[EHNUR WP 3]

SHORT AND MID-TERM TRENDS OF THE DEVELOPMENT OF NUCLEAR ENERGY

KLAUS GUFLER[1]

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Media owner and editor:

University of Natural Resources and Life Sciences Vienna, Department of Water, Atmosphere and Environment, Institute of Safety and Risk Sciences, Borkowskigasse 4, 1190 Wien, Austria

URL: http://www.risk.boku.ac.at

EXECUTIVE SUMMARY

Objective and approach

The objective of the work package "short- and mid-term development of the global nuclear landscape" is to compare historical projections on the development of the global installed nuclear capacity with more recent projections and scenarios. By analysing the indicators and factors used in other projections shortfalls will be worked out. Relevant indicators and factors will be extrapolated and used to create own scenarios. The outcome of the analyses will be used as background for the development of four scenarios for the short (2020) and mid-term (2030) development of nuclear power around the world. These scenarios are based on variables like national nuclear development strategies, planned life time extension programs, construction schedules, planning schedules, construction and planning stops. The developed scenarios will be compared with existing projections by the IAEA, the WNA and the IEA and similarities and differences will be worked out. The scenarios will be used to evaluate the short and mid-term trends and will help answering the question whether a nuclear renaissance – according to the criteria by McLellan (2008) – is under way likely to happen.

Background

Starting from the late 1950´s nuclear energy production entered the electricity markets. Until the mid-1980´s more and more nuclear power stations went online around the globe. The nuclear industry at that time was focused mainly on Europe and North America. In 1979 the accident at Three Mile Island (TMI) nuclear power station raised the awareness of the public that nuclear power plants can suffer accidents, which could affect the surrounding areas. TMI had an impact on the nuclear industry (Char and Csik, 1987) by increasing the concerns of the public regarding the nuclear safety issues. The public acceptance decreased. Simultaneously, the capital costs necessary to build a new nuclear power plant increased (partly due to increased requirements of the licensing and partly due to increased construction times), so that the interest of the utilities to invest in new reactors decreased. The Chernobyl accident in 1986 had severe implications on the global nuclear landscape and the global nuclear market. After Chernobyl the number of new nuclear power plants ordered decreased strongly. Between 1990 and 2005 only a few new nuclear power stations were completed and went operational.

In the early years of the new century the discussion on a nuclear renaissance started. (McLellan, 2008) The discussion on a nuclear Renaissance was triggered by the discussion on global warming and greenhouse gas emissions (Wang and Hansen, 2007). The nuclear industry was seeking to create a better – more positive –image and a new role for the nuclear power. McLellan (2008) summarizes the indicators for a nuclear renaissance with improved performance, reduced construction costs and construction time for new nuclear power plant designs. He focuses on the situation in the US and in Canada around the year 2005. At that time the discussion on the nuclear renaissance swapped from North America to Europe.

It is important to analyze what actually has been accomplished after the proclamation of a nuclear renaissance. The question to what extent an expansion of nuclear power is visible on a global scale and when differentiating between developments in various regions of the world was elaborated, based on information on current planning. The analyses focus on the upcoming future (2020 and 2030).

Conclusions

The operational load factors increased all over the world since the 1980 until 2013, so that the annual nuclear electricity production could increase despite of stagnation in installed capacity. New nuclear power plant designs were proposed around the globe in that time, but by in 2013 only 1% of the global nuclear power reactor fleet can be considered as advanced generation reactors (Gen III, Gen III+ and Gen IV). Today, still 90% of the global power reactor fleet consists of second generation reactors and 9% of the reactors are first generation designs.

The WP 3 report focusses on the development of nuclear power reactors fleet in a short- and mid-term perspective and analyses whether new nuclear power plant designs (Gen III, Gen III+ and Gen IV) are going to be the drivers for a nuclear Renaissance.

