extended from 40 to 60 years, there is currently no scientific evaluation available whether the average of the currently operated power plants is able to technically and economically reach an operating life of 60 years.

Secondly, the development path significantly depends on the assumed **degrees of realisation** of the new construction plans **in a few countries** that jointly account for the majority of the known plans. These are in particular the US, China, Russia, India and Japan. A change in the factors of one of these countries would have a significantly larger impact than that of countries with a lower number of announced projects.

Importance of nuclear energy for the worldwide electricity supply and comparison with OECD-NEA

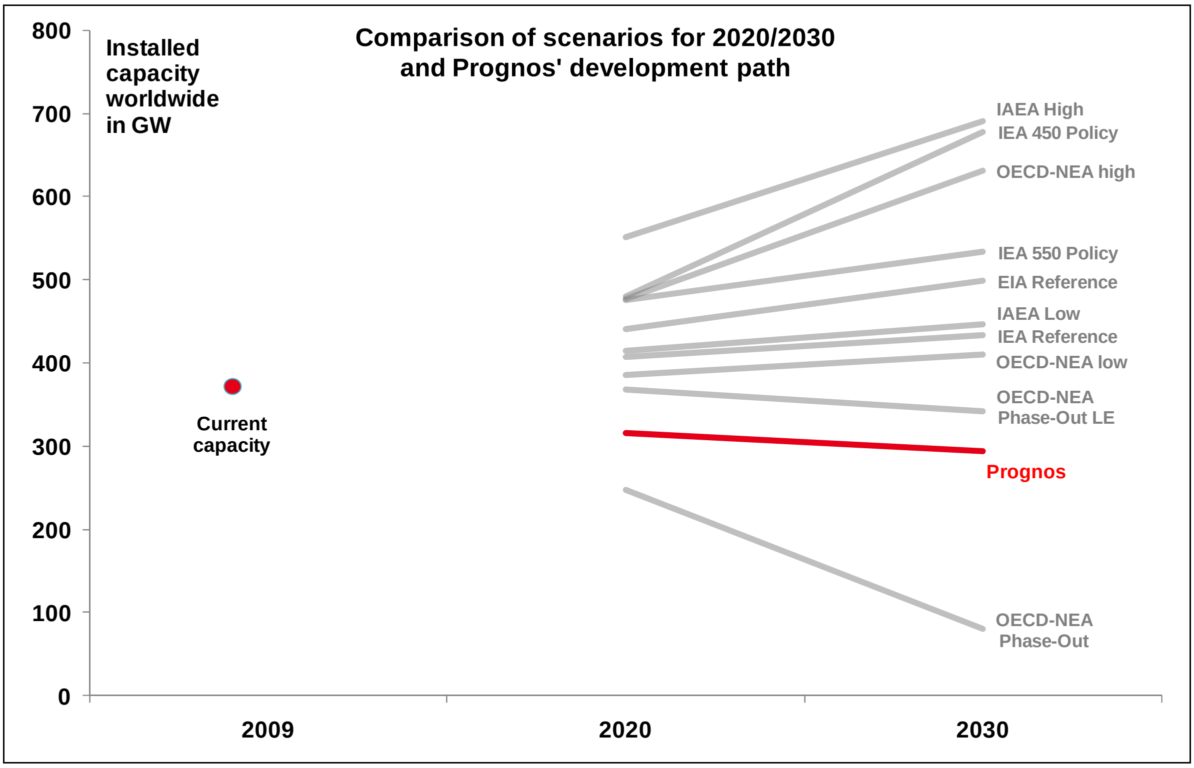
(7) In the reference scenario World Energy Outlook 2008, the International Energy Agency expects an increase of worldwide **electricity generation capacities** of all power plant types from 4,344 GW (2006) by about 72% to 7,484 GW in 2030. In relation to this development, the share of nuclear energy in our development path drops **from 9% to about 4%** in 2030.

(8) In relation to worldwide **electricity generation**, the share of nuclear energy according to our development path will decrease from **14.8%** in 2006 to 9.1% in 2020 or to **7.1% in 2030,** respectively. Here we assume the same full-load hours for nuclear power plants that result from the World Energy Outlook 2008.

(9) Comparing the **capacity** development we expect with the current **OECD-NEA** scenarios, it is closest to the results of the scenario “OECD-NEA phase out LE”. This scenario assumes a long-term worldwide phasing-out of nuclear energy (i.e. no new construction) with a simultaneous extension of the operating life of all reactors to a maximum of 60 years (see Figure 22). Due to these extensions, the number of existing reactors does not decrease as fast in the OECD-NEA scenario as in our development path.

The results of our scenario and the OECD-NEA scenario coincide as we expect a certain number of newly constructed reactors with a total capacity that corresponds to the lifetime extensions of existing reactors assumed by OECD-NEA.

Figure 23: Comparison of expansion scenarios 2020/2030 and the development path presented by Prognos



Source: Prognos AG. LE: Life Extension. In order to derive the net capacity from our development path of gross capacity (see Figure 21), we generally multiply gross capacity with a factor of 0.95.

5.3 Conclusions

For the future development of nuclear energy we arrive at the following **conclusions**:

- **Until 2030, we do not expect any renaissance of nuclear energy use**. Age-related decommissioning will rather result in a significant decrease of the number of reactors, installed capacity, and electricity generation in nuclear power plants. Until 2020, the number of nuclear power plants operating worldwide is expected to decrease by 22 %, until the year 2030 by approximately 29%, compared to the reference level in March 2009.

- Despite **increased construction activity** compared to the last 10 years, new constructions of nuclear power plants will **not reach the levels of the construction boom in the 1970s/80s**.

- There is an **increase in announcements** of nuclear power plants. In the past, however, mainly the US, but also other countries had ambitious expansion plans that did not materialize. We expect that about 23% of the new nuclear power plants announced by ATW until 2020 and about 35% of the projects announced by WNA until 2030 will be built.

- If all announced power plants would be realised, the resulting construction activity would outclass the immense increase that occurred in the 1970s. This appears to be highly **unrealistic**.

- Also in relation to the expected large increase in global **electricity demand**, nuclear energy becomes significantly less important until the year 2030. The contribution of nuclear energy to worldwide **electricity generation** is expected to decrease from 14.8% in 2006 to 9.1% in the year 2020 and to 7.1% in 2030, respectively.

- A reduced contribution of nuclear energy to global electricity generation can also be derived from **other scenarios**, e.g. the “low”- scenario of the OECD/Nuclear Energy Agency (NEA) and the reference scenario of the World Energy Outlook 2008 of the International Energy Agency.

- The **capacity** development we expect has the closest correspondence to the current scenario of OECD-NEA “phase out Life Extension”.

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7 Appendix

7.1 Case studies of nuclear energy expansion

7.1.1 China

(1) The most heavily populated country in the world with its 1.328 billion inhabitants promotes the use of nuclear energy like no other. The currently grid-connected eleven nuclear power plants with an **installed capacity of slightly less than 9 GW** account only for 1.9 % of total electricity generation; however, there are another eleven nuclear power plants with a total capacity of 11 GW under construction (OECD 2009b). In addition, there are **plans** for 24 nuclear power plants with a total capacity **in excess of 26 GW** and at least 70 announced nuclear power plant projects with a capacity of 70 GW (WNA 2009b). Total capacity would thus reach 116 GW.