The analysis of past development demonstrated that the first wave of nuclear built-up was triggered by activities in Europe and North America. In the (former) Soviet Union and its East-Europe allies (CIS region) there was a significant trend towards nuclear energy usage, but the number of realized reactor units was low compared to the markets in Europe and North America. When looking at the historical data on the installed nuclear capacity it is a striking observation that all over the last decades the projections on expected future nuclear expansion published within these years dramatically overestimated the actual build up within the projection periods. Based on that experience one has to be very careful regarding todays projections into the future.

Taking into account the development in recent years and the scenarios for future nuclear development around the world a shift from “traditional” nuclear markets towards “emerging” nuclear markets can be observed. The current increase in installed capacity is driven by Asia (and partly by the CIS region) and it can be expected that this will also be the case till 2020 and 2030.

A differentiation between regional developments is crucial to understand the future trends in nuclear energy production on a global level. It is not possible to summarize the overall trend by one generalized term, like “nuclear renaissance”. . However, all created scenarios identified similar, more differentiated trends.

The installed nuclear capacity in Europe will drop slightly up to 2020 and suffer a significant drop until 2030. North America experiences a stagnation of its level of installed nuclear capacity until 2020. After 2020 a decrease of installed nuclear capacity will be seen. The CIS region will have an increase of installed nuclear capacity to 2020 and 2030. Asia will experience a strong expansion of installed nuclear capacity until 2020 and 2030. Asia is going to be the largest nuclear market of the future, mainly driven by China.

This shift of the global nuclear landscape towards Asia brings several future challenges for the nuclear industry. One crucial factor might be the nuclear fuel cycle facilities, which by 2013 are located in North America, Europe and the CIS region. As the center of the nuclear market is moving, also new nuclear fuel cycle facilities are likely to be built in the new focus region of the nuclear industry. Such a development might be critical in terms of proliferation concerns (in particular related to sensitive facilities like uranium enrichment) (see WP 9 report).

The construction time of new reactors - one promise of the nuclear renaissance to be reduced - must be considered on a regional level too. The construction time of new reactor designs in Europe and the US exceeds the scheduled time frame by several years. The average construction time of nuclear power reactors over the past two decades in the UK was about 6.1 years and in France 9.4 years. The construction time of reactors in Asia and the CIS region is far below the levels in Europe and North America (i.e. Japan 4.4 years, Korea 4.6 years, China 5.8 years) (Schneider, 2012).

The study revealed that a distinction between the construction time of old reactors designs (proven Gen II designs) and new advanced reactor designs is necessary in order to make a sensible comparison. The study revealed that the construction of old designs in China suffers some delays (up to 1 year). The construction of new advanced reactors in Asia and CIS are suffering bigger delays (1-2 years). In Europe the construction delays for Gen III+ are huge. The EPR at Olkiluoto was scheduled to be operational in 2009 (construction started in 2005). In February 2013 TVO announced that the operation will not start until 2016. (WNN, 2013)

If comparing the reactor generations under construction and in planning phase in Asia and the CIS region, a significant difference can be noted. In the CIS region mainly Gen III+ reactors are under construction or planned. In Asia there are several Gen II designs under construction. Gen III and Gen III+ designs will become operational mainly after 2018. Nevertheless there will be some Gen II designs being completed even after 2018.

The proclamation of a nuclear Renaissance in based on the promise to introduce an improved and advanced generation of nuclear power plants. The analysis performed here highlights that despite the share of advanced generation reactors - on a global level - will indeed increase towards 2020 and 2030; the large majority of nuclear power plants in operation will still consist of reactors from the second generation. Depending on the scenario the share of Gen II reactors in 2020 will be between 73 and 86 percent. In 2030 the share of second generation reactors will be between 68 and 75 percent. Advanced generation reactors (Gen III and Gen III+) will contribute between 10 and 22 percent to the nuclear power reactor fleet by 2020. The share will increase towards 2030 between 21 or 26 percent. Gen IV reactors´ contribution will be at around 1 percent or lower. The rest are going to be first generation reactors. Those results make clear, that by 2030 the nuclear power reactor fleet will consist mainly by second generation reactors. Chapter 9 of the EHNUR report presents the safety related questions and problems of second generation reactors.

If looking on the regional distribution the fact of second generation reactors becomes even clearer. In North America and Europe the second generation reactors in 2020 and 2030 will contribute with over 90 percent to the regional power reactor fleet. The situation in Asia and the CIS is a different. In Asia the share of second generation reactors in 2020 will be between over 60 percent and in 2030 around 52 percent. In the CIS region Gen II reactors in 2020 will contribute over 56 percent and in 2030 over 52 percent.

The nuclear renaissance is not happening on a global level. There are some indicators that we might see a regional renaissance of nuclear power, which is not driven by the assumed factors of a global nuclear Renaissance. If talking about renaissance the only markets were this term could be used is the CIS region, were after the Chernobyl accident and the crash of the Soviet Union several projects were halted. Asia will experience a strong growth of nuclear power production, but the starting level in Asia is very low. Asia will introduce nuclear power on a large scale, but it does not seem to be a nuclear renaissance because there was no peak in the past. From the data no trend towards a nuclear renaissance is visible for Europe and North America. It seems more likely that in the “traditional” nuclear markets the installed nuclear capacity will decrease until 2030.

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1. INTRODUCTION

1.1. BACKGROUND

Starting in the mid-fifties the first the first commercial nuclear power plants became operational. At that time nuclear power was seen as the technology of the future, solving the energy problems of the future. In this context Lewis L. Strauss in 1954 stated:

"Our children will enjoy in their homes electrical energy too cheap to meter...." (Strauss, 1954)

History has shown that nuclear power was not able to fulfill this dream. Nevertheless future projections from the 1960 to the 1980 were very ambitious but reality lacked behind. In the 1970s the oil crises led to a growth of nuclear power in Europe and the North America, but not all planned nuclear power projects were carried out, mainly due to economic reasons. (Char and Csik, 1987) In 1979 the accident at Three Mile Island nuclear power station raised the awareness of the public that nuclear power plants can suffer accidents, which could affect the surrounding areas. TMI had an impact on the nuclear industry (Char and Csik, 1987) by increasing the concerns of the public regarding security. The public acceptance decreased. The Chernobyl accident in 1986 had severe implications on the global nuclear landscape and the global nuclear market. After Chernobyl the number of new nuclear power plants ordered decreased strongly. Between 1990 and 2005 only a few new nuclear power stations were completed and went operational. (Section 3.1)

In the early years of the new century the discussion on a nuclear Renaissance started. (McLellan, 2008). It was triggered by the discussion on global warming and greenhouse gas emissions (Wang and Hansen, 2007). The nuclear industry was seeking to create a new – more positive –image and role for the nuclear power. McLellan (2008) summarizes the indicators for a nuclear Renaissance with improved performance and reduced construction costs and time for new nuclear power plant designs. He focuses out the situation in the US and in Canada around the year 2005. At that time the discussion on the nuclear Renaissance swapped from North America to Europe.

As in the 1970s and 1980s the future projections – following the discussion on a nuclear Renaissance – started to be more ambitious. Different projections indicated a strong growth of installed nuclear capacity for the first half of the 21st century. Reality lacked behind the projections.

By June 2013 according to the IAEA 436 nuclear power reactors were in operation (IAEA Pris, 2013). The installed nuclear capacity is about 372 GW_e net (IAEA Pris, 2013). If excluding the 48 nuclear power reactors in Japan - still shut down due to the Fukushima Daiichi nuclear accident – 388 nuclear reactors are able to produce electricity by June 2013. There are 61 Units under construction in 13 countries around the world. Additionally there are 202 units in a planning phase in 18 countries. In 2011 the IAEA (2011a) noted that 65 reactors were in construction in 15 countries, and 151 reactors in 22 countries were in a planning phase (IAEA, 2011a).