Originally the Chinese government had formulated in its **5-year-plan** (2006-2011) the goal to reach a total nuclear generation capacity of 40 GW by the year 2020. According to information from the National Development and Reform Commission, the installed capacity shall increase to 120-160 GW by 2030 (ATW 2007a; German Trade & Invest 2008). It is questionable whether this capacity increase can be implemented to this extent because of scarce manufacturer capacities. According to WNA, in 2008 China withdrew planned projects comprising about 10 GW.

(2) Building and operating a nuclear power plant, also in China – similar to other countries – requires several **licenses**. According to the IAEA, licences for the operating site, the construction, the commissioning, the operation and the decommissioning are required.

Licenses are granted by the National Nuclear Safety Administration (NNSA) and the State Environment Protection Administration (SEPA). There is no information available regarding the duration of such a licensing process. It might be possible that this process takes less time than in other countries due to the centralized decision-making by the government.

(3) Information published so far regarding **investment costs** of Chinese nuclear power plants imply that the construction of an average power plant with a capacity of 1,000 MW is less expensive than in Western Europe or the US, for instance. According to our calculations, specific investment costs usually amount to between 1,000€/kW and 1,400 €/kW.

(4) The first power plants in China still were turnkey projects built by manufacturers from France, Japan and the US. However, due to technology transfer, an increasing number of newer power plants is built by **Chinese manufacturers**. This development implies that many of the currently planned reactors are likely to be built nearly completely in China. They increasingly use reactor type CPR-1000, a 1,000 MW pressurised water reactor based on a French design.

Already in the beginnings of the new millennium China completed the second unit of the **power plant Ling Ao** during slightly more than five years. It started commercial operation on 8 January 2003, two months earlier than planned (ATW 2003).

The new power plants have a similarly **short planned construction time**. It can be assumed that they also will be completed within six years.

Currently, one of the largest Chinese construction projects is the **power plant Yangjiang**. With six 1,000 MW reactor units and estimated total investment costs of 9 billion €, all six units of the power plant are planned to be put into operation by 2017 at the latest (ATW 2009a). Construction work for the first unit started in late 2008, and in spring 2009 the construction of the second unit was to be started.

(5) Among the strengths of the Chinese nuclear industry are short construction times and **completion of the projects often corresponds to the plan**. Hardly any other country has – within such a short time – planned so many power plants and connected them to the grid. It remains unclear though to what extent there have been critical site assessments or any citizen participation and whether the planning phase included environmental aspects. The information that is available is insufficient for any detailed considerations.

7.1.2 USA

(1) The US has the worldwide largest nuclear power generating capacity with 104 operating nuclear power plants. Total installed capacity amounts to approximately 101 GW. This accounts for 19.2 % of power plant capacities installed in the US (OECD 2009c).

Despite expected increasing electricity demand in the next decades, according to the IAEA there is only one nuclear power plant under construction. Construction start was in 1972. There is no exact completion date yet. 1996 was the last time a reactor was connected to the grid. There are **no specific plans for additional**

power plants. However, the US energy groups have submitted applications for a total of 17 combined construction and operation licences for a total of 26 reactors to the Nuclear Regulatory Commission (NCR). Another five applications for a total of seven reactors are expected to be submitted within the next two years (NRC 2009a). The planned duration of the approval process is at least three years according to the NRC (NRC 2009b).

(2) Currently, it remains completely unclear how many of these licences will be granted or used. There are several reasons for this situation:

There is no solution for the permanent disposal of high-level radioactive waste yet. The plans for the permanent repository "**Yucca Mountain**" that had been planned for several decades was put on hold by the US government at the beginning of this year (WNN 2009b). The reason was a debate on a possible insufficient disposal capacity. Some experts mean that the already existing radioactive waste that in the meantime is kept in intermediate storage depots such as cooling basins within the power plants or in waste containers would use up already the majority of the capacity. In addition, it is unclear whether the safety can be guaranteed over the long storing period (Jurewitz 2009).

The second big hurdle is the **high investment costs** and the question of who will be financing them. Moody's analysts have continuously raised the cost prognosis for nuclear power plants over the last years. They forecast specific investment costs for US nuclear power plants of up to 7,000 US$/kW (Moody's 2008). This assumption is supported by several press releases of energy utilities which state that the planned costs partially have doubled (WNA 2008).

(3) The large number of license applications has not necessarily resulted in a large increase of new constructions. In the 1960s and 1970s, there were more than 200 orders for new nuclear power plants, but only 13 projects materialized (Jurewitz 2009).

(4) Despite the high investment costs, the majority of US nuclear power plants has been able to operate profitably. In the last 25 years, 13 nuclear power plants have been decommissioned. Their average operating life was 23 years. Some experts say that they were only decommissioned to **abandon inefficient power plants** (Jurewitz 2009). In the last ten years, no reactor has been decommissioned. On the contrary, the NRC granted to 52 reactors lifetime extensions of up to 20 years. The extension of the license does not mean, though, that the nuclear power plants actually will be operated that long. This is only decided based on

safety-related or economic optimizations. Another 18 applications for a longer operating life are currently processed and according to the NRC another 20 applications will be submitted (NCR 2009c). The operating power plants have an average age of 29 years.

(5) Between 1990 and 2006, the average utilization rate of US nuclear power plants could be increased from 65% to 90%. In many power plants capacity-enhancing measures, such as more efficient turbine or evaporator systems, were implemented. According to NRC, the installed capacity has been increased by more than 5 GW since 1977. The potential of this kind of capacity-enhancement has been exhausted, though. A continuation of this trend is not to be expected (Jurewitz 2009; NRC 2009d).

(6) Last year, some US energy providers have made statements about their plans for new constructions. For the next ten years, there are at least ten units announced. As the operators assume total costs of between **5.6 and 17.5 billion US$** it remains questionable whether all units will really be built (WNA 2008). The wide range shows the financial insecurity that operators have to deal with in their planning process. Due to this fact, it is difficult to make assumptions regarding the future expansion. Above all the financing remains unclear. Due to the large decrease in construction activity in the last two decades, there remains the question whether the planned power plants can be built at all until 2020. “Vision 2020”, the plan of the US nuclear power industry presented in 2001, includes orders, construction or completion for an additional 50 GW by 2020. It is very unlikely to be implemented, though (NEI 2001). In this case, the scarcity of qualified staff should be an issue. Since 1980, the number of graduates, engineers, qualified boiler constructors, pipe fitters as well as operating and maintenance staff has been decreasing in the US (Schneider & Frogatt 2007).

In 2005, the US government passed legislation (Energy Policy Act) that intends to provide investment incentives for the new construction of nuclear power plants. Among the incentives, there are credit guarantees of up to 80% for the first new installed 6,000 MW as well as additional financial support of up to 2 billion US$ in case of substantial construction delays for the first six nuclear power plants (Schneider & Froggatt 2007; Jurewitz 2009).

(7) The unclear financing situation and the missing permanent repository capacities for high-level radioactive waste will cause large problems. Only if these conflicts are solved, major construction activities regarding new nuclear power plants may become probable again.