1.2. OBJECTIVE

The objective of the work package "short- and mid-term development of the global nuclear landscape" is to compare historical projections on the development of the global installed nuclear capacity with more recent projections and scenarios. By analysing the indicators and factors used in other projections shortfalls will be worked out. Relevant indicators and factors will be extrapolated and used to create own scenarios. The outcome of the analyses will be used as background for the development of four scenarios for the short and mid-term development of nuclear power around the world. The developed scenarios will be compared with existing projections and similarities and differences will be worked out. The scenarios will be used to evaluate the short and mid-term trends and will help answering the question if a nuclear Renaissance – according to the criteria by McLellan (2008) – is likely to happen.

2. METHOD

2.1. FOCUS

Within WP3 a data base has been developed that contains past, actual and projected future nuclear power plants. In the open literature no adequate database was available. The IAEA Power Reactor Information System (PRIS) is a very comprehensive database for past and actual Information, but in order to create scenarios there was the need to include also reactors in construction and planning phase. The relevant information was added on a country by country, and unit by unit base.

The scenarios evaluated by the work package 3 were based on the findings in the literature and on publicly available projections. In case of uncertainties (i.e. likely life time extensions, construction delays, etc…) the database was complemented by expert judgment by the project team. Additionally the accident at the Fukushima Daiichi nuclear power plant happened during the project, and was therefore considered in the scenarios. One scenario was built on the pre- Fukushima database, three on the post Fukushima Database.

2.2. DATA MINING, FOCUS AND EXTEND

Only publicly available information was used for the project. The data mining can be divided into two parts. First there was made a selection of projections for nuclear power by international authorities and agencies. The second step was the mining of data relevant for short and mid-term development of nuclear capacities on a country by country base.

2.3. SCENARIOS AND PROJECTIONS

For the international projections an in-depth analysis was performed, in order to identify the relevant projections for the nuclear capacity development up to 2020 and 2030. The projections were selected by the following criteria:

- Detailed description of the used method
- Information of installed nuclear capacity by 2020 and/ or 2030 is given
- Information on regional development trends included
- Possibility of changes in future trends caused by the Fukushima is taking into account

A first scoping turned out, that projections by two authorities (IEA, IAEA) could be used for the purpose of work package 3. In a further step an additional projection was added in order to take into account one ambitious projection performed before the Fukushima Daiichi accident. The additional projection taken into account was created by the WNA.

The Projections used for the comparison were:

- IAEA 2011 projection low (IAEA, 2011)
- IAEA 2011 projection high (IAEA, 2011)
- IEA 2012 New policy scenario (IEA, 2012)
- IEA 2012 Current policy scenario (IEA, 2012)
- IEA 2012 450 Scenario (IEA, 2012)
- WNA 2008 Nuclear Century Outlook high (WNA, 2008)

The projections by the IAEA and the IEA are meeting all the four above described criteria. The WNA Outlook is meeting three of the criteria.

The projection by the IAEA and the IEA follow a well described methodology, which is elaborated in following chapter of this report. The assumptions were clear and could be used for the theory development and to build up own assumptions derived by the two Agencies. The IAEA projection – not surprisingly- has a clear and detailed focus on nuclear energy, while the IEA projections only mention nuclear as one technology under others. Nevertheless the IEA projections contained all necessary data to be able to compare their projections with other outlooks and scenarios.

The WNA Nuclear Century Outlook was created in 2008, and claims to be unique due to the fact that it is looking not only to 2030 or 2050 but having benchmarks in 2060 and 2100. Additionally the WNA Nuclear Century Outlook states not to be a scenario but rather to demonstrate the boundaries of likely nuclear growth. The WNA nuclear century outlook has two trajectories – a low and a high trajectory. The low trajectory is considers pessimistic assumptions, the high trajectory optimistic assumptions. The Outlook is built on a country by country assessment of the growth potential of nuclear power programs. The population of the countries are the key factor, on which the estimation of needed energy and nuclear capability is based on. The high trajectory assumes a full policy commitment to nuclear power. It assumes that fuel availability will not be a constraint for the growth of nuclear, because it's assuming that additional uranium will be found, that the thorium fuel cycle will be implemented and that breeder reactors will provide fuel and a closed fuel cycle. (WNA, 2008)

In addition to the projections used for comparison and evaluation of the own scenarios for 2020 and 2030, projections from the time of the first strong growth of nuclear were mined, described and compared. Projections by OECD, IAEA and USAEC were used for this purpose. The projections were extracted from IAEA bulletins.

TABLE 1: PROJECTIONS AND SOURCES

Agency/ Authority	Projection	Source
IAEA	1974 most likely, 1974 max, 1986 low, 1986 high, 2011 low, 2011 high	Goodman and Krymm, 1975 Char and Csik, 1987 IAEA, 2011
IEA	2012 NPS, 2012 CPS, 2012 450 Scenario	IEA, 2012
OECD	1969 low, 1969 high, 1970, 1973 reference case, 1973 accelerated case, 1974 reference case, 1975 low, 1975 high, 1976 low preliminary, 1976 high preliminary	Krymm, 1973 Goodman and Krymm, 1975, Krymm and Woite, 1976 Eklund, 1981 Laue, 1982
USAEC	1974 min, 1974 max	Goodman and Krymm 1975
WNA	WNA 2008	WNA 2008

The aim of this historical data grabbing was to identify similarities in the approach, and the identification of data relevant for the future development trends. Even if the approach was not described properly in every single publication, the bottlenecks, constraints and main drivers were visible and could be used for the project.

The projections, forecasts and scenarios regarding the development of nuclear power from different authorities and Think Tanks for an easier handling will be called forecasts in the chapter, if not explicitly titled in a certain way.

The more recent projections available in the open literature rely on different assumptions and different methods. Fundamental assumptions used for the different projections were described by the IAEA (2011, p. 6) as follows:

- Economic growth
- Correlation of economic growth and energy use
- Technology performance and costs
- Energy resources availability and future fuel prices
- Energy policy and physical, environmental and economic constraints

Some projections additionally include other factors like

- Climate targets (CO_2 reduction Goals)
- New technologies
- Policy driven changes (IEA, 2012)

Not all of the projections include nuclear power for the future energy system. The Global Environmental Assessment excludes nuclear power in their frame conditions (GEA, 2012). Only a few projections have a special focus on the development of nuclear power. While the IAEA and the WNA projections clearly focus on the installed nuclear energy production, others like the IEA use a wider approach, but recognize the role of nuclear power a future energy system (IEA, 2012).

The selected projections were described in a more detailed way in the following section. The projections which are to be discussed are:

- IAEA 2011 projection low
- IAEA 2011 projection high
- IEA 2012 New policy scenario
- IEA 2012 Current policy scenario
- IEA 2012 450 Scenario
- WNA 2008 Nuclear Century Outlook high

The IAEA 2011 projections were published after the Fukushima Daiichi nuclear accident in Japan in March 2011, and with the background of the financial and economic crisis still pending. The IAEA 2011 projections were based on:

- National projections supplied by each country for a OECD/NEA study
- Indicators of development published by the World Bank
- Global and regional energy, electricity and nuclear power projections made by other international organizations. (IAEA, 2011, p. 6)

The projections for installed nuclear capacity for the year 2030 were reduced – compared to the projections from 2010 – significantly. The IAEA low projections were decreased by 8% and the high projection by 7% compared to the IAEA 2010 projections. The IAEA projections from 2012 were once again cut down by 9% for 2030 – for the low scenario, and decreased by 1% for the IAEA 2012 high scenario. (IAEA 2012a p.8)

TABLE 2: DATA COMPARISION IAEA 2011 (IAEA 2011, P. 17) AND 2012 PROJECTIONS (IAEA 2012A, P. 17) (GWE)

	2020 low	2020 high	2030 low	2030 high	2050 low	2050 high
IAEA 2011	429	525	501	746	560	1228
IAEA 2012	421	508	456	740	469	1137

The IEA World Energy Outlook 2012 Scenarios are built on different factors like economic activities, demographic changes, energy prices, CO_2 prices and energy efficiency development (IEA 2012 p.33). The IEA identified the economic conditions, energy prices and weather as major driver for the short term when it comes to energy demand and fuel mix. For mid- and long term changes governmental actions were identified as the major drivers (IEA, 2012, p.50).