7.1.3 India

(1) Currently, India has 17 nuclear power plants with an installed gross capacity of over **4 GW**. The capacity accounts for 2.5 % of the Indian electricity generation (OECD 2009d). Out of the six power plants with a gross capacity of 3.1 GW that are under construction, there is a high probability that five will be completed within the next two years. In addition, ten nuclear power plants with an installed capacity of 9.7 GW are planned and another 15 power plants with a gross capacity of about 11.2 GW are announced (WNA 2009d). As India has not yet signed the Nuclear Non-Proliferation Treaty there have been restricted international trade relations regarding nuclear energy technology and fuel. This resulted in an isolated development of Indian technology. By **relaxing these trade embargos**, India will increasingly be able to cooperate with other countries, such as China, Russia and the US (WNA 2009d).

The state-owned Nuclear Power Corporation of India (NPCIL) is in charge of all Indian activities regarding the **peaceful use of nuclear energy**. The supervisory authority is the Department of Atomic Energy (DAE) that does not report to any ministry, but directly to the Prime Minister Office. NPCIL is responsible for the design, construction and operation of nuclear power plants. The **licensing process** and safety supervision are the responsibility of the Atomic Energy Regulatory Board (AERB). There is no information available regarding the duration of the licensing process.

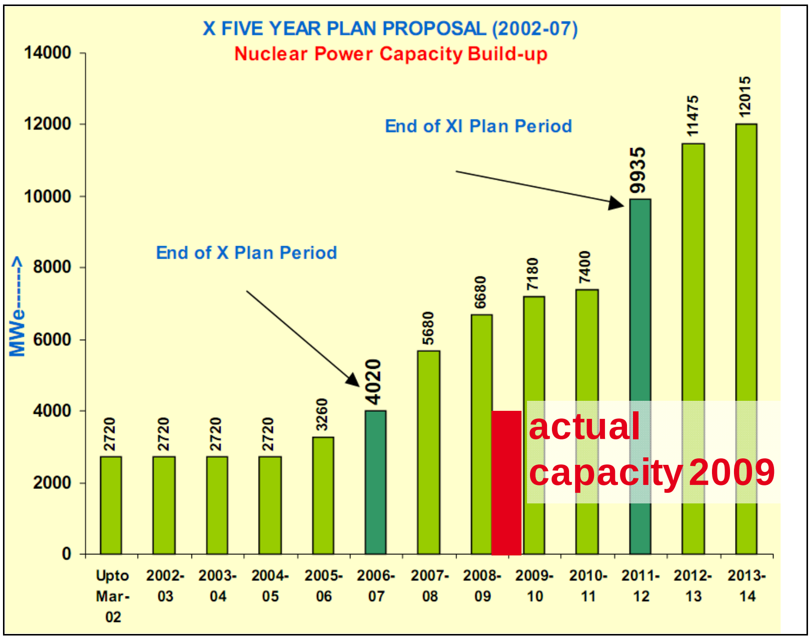
(2) According to operator and press information, the **specific investment costs** of the power plants currently under construction are between 1.000 €/kW and 2,400 €/kW. According to other reports, for the completed nuclear power plants actual costs exceeded planned costs by 170% to 390 % (Thomas et al. 2007). In addition, the estimated construction time of the nuclear power plants currently under construction will be up to eight years. Against this background, it is questionable whether the above mentioned plans can be implemented. Particularly, the four planned heavy water reactors Kakrapar 3/4 and Rawatbhata 7/8 with construction start in 2009 and start of operation in 2012 have an unrealistic time schedule.

(3) It is noticeable that the Indian power plant fleet comprises a **variety of reactor types**. Whereas other countries often decide on one reactor type (mainly pressurised water reactors), India continues to plan three different types. In addition to pressurised and heavy water reactors, there are also fast breeder reactors planned (IAEA/PRIS 2009a).

(4) Above all, the two 1,000 MW pressurised water reactors with Russian design at the site of Kudankulam are expected to **significantly increase the share** in electricity production. According to NPCIL, the construction status of the two reactors is 80% and 91%, respectively. Kudankulam 1 is expected to be completed in August 2009 and Kudankulam 2 in May 2010.

(5) It remains unclear for the time being whether the plans of the DAE – an installed capacity of 20 GW by 2020 – can be implemented. Figure 24 shows that the prognosis (for 2009 an installed capacity of more than 6.6 GW) is about 2.5 GW higher than the current status of 4 GW. Only including the nuclear power plants currently under construction, the 2009 goal of 7.1 GW would be reached; these projects, however, have all been delayed during the last years. Therefore it is unlikely that there will be an installed capacity of almost 10 GW by 2012 and about 20 GW by 2020.

Figure 24: Planned nuclear power plants in India until 2014



Source: DAE "Long Term Vision of the Department of Atomic Energy" 2001; emphasis added in red

(6) According to a current study of the consulting company Accenture, a large majority (96%) of the Indian population considers the future expansion of the use of nuclear power necessary (Accenture 2009). Even though there are individual protest movements against specific construction projects, it cannot be compared to opposition movements in other countries (Gadekar 2009).

Even though in many nuclear-energy related areas, China is ahead of India, the country remains a **strong growth market**. Due to the opening of the market after almost 30 years of isolated development, an increasing number of international contracts is to be expected for the coming years (WNN 2009d).

7.1.4 Russia

(1) Russia currently operates 31 reactors with an installed capacity of **21.7 GW** which accounts for 16% of total electricity generation in the country. Thus, the country has the fourth largest nuclear generation capacity in the world. The mean age of the reactors currently is 27 years; and the power plants are planned to generate electricity at least during 35 years on average. According to IAEA and WNA, there are currently eight reactors with a total capacity of more than 6 GW under construction. The construction of three nuclear power plant was started more than 20 years ago and today it is not clear whether and when they will be completed.

(2) Currently there are 22 planned or announced nuclear power plants with a total gross capacity of **18.5 GW** until 2020. In addition, there are plans for a further 15 reactors with a total capacity of about 18 GW. For these power plants, there is no date of construction start or date of completion yet. Taking into account that during the last 20 years only 5 nuclear power plants were connected to the grid and that they had an average construction time of 13 years, the above mentioned plans do not appear to be realistic. Not only the high investment cost for new power plants, but also the **costs for cleaning up contaminated sites** after decommissioning are extremely high. A fund that was founded in 2001 for the dismantling of decommissioned reactors has spent all money for other purposes and is currently almost depleted (Popova 2009).

(3) Similar to many other countries, the construction and operation of nuclear power plants requires many licenses and approvals. These are granted by the state organization Federal Environmental, Industrial and Nuclear Supervision Service, abbreviated "**Rostechnadzor**". There is no information available regarding the duration of the licensing process.

(4) According to press information, the **specific investment costs** of power plants currently under construction are between 670 €/kW and 3,800 €/kW. The upper limit of the data refers to the two 35 MW pressurised water reactors Severodvinsk 1/2 that will be built on a floating platform. They were originally intended to generate electricity and heat in the shipyard Severodvinsk. After it has become known that the time schedule and subsequently the

completion of this nuclear power plant will be delayed until the end of 2012, it is currently unclear where the floating nuclear power plant will be located (Barent Observer 2008, 2009). For power plants in the 1,000 MW range, specific investment costs are stated at between about 1,400 €/kW and 1,900 €/kW. They are thus at level similar to Asian nuclear power plants.

(5) The current **infrastructure** status and **workforce** situation are problematic for the expansion plans. According to press reports, there is only one company in Russia that is able to manufacture reactors – and only one per year. Many trained employees soon will retire and their payment is assessed as "miserable". According to estimates of energy experts, less than 10% of the almost 55,000 workers and employees of construction sites and power plants are trained specialists (Hassel 2009).