The accident at the Fukushima Daiichi Nuclear Power plant was taken into account when evaluating the nuclear share in 2035. Several assumptions used in the last WEO were re-elaborated due to the accident at Fukushima.

For the New Policy Scenario (NPS) it is assumed that Germany will perform the accelerated phase out, and Switzerland will not replace its nuclear reactors as planned previously. Japan will restart all reactors, with the exemption of the plants at Fukushima Daiichi and Daiini. The lifetimes for Japanese reactors built before 1990 were limited to 40 years (instead of 50 years in the last WEO) and the lifetime of reactors built after 1990 were limited to 50 years (instead of 60 years previously) (IEA, 2012 pp. 190). Nuclear and renewables will be extended and supported by loan guarantees in the US. (IEA, 2012, p. 632) Additionally no new plants will be built in Japan – except the two in construction phase. For Europe and the US the report assumes a slower growth than expected in last report. China will lift its moratorium on new approvals and go ahead with their ambitious program. (IEA, 2012 pp. 190) China will have 70-80 GW of nuclear capacity by 2020. The Russian nuclear sector will be strongly supported by the state (IEA, 2012, p. 633). The New Policy Scenario assumes the installed capacity as follow:

TABLE 3: DATA FROM IEA 2012 ,P. 554 (GWE)

	2015	2020	2025	2030	2035
NPS 2012	422	474	519	551	583

The IEA World Energy Outlook 2012 Current Policy Scenario (CPS) is assuming lifetime extension of most US nuclear power plants beyond 60 years (IEA, 2012, p. 632). In Japan the Fukushima Daiichi units 1-4 are planned to be decommissioned. For Germany the decided phase out is taken into account. China will start construction of 40 GW of new nuclear power plants by 2015 (IEA, 2012, p. 633). The Current Policy Scenario assumes the installed capacity as follow:

TABLE 4: DATA FROM IEA 2012 ,P. 555 (GWE)

	2020	2030	2035
CPS 2012	476	526	524

The IEA World Energy Outlook 2012 450 Scenario is assuming a stronger support of nuclear and renewables in Russia. In China continued supports to nuclear capacity additions post 2020. For the US an extended support to nuclear alongside with renewables and CCS. For India an expanded support to renewables nuclear and efficient coal (IEA, 2012, pp. 633)

TABLE 5: DATA COMPARISION OF IEA 2012 (IEA, 2012, ,P. 555) AND 2009 PROJECTIONS (IEA, 2009, ,P. 324) (GWE)

	2020	2030	2035
IEA 450 2012	495	699	796
IEA 450 2009	519	735	NA

The WNA Nuclear Century Outlook was created in 2008, and claims to be unique due to the fact that it is looking not only to 2030 or 2050 but having benchmarks in 2060 and 2100. Additionally the WNA Nuclear Century Outlook states not to be a scenario but rather to demonstrate the boundaries of likely nuclear growth. The WNA nuclear century outlook has two trajectories – a low and a high trajectory. The low trajectory considers pessimistic assumptions, the high trajectory optimistic assumptions. The Outlook is built on a country by country assessment of the growth potential of nuclear power programs. The population of the countries are the key factor, on which the estimation of needed energy and nuclear capability is based on. The high trajectory assumes a full policy commitment to nuclear power. It assumes that fuel availability will not be a constraint for the growth of nuclear power, because it's assuming that additional uranium will be found, that the thorium fuel cycle will be implemented and that breeder reactors will provide fuel and a closed fuel cycle. (WNA, 2008)