In addition, there are doubts regarding the **safety** of Russian nuclear power plants. Design faults on Chernobyl-type reactors cannot be corrected afterwards. There are reports on cracks, defective weld seams as well as a "low safety conscience" in the nuclear power plants. Similar to other countries that operate nuclear power plants, Russia does not have any concept regarding the permanent disposal of high-level radioactive waste. Currently, the residuals are stored in **interim depots** the safety precautions of which can be classified as doubtful. Even though there are plans for a new interim storage depot, it will only be completed in 2015 at the earliest (Hassel 2009).

(6) To what extent Russia will pursue the use of nuclear energy in the **future** depends mainly on the financing question and the safety problems to be solved. For the Russian economy, the new construction of nuclear power plants is of high importance. Currently, natural gas accounts for 43% of the Russian electricity generation (IEA 2008). This high share should be reduced in the future. Here, Gazprom has set the goal to export the saved natural gas in order to benefit from higher gas prices. This strategy will only succeed if the contribution of nuclear or other electricity generation is increased or if demand is reduced (Popova 2009).

7.1.5 France

(1) After the US, France has the second largest nuclear generation capacity of the world with 59 operating reactors. With a gross capacity of over **66 GW**, nuclear power plants supply about 77% of the French electricity demand. The most recently completed nuclear power plant, Civaux, had its two units connected to the grid in 2002. With the European pressurized water reactor (EPR), currently one of two construction projects is realised in Flamanville. The other reactor – also an EPR – is built in Olkiluoto (Finland). In

France, power plants are built by the French state-owned Areva and operated by Electricité de France (EdF). According to press releases, a second EPR is planned at the location Penly in Normandie (Verivox 2009a).

(2) Similar to other countries, approvals are required to construct and operate a nuclear power plant. According to the IAEA, the **licenses** include site, construction, commissioning, operation, and decommissioning. Applications for licenses are submitted to the State's atomic authority "Autorité de sûreté nucléaire" (ASN) and approved by this body. According to information from this authority, the complete approval process from submitting the application until granting the operating license for the power plant Civaux took seven years altogether.

(3) The costs for the current EPR at the location Flamanville will be substantially higher than expected. The total costs were calculated at about 3.6 billion €, however they will increase due to considerable **construction delays**. At the end of 2008, EdF declared that the costs would amount to at least 4 billion € (ATW 2008; Verivox 2009b). Whether these are the final costs remains to be seen. For the construction of the Finish EPR, **additional costs** after less than three years of construction amounted to over 1.5 billion € (HB 2008).

According to our own calculations, the average construction time of French reactor units is about seven years. It remains to be seen whether this also applies to the EPR in Flamanville, as the construction had to be interrupted several times until now. There appear to be **problems** with the concrete foundation and the steel construction (Greenpeace 2008; Verivox 2009b).

(4) In France, nuclear energy is represented by **two state-owned companies**. The state-owned energy utility Electricité de France (EdF) owns and operates all nuclear power plants in France. In the recent past, EdF has acquired energy utilities abroad or bought shares in them and has thus ensured access to nuclear power plants in other countries. The nuclear group Areva with the State as majority shareholder offers the complete range of nuclear technology and covers the entire nuclear value-added chain from uranium mining via power plant planning to fuel recycling and the dismantling of decommissioned reactors.

Currently in Europe Areva builds the European pressurised water reactors in Finland and France. Areva plans to build further reactors, among others, in China, India and the US. An 8 billion € contract with China was signed for the construction of two reactors at Taishan (WNN 2007).

EdF has announced that it will gradually start **decommissioning** and **replacing** the old reactors with new ones from 2020 onwards. According to the planning, each year a new EPR will be connected to the grid. Whether this ambitious plan will be implemented, we can only assess after 2015 after the completion of the reactor in Flamanville (EdF 2009; 4ecotips 2006).

(5) Among the **strengths** of the French nuclear industry is the worldwide distribution of French technology. Because of existing orders for the coming years, the good initial position will be further reinforced. Areva has announced to build a production plant for EPR pressure vessels in the US in the near future and to expand production at home (2009a). **Problems** include current issues regarding the construction of the two European reactors in Finland and France as well as the missing solution for the permanent disposal of high-level radioactive waste. According to WNA, the latter problem will be solved by 2025 at the earliest in case a location for the permanent repository has been found and developed.

7.2 Analysis of possible newcomers

(1) In addition to countries that already use nuclear energy there are several states that – according to their own information – also want to use nuclear energy, but have never applied this technology before (possible "newcomers"). There are also countries, such as Italy or Kazakhstan that are considering a re-entry to nuclear energy after they had phased it out in the past. Table 7 shows all countries that are included in the WNA list of planned or announced nuclear power plants and have not constructed or operated any nuclear power plants yet. Iran will be excluded as its first reactor will soon be completed.

(2) For the analysis of possible **newcomers**, we will take into consideration whether these countries have signed the IAEA Convention on Nuclear Safety. Here we distinguish whether the convention is signed and has entered into force in the individual country, signed and entered into force (by joining) or whether the country is not listed as a member (as of 24 December 2008). Then we will analyse whether the country has a supervisory authority for civil nuclear plants as well as a research reactor. We have also researched whether there is a specific time schedule for the use of nuclear energy.

(3) We will analyse the **credit rating of the countries** using the Country Risk Classification of the OECD. The classification is based on two components. On the one hand, a quantitative estimate of the default risk of a State and, on the other hand, a qualitative assessment of the country. The classification uses an eight-step scale from 0 (no default risk – politically stable) to 7 (highest default risk – politically extreme instable).

(4) Using the two indicators of the World Bank, we will additionally include the political situation of the individual country. **Political stability** and the amount of existing violence within a country are measured; and the probability of a destabilisation of the government by unconstitutional, politically motivated violence or terrorism is assessed.

In addition, the **regulatory quality** of the State is measured. This indicator evaluates the efficiency of a government to formulate and implement appropriate regulation and measures in order to make the development of the private sector possible and beneficial. The indicators range from 0 (politically very instable or very bad regulation) to 100 (politically very stable or very good regulation) (Kaufmann et al. 2008).

Table 7: Possible newcomers to nuclear power use

Country	Convention signed	Authority	Research reactor	Schedule	Credit rating	Political stability 2007	Regulatory quality 2007
Bangladesh	X	X	X	X	6	9	21
Belarus	(X)	X	-	X	7	53	5
Egypt	(X)	X	X	X	4	22	35
Indonesia	X	X	X	X	5	15	44
Israel	(X)	X	X	-	3	13	83
Italy	X	X	X	n/a	0	62	74
Kazakhstan	(X)	X	X	X	4	58	34
North Korea	-	n/a	n/a	n/a	7	57	0
Poland	X	X	X	X	2	67	72
Thailand	-	X	X	X	3	17	56
Turkey	X	X	X	X	4	21	60
UAE	-	n/a	-	X	2	73	72
Vietnam	-	X	X	X	5	56	36

Convention signed: X = "Signed" and "Entered into force", (X) = "Signed" OR "Entered into force" by joining. - = not a member, n/a – not available
Source: IAEA 2007a,b,c,d,f,g,h, IAEA2008a,b,c,d,e,f,g,h, OECD 2009a, World Bank 2008

(5) **Bangladesh** has signed the Convention in 1995 and it entered into force in 1996. Since 1986, there has been a 3 MW TRIGA Mark II research reactor at the location of Savar. The Bangladesh Atomic Energy Commission (BAEC) has announced in 2005 that it will build two 500 MW reactors until 2015. This plan has been repeatedly confirmed since then including the intention to build together with China a 600 MW reactor. Bangladesh, the politically most instable State of possible newcomers is evaluated with a high credit default risk and a weak regulatory quality (IAEA 2007f; IAEA 2007g; IAEA 2008a; IAEA 2008c; WNA 2009a).

(6) **Belarus** has not signed the Convention on Nuclear Safety, but joined it in 1999. Even though there is currently no research reactor, the responsible authorities have announced a plan according to which a nuclear power plant with two 1,000 MW reactors of Russian design will be connected to the grid in 2016 and 2018, respectively. According to the World Bank, the political situation in Belarus is comparatively stable. However, it has the highest credit default risk; and the government does not seem to have any regulatory capacity (IAEA 2007f; IAEA 2007h; IAEA 2008b; IAEA 2008c; WNA 2009a).

(7) **Egypt** signed the Convention already in 1994, but it has not yet entered into force. The responsible authorities (Atomic Energy Authority, Nuclear Material Authority, and Nuclear Power Plants Authority) monitor the two operating research reactors – a 2 MW reactor from 1961, and a 22 MW reactor that started operations in 1997. Since 1964 there have continuously been plans for diverse nuclear power plants that never have materialized. The latest plans include a 1,000 MW power plant by 2017 at the latest. Egypt

has a middle position regarding the credit default risk. Political stability and regulatory capacity appear to be rather weak (IAEA 2007f; WNA 2009a).

(8) **Indonesia** has signed the Convention in 1994 and it entered into force in 2002. The Indonesian supervisory authority National Atomic Energy Agency has been operating since 1987 a 30 MW research reactor. The time schedule published by the authority in 2007 has the goal to put a 1,000 MW reactor into operation in 2017 and to have approximately 4,000 MW of installed capacity by 2025. Indonesia is assessed to have a high credit default risk and low political stability. As opposed to this, regulatory qualities appear to be more pronounced (IAEA 2007b; IAEA 2007f; IAEA 2008a; IAEA 2008d; WNA 2009a).

(9) **Israel** has signed the Convention; however it has not entered into force yet. The Israeli atomic authority Israel Atomic Energy Commission operates a 5 MW and a 70 MW research reactor. Regarding the latter there are suspicions that it is used for military plutonium production. There are data regarding a power plant with two reactors with a total capacity of 1,200 to 1,500 MW. It remains totally unclear though when this plan should be realised. Israel has a medium credit default risk; however due to the Middle-East conflict, the political stability is assessed to be very low. The State is assigned a high regulatory efficiency (IAEA 2008c; WNA 2009a).

(10) **Italy** has already practical experience regarding nuclear power plants. Between 1963 and 1987, the country operated a total of four nuclear power plants with a capacity of between 160 MW and 880 MW. Two further boiling water reactors with 982 MW each were at this point almost completed and six reactors were in the planning phase. Then the Italian government reacted to the Chernobyl incident and stopped all nuclear activities. Italy signed the convention in 1994 which entered into force in 1998. The responsible authority Agency for New Technology, Energy and the Environment (ENEA) keeps on operating several research reactors with a capacity of between 5 kW and 1 MW. In Italy there is an ongoing debate regarding the re-entry to nuclear energy. The result is unpredictable. According to authority information it is not possible to say exactly whether, when and how many nuclear power plants could be built at what locations. As an EU member, Italy has no credit default risk. The State is evaluated to be politically comparatively stable and to have good regulatory qualities (IAEA 2007a; IAEA 2007f; IAEA 2008c; IAEA 2008e; WNA 2009a).

(11) **Kazakhstan** signed the Convention already in 1996; it has not entered into force yet, though. Similar to Italy, the State already operated nuclear power plants in the past. A 90 MW reactor with Russian design was operated between 1973 and 1999. The country has large uranium resources which benefits a renewed use of nuclear energy. The authorities currently monitor the operation of a total of four research reactors. They have a capacity of between 400 kW and 60 MW. According to the time schedule, several nuclear power plants with different capacities are to be connected to the grid from 2016 onwards, at the earliest. There has been no decision made regarding the type of reactors. Both credit rating and political stability are assessed to be medium. According to the World Bank, regulatory qualities appear to be rather weak (IAEA 2007f; WNA 2009a).

(12) Due to the scarce information on **North Korea**, it is currently very difficult to provide specific data regarding the nuclear programme. The State has not signed the Convention. No information regarding authorities, research reactors or planned power plants are available. According to the OECD, there is a maximum credit default risk. Political stability is assessed to be medium. There is no data regarding regulatory qualities (IAEA 2008c; WNA 2009a).

(13) **Poland** signed the Convention in 1994 and it entered into force in 1996. The Polish atomic energy authority PAA currently monitors a 30 MW research reactor. In 1982, the then government commissioned construction work for a nuclear power plant with four reactors of Russian design at the location of Zarnowiec. These were stopped in 1992 as a reaction to the Chernobyl incident. PAA announced at the beginning of the year that at least two power plants with a total capacity of 3,000 MW are to be built with one reactor starting operations in 2020. There are also considerations regarding a nuclear power plant to be jointly operated with the neighbouring countries Estonia and Latvia. The default risk is estimated to be low. Poland is politically stable and has good regulatory qualities (IAEA 2007c; IAEA 2007f; IAEA 2008c; IAEA 2008g; WNA 2009a).

(14) **Thailand** has not signed the Convention yet. The Thai authority Office of Atoms for Peace (OAP) is responsible for the monitoring of a 2 MW research reactor which has been operating since 1977. Another one is currently under construction. In addition, the construction of two reactors with a total capacity of 2,000 MW until 2020 is planned. In 2022, the installed capacity is planned to amount to 4,000 MW. Despite medium default risk and difficulties with the political stability, the government is assigned comparatively good regulatory qualities (IAEA 2008c; WNA 2009a).

(15) In **Turkey**, similar to Egypt, the use of nuclear energy has been planned for several decades. The Convention was signed already in 1994, and it entered into force two years later. The responsible authority supervises a 5 MW research reactor. Currently, the Turkish nuclear authority Turkish Atomic Energy Authority (TAEK) plans at the location of Akkuyu a power plant with four units and a total capacity of 4,800 MW. It is planned to be put into operation gradually from 2016 onwards. According to the OECD, Turkey has a medium credit default risk. The country is categorized as politically instable, but has good regulatory qualities. The following overview shows the Turkish plans for the use of nuclear power (IAEA 2007d; IAEA 2007c; IAEA 2008c; IAEA 2008h; WNA 2009a).

In **Turkey, attempts to build nuclear power plants** failed due to financing problems, protests of people in the neighbouring region and the risk of earthquakes:

1965 First discussions regarding nuclear power plants in Turkey
1976 **First tenders** for Akkuyu
1997 Renewed tender for Akkuyu
1998 **Earthquake** with the epicentre about 100 km off Akkuyu
2000 **Tender stopped** due to financing problems because of the consolidation of public finances and the fight against inflation; no general renunciation of nuclear power
2004 **Revival** of nuclear power plant plans announced
2006 Commissioning planned for 2012
2008 Announcement of construction start for two nuclear power plants in Akkuyu and Sinop already in 2008; did not materialize
2009 General **agreement** with Russia regarding the construction of 4 units in Akkuyu

Source: Süddeutsche Zeitung, Frankfurter Allgemeine Zeitung, SPIEGEL, Handelsblatt

(16) The **United Arabic Emirates (UAE)** have not signed the Convention yet. There are currently no research reactors in this country. The responsible authority Emirates Nuclear Energy Corporation (ENEC), however, plans to have at least three nuclear power plants with a capacity of 1,500 MW each from 2020 onwards. Credit default risk is assessed to be very low. The State is politically stable and has good regulatory qualities (IAEA 2008c; WNA 2009a).

(17) **Vietnam** has not signed the Convention yet either. The Vietnam Atomic Energy Commission (VAEC) currently monitors a 500 kW research reactor. According to the government, in 2014 the construction of two reactors with a total capacity of 2,000 MW will start. In 2018 the construction work for another two units is planned to start. By 2030, a total installed capacity of 10 GW shall

be connected to the grid. Vietnam’s default risk is assessed to be high. It is politically stable, but the government has only weak regulatory qualities (IAEA 2007f; IAEA 2008c; WNA 2009a).

(18) Due to the **heterogeneity of the named countries** that want to start or re-start the use of nuclear energy, generalising **conclusions** will not be sufficient: on the one hand, there are countries with a comparatively good credit rating and stable structures, such as UAE, Poland or Italy; on the other hand there are possible newcomers that are very unlikely to overcome the high barriers for starting nuclear energy use in the medium term. At this point, we do not want to give a general assessment of possible newcomers. The expansion plans of all countries with planned or existing nuclear power use will be included in the indicator-based evaluation in the final Chapter 5 (see there).

7.3 Table appendix

Table 8: Number of reactors in operation worldwide by countries and reactor types in 2009

	BWR	FBR	GCR	LWGR	PHWR	PWR	Total
Africa/Austr.							
Africa							
SOUTH AFRICA						2	**2**
America							
Rest of America							
ARGENTINA					2		**2**
BRAZIL						2	**2**
CANADA					18		**18**
MEXICO	2						**2**
USA							
UNITED STATES OF AM.	35					69	**104**
Asia							
China					2	9	**11**
India	2				15		**17**
Rest of Asia							
JAPAN	30					23	**53**
KOREA, REPUBLIC OF					4	16	**20**
PAKISTAN					1	1	**2**
TAIWAN, CHINA	4					2	**6**
Europe							
Eastern Europe							
ARMENIA						1	**1**
BULGARIA						2	**2**
CZECH REPUBLIC						6	**6**
HUNGARY						4	**4**
LITHUANIA, REP. OF				1			**1**
ROMANIA					2		**2**
SLOVAK REPUBLIC						4	**4**
SLOVENIA						1	**1**
UKRAINE						15	**15**
Russia		1		15		15	**31**
Western Europe							
BELGIUM						7	**7**
FINLAND	2					2	**4**
FRANCE		1				58	**59**
GERMANY	6					11	**17**
NETHERLANDS						1	**1**
SPAIN	2					6	**8**
SWEDEN	7					3	**10**
SWITZERLAND	2					3	**5**
UNITED KINGDOM			18			1	**19**
Total	**92**	**2**	**18**	**16**	**44**	**264**	**436**

BWR Boiling Water Reactor
FBR Fast Breeder Reactor
GCR Gas Cooled Reactor
LWGR Light Water-cooled Graphite-mod. Reactor
PHWR Pressurised Heavy Water Reactor
PWR Pressurised Water Reactor
Source: IAEA/PRIS 2009a

Table 9: Gross capacity of reactors in operation worldwide by countries and reactor types in 2009 in MW

	BWR	FBR	GCR	LWGR	PHWR	PWR	Total
Africa/Austr.							
Africa							
SOUTH AFRICA						1,888	**1,888**
America							
Rest of America							
ARGENTINA					1,005		**1,005**
BRAZIL						1,870	**1,870**
CANADA					13,425		**13,425**
MEXICO	1,364						**1,364**
USA							
UNITED STATES OF AM.	35,456					70,292	**105,748**
Asia							
China							
China					1,400	7,558	**8,958**
India							
INDIA	320				3,800		**4,120**
Rest of Asia							
JAPAN	28,569					19,366	**47,935**
KOREA, REPUBLIC OF					2,811	15,582	**18,393**
PAKISTAN					137	325	**462**
TAIWAN, CHINA	3,276					1,902	**5,178**
Europe							
Eastern Europe							
ARMENIA						408	**408**
BULGARIA						2,000	**2,000**
CZECH REPUBLIC						3,850	**3,850**
HUNGARY						1,970	**1,970**
LITHUANIA, REP. OF				1,300			**1,300**
ROMANIA					1,412		**1,412**
SLOVAK REPUBLIC						1,844	**1,844**
SLOVENIA						730	**730**
UKRAINE						13,835	**13,835**
Russia							
RUSSIAN FEDERATION		600		11,048		11,594	**23,242**
Western Europe							
BELGIUM						6,092	**6,092**
FINLAND	1,780					1,020	**2,800**
FRANCE		140				65,880	**66,020**
GERMANY	6,734					14,763	**21,497**
NETHERLANDS						515	**515**
SPAIN	1,558					6,170	**7,728**
SWEDEN	6,450					2,933	**9,383**
SWITZERLAND	1,610					1,780	**3,390**
UNITED KINGDOM			10,652			1,250	**11,902**
Total	**87,117**	**740**	**10,652**	**12,348**	**23,990**	**255,417**	**390,264**

BWR Boiling Water Reactor
FBR Fast Breeder Reactor
GCR Gas Cooled Reactor
LWGR Light Water-cooled Graphite-mod. Reactor
PHWR Pressurised Heavy Water Reactor
PWR Pressurised Water Reactor
Source: IAEA/PRIS 2009a

Table 10: Lifetime of operating reactors worldwide

	Number of reactors	Mean operating time (years)	Operating time min. (years)	Operating time max. (years)
Africa/Austr.				
Africa				
SOUTH AFRICA	2	24	23	25
America				
Rest of America				
ARGENTINA	2	30	25	35
BRAZIL	2	16	8	24
CANADA	18	25	16	38
MEXICO	2	16	14	19
USA				
UNITED STATES OF AMERICA	104	29	13	39
Asia				
China				
CHINA	11	8	2	15
India				
INDIA	17	18	2	40
Rest of Asia				
JAPAN	53	23	3	39
KOREA, REPUBLIC OF	20	16	4	31
PAKISTAN	2	23	9	36
TAIWAN, CHINA	6	27	24	30
Europe				
Eastern Europe				
ARMENIA	1	29	29	29
BULGARIA	2	18	15	20
CZECH REPUBLIC	6	17	6	24
HUNGARY	4	24	22	26
LITHUANIA, REPUBLIC OF	1	22	22	22
ROMANIA	2	7	2	12
SLOVAK REPUBLIC	4	17	9	24
SLOVENIA	1	26	26	26
UKRAINE	15	20	3	28
Russia				
RUSSIAN FEDERATION	31	27	3	37
Western Europe				
BELGIUM	7	29	24	34
FINLAND	4	29	27	32
FRANCE	59	24	7	35
GERMANY	17	27	20	34
NETHERLANDS	1	36	36	36
SPAIN	8	25	21	38
SWEDEN	10	30	24	37
SWITZERLAND	5	34	24	40
UNITED KINGDOM	19	27	14	41
Total	**436**	**24**	**2**	**41**

Source: IAEA/PRIS 2009a

Table 11: Construction time of operating reactors worldwide

	Number of reactors	Mean construction time (years)	Construction time min. (years)	Construction time max. (years)
Africa/Austr.				
Africa				
SOUTH AFRICA	2	9	8	9
America				
Rest of America				
ARGENTINA	2	8	6	10
BRAZIL	2	19	14	25
CANADA	18	8	5	11
MEXICO	2	16	14	18
USA				
UNITED STATES OF AMERICA	104	9	3	23
Asia				
China				
CHINA	11	6	5	9
India				
INDIA	17	10	5	15
Rest of Asia				
JAPAN	53	5	3	7
KOREA, REPUBLIC OF	20	5	4	6
PAKISTAN	2	7	6	7
TAIWAN, CHINA	6	6	6	7
Europe				
Eastern Europe				
ARMENIA	1	5	5	5
BULGARIA	2	10	8	12
CZECH REPUBLIC	6	10	6	16
HUNGARY	4	9	7	10
LITHUANIA, REPUBLIC OF	1	10	10	10
ROMANIA	2	19	14	24
SLOVAK REPUBLIC	4	12	8	17
SLOVENIA	1	8	8	8
UKRAINE	15	8	4	21
Russia				
RUSSIAN FEDERATION	31	7	4	20
Western Europe				
BELGIUM	7	6	4	8
FINLAND	4	7	6	8
FRANCE	59	7	5	16
GERMANY	17	7	5	11
NETHERLANDS	1	4	4	4
SPAIN	8	9	5	11
SWEDEN	10	7	5	10
SWITZERLAND	5	6	4	11
UNITED KINGDOM	19	12	6	24
Total	**436**	**8**	**3**	**25**

Source: IAEA/PRIS 2009a

Table 12: Lifetime of decommissioned reactors worldwide

	Number of reactors	Mean operating time (years)	Operating time min. (years)	Operating time max. (years)
America				
Rest of America				
CANADA	7	19	5	26
USA				
UNITED STATES OF AMERICA	28	16	0	34
Asia				
Rest of Asia				
JAPAN	6	26	11	33
KAZAKHSTAN	1	26	26	26
Europe				
Eastern Europe				
ARMENIA	1	11	11	11
BULGARIA	4	26	25	28
LITHUANIA, REPUBLIC OF	1	21	21	21
SLOVAK REPUBLIC	3	20	4	28
UKRAINE	4	13	2	19
Russia				
RUSSIAN FEDERATION	5	26	19	47
Western Europe				
BELGIUM	1	25	25	25
FRANCE	11	20	9	25
GERMANY	19	14	0	36
ITALY	4	19	9	26
NETHERLANDS	1	28	28	28
SPAIN	2	27	18	37
SWEDEN	3	21	10	28
UNITED KINGDOM	26	35	14	47
Total	**127**	**22**	**0**	**47**

Source: IAEA/PRIS 2009a

Table 13: Reactors under construction in 2009 whose construction has been halted

	Construction halted	Construction start (date)
Asia		
India		
PFBR	1	23-Oct-04
Europe		
Eastern Europe		
BULGARIA		
BELENE-1	1	01-Jan-87
BELENE-2	1	31-Mar-87
UKRAINE		
KHMELNITSKI-3	1	01-Mar-86
KHMELNITSKI-4	1	01-Feb-87
Russia		
BELOYARSKY-4 (BN-800)	1	18-Jul-06
KALININ-4	1	01-Aug-86
KURSK-5	1	01-Dec-85
Total	**8**	

Source: IAEA/PRIS 2009a, ATW, WNA, WNN, information from power plant operators etc. To determine the current status of each individual project listed officially "under construction" by the IEA, we matched the IEA information against other sources. A project was grouped in the category "construction halted" when this expression was used in the literature, or when – according to the literature – no construction works took place.

7.4 Methodology

The methodological approach for a quantitative presentation of future reactor numbers and capacities comprises **several steps**. During the first step, different original data was collected and partially tested for plausibility and – if necessary – corrected. Then, the different original data were compared with each other. The last step was to make specific assumptions regarding the individual data categories in order to derive at a quantitative overall picture.

7.4.1 Original data

We can distinguish five different types of original data.

1. Existing operating reactors (3/2009). The IAEA provided these data on currently operating reactors in its Power Reactor Information System (PRIS) which according to the IAEA is the most comprehensive data base on individual nuclear reactors worldwide.

2. Reactors under construction (3/2009). Also here, we used the current PRIS data of the IAEA.

3. Plans and proposals of individual reactor units (4/2009). The WNA compiles for many countries lists that comprise individual reactor units with names, i.e. locations. Often there is capacity data provided together with the name and sometimes even the intended date of construction start and/or start of operation. We only use reactor unit-related data if it includes both the capacity and at least one date; in this case we assume a certain progress in the planning process. In principle, all these data were retrieved in April 2009. The data on Russia are an exception; here we used the data status as of the beginning of May 2009 due to current announcements of the Russian government. The same applies to South Korea where also more current data was available.

4. Planned reactors (4/2009). Aggregated data regarding the number and capacity of planned reactors on a country level is available from the WNA.

5. Proposed reactors (4/2009). Analogously to the previous category, the WNA provides a second category of aggregated number and capacity data on the country level. Here the WNA uses the term “proposed” reactors (see 3.2)

7.4.2 Data validation

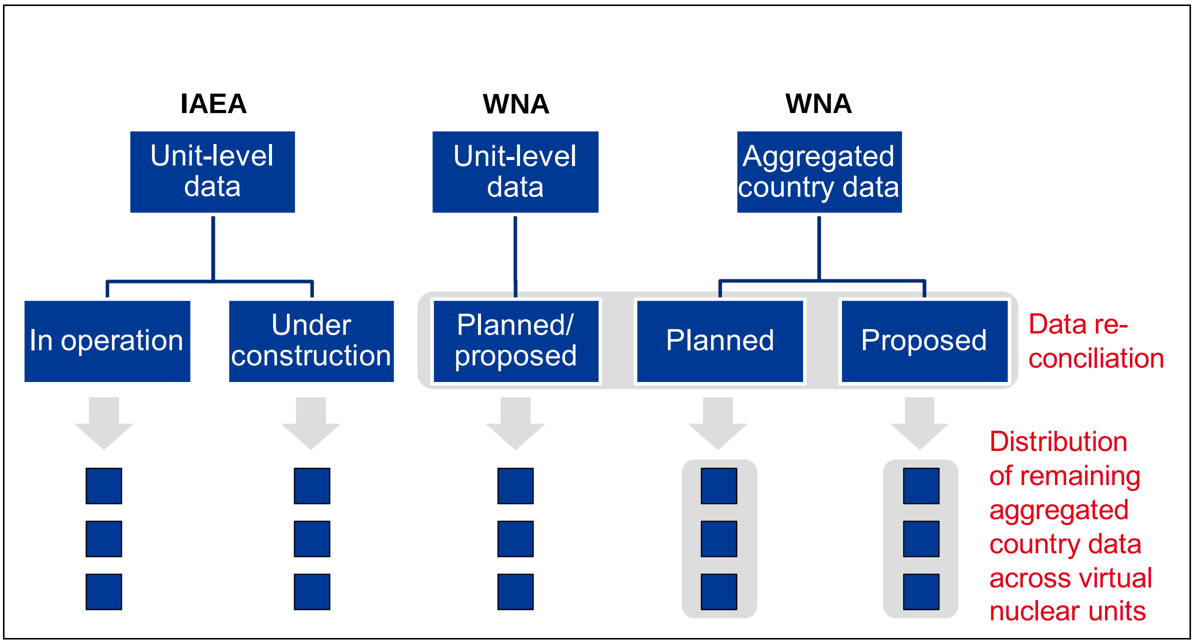
The 45 reactor units defined by the IAEA as “under construction” were individually validated. For this purpose, we analysed media information and articles from the specialist press. Based on our assessment, we have to assume that for 8 of the 45 reactors the construction has come to a standstill (see 3.4).

7.4.3 Data reconciliation

The original data has to be reconciled as they are on two different aggregation levels – one per individual reactor unit and the other aggregated on the country level.

Figure 25 illustrates the process of data reconciliation. The individual reactor units in operation and under construction stated by the IAEA were directly used without any further matching. As opposed to this, the WNA reactor unit data overlaps with the aggregated WNA country data. Therefore, the aggregated country data were adjusted for the data per reactor unit. That means that the total of all individual units (planned or proposed) were deducted from the aggregated WNA country data.

Figure 25: Method of data reconciliation for IAEA and WNA data



Source: Prognos AG

7.4.4 Assumptions

In order to be able to quantify the future number of operating nuclear reactors, we had to make several assumptions in accordance with the operating status of the individual reactor (operating, under construction, planned etc.)

For the currently **operating reactors**, we made a differentiation according to age and assumed that they would have total operating lives of 40, 45 and 45 or more years (Table 14). Exceptions from these lifetimes were made if there was WNA data for individual reactors stating a planned or decided shorter lifetime, such as in Germany (see 2.2).

Table 14: Assumptions regarding total lifetime of currently operating reactors

	Start of operation in, or after		
	1965	**1980**	**1986**
Lifetime (years)	40	45	≥45

Exceptions from these lifetimes were made if there was WNA data for individual reactors stating a planned or decided shorter lifetime,
Source: Prognos AG.

For most power plants **under construction**, there was a date of expected start of operation available. If the resulting expected construction time coincided with the country-specific average or was longer than that, we have used this value directly. If the resulting value was shorter than the country-specific average in the past, we assumed the planning not to be plausible. In such cases, we corrected the data and used a global mean value of eight years construction time (see Table 15). Only for some Asian countries we made an exception to this rule, as they had significantly shorter construction times in the recent past. For China and India, we assumed a country-specific average value of six years construction time and for Japan and Korea five years (see Chapter 2.4).

Table 15: Assumptions regarding the construction time in individual countries

	Assumed construction time (years)		
	5	**6**	**8**
Countries	Japan, South Korea	China, India	all other countries

Source: Prognos AG

In many cases, the country-specific average values were used because – in comparison to past experience – the intended construction times appeared to be overambitious (Example: Canada, 5 years intended).

The IAEA has several power plants listed in the category "under construction" that – after analysing several sources – were classified as "construction halted". In our model, their completion is postponed into the far-away future and not relevant for the here studied period until 2030.

The **plans and proposals for individual reactor units** on the WNA list contain varying time data. For some units, it states the expected construction date, for others the expected date for the start of operation. For some units, even both dates are available. We have to distinguish between these three cases.

If only the date of construction start was available, we have used the average, country-specific construction times from Table 15 in order to calculate the date of the start of operation. If only the start of operation was known, the average construction time was deducted in order to determine the start of construction. If the result for the construction start was a time in the past – which means that the planned reactor would have to be under construction already – the entire construction process was recalculated and moved into the future, and the expected construction start was the end of 2009.

The last alternative was that both dates, i.e. the planned construction start and the planned start of operation, were included in the WNA list. In this case, we tested – as described above – the plausibility of the planning by comparing it with the country-specific average values. If the planning was overambitious the date of the start of operation was postponed.

All in all, there is a slight change in comparison to the aggregated original WNA data due to the individual reactor-based plans and proposals (Table 16).

Table 16: Adjustment of WNA aggregated country data for WNA data per generation unit

WNA	Original data		Adjusted data	
	Number	Gross capacity (GW)	Number	Gross capacity (GW)
planned	111	123	45	48
proposed	273	270	216	203
WNA reactor units			113	128
Sum until 2030	**384**	**393**	**374**	**378**
Deviation due to individual reactor units, which were announced for the time after 2030 only				
Number	-10			
Gross capacity	-15			

Source: WNA 2009g

The original WNA data refers in its aggregated form to a start of operation within the next 20 years. The individual reactor-related WNA data contains even projects, though, with a date of start of operation after the year 2030. This results in a deviation from the original WNA data of 10 reactors by the year 2030.

For the other **aggregated country data** of **planned reactors**, the WNA only states a general time goal. The WNA expects these reactors to be put into operation within 8 years without providing specific dates for individual reactors (see 3.2). Based on this time goal, for calculation purposes we divided the aggregated country level into individual virtual power plant units with an average gross capacity each. This means, for instance, that 10 units with a total capacity of 12 GW were divided into 10 times one unit with a gross capacity of 1.2 GW each. In our model, these reactors were – based on specific assumptions – distributed over the time line in such a way that their calculatory construction time corresponded to the assumptions (see above) and that they would be put into operation by the date corresponding to the time goal. For the **aggregated country data** of the **proposed reactors** that the WNA expects to be put into operation within the next 20 years, we used the same principal procedure as for the planned reactors (see above).

Now we have described all the steps that were necessary for mapping the plans and proposal lists of the WNA (see Chapter 3.2). The realistic development path described in Chapter 5 includes further assumptions regarding the country-specific degree of realisation, the maximum available supply of reactor pressure vessels and the international economic crisis. These are directly described in Chapter 5.

7.5 List of abbreviations

ATW	International Journal for Nuclear Power (“Internationale Zeitschrift für Kernenergie“, formerly: “Atomwirtschaft“)
BWR	Boiling water reactor
DAE	Department of Atomic Energy
DOE	US Department of Energy
EIA	Energy Information Administration
EPR	European Pressurized Water Reactor
FBR	Fast breeder reactor
GCR	Gas-cooled reactor
GW	Gigawatt
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
kW	Kilowatt
LWGR	Light water-cooled graphite-moderated reactor
MW	Megawatt
NEA	Nuclear Energy Agency
NEI	Nuclear Engineering International
NRC	Nuclear Regulatory Commission
OECD	Organisation for Economic Co-operation and Development
PFBR	Prototype Fast Breeder Reactor
PHWR	Pressurised heavy water reactor
PRIS	Power Reactor Information System, the reactor data base of the IAEA
PWR	Pressurised water reactor
TWh	Terawatt-hours
WEO	World Energy Outlook
WNA	World Nuclear Association
WNN	World Nuclear News