TABLE 6: WNA NUCLEAR CENTURY OUTLOOK SOURCE: DATA TAKEN FORM WORLD-NUCLEAR.ORG

	2030 low	2030 high	2060 low	2060 high	2100 low	2100 high
Current nuclear programs	559	1087	951	2939	1729	9137
Nations planning Nuclear	30	123	78	300	126	910
Potential Entrants	13	140	111	429	207	999
Total	602	1350	1140	3688	2062	11046

Figure 1 shows the different international projections by the IAEA, the IEA and the WNA up to 2050. It can be stated that the projections, even in a short term, show some significant differences depending on the above described assumptions. The figure shows the development after Fukushima and its implication on a short and medium term. The WNA Nuclear Century Outlook high is the most exposed international projection in the year 2030.

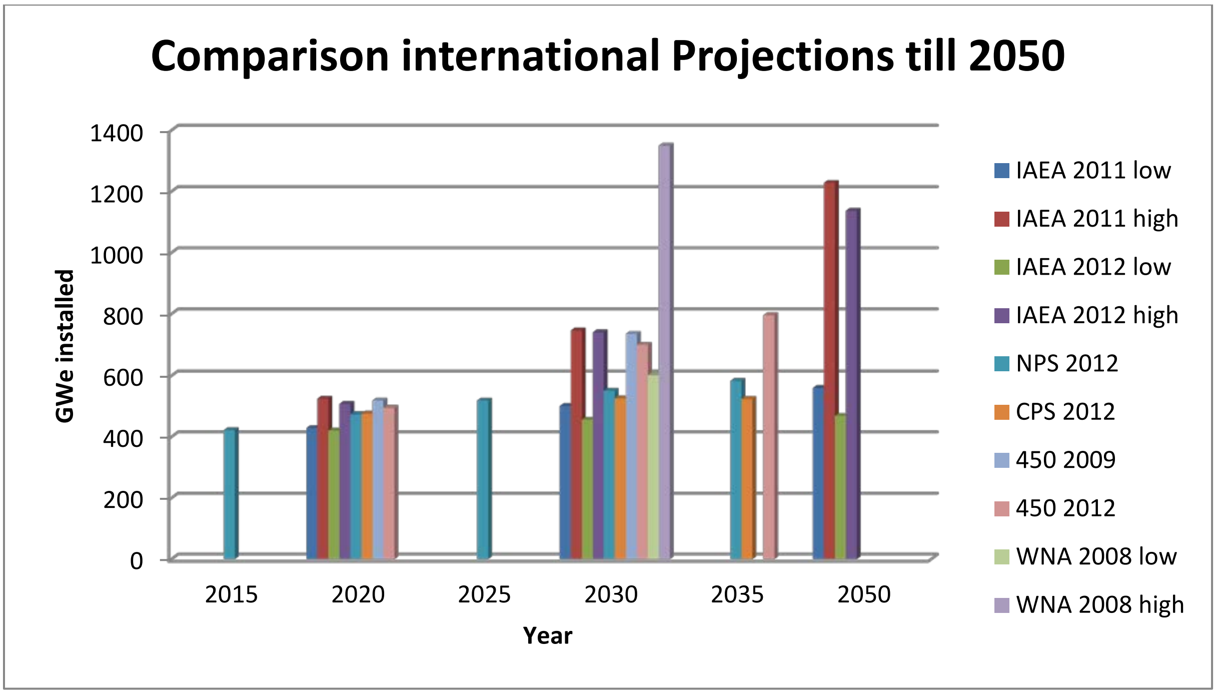


FIGURE 1: COMPARISON OF INTERNATIONAL PROJECTIONS UP TO 2050

Figure 2 gives an impression how ambitious the assumption of the WNA 2008 high outlook is, and how big the differences between the trajectories are.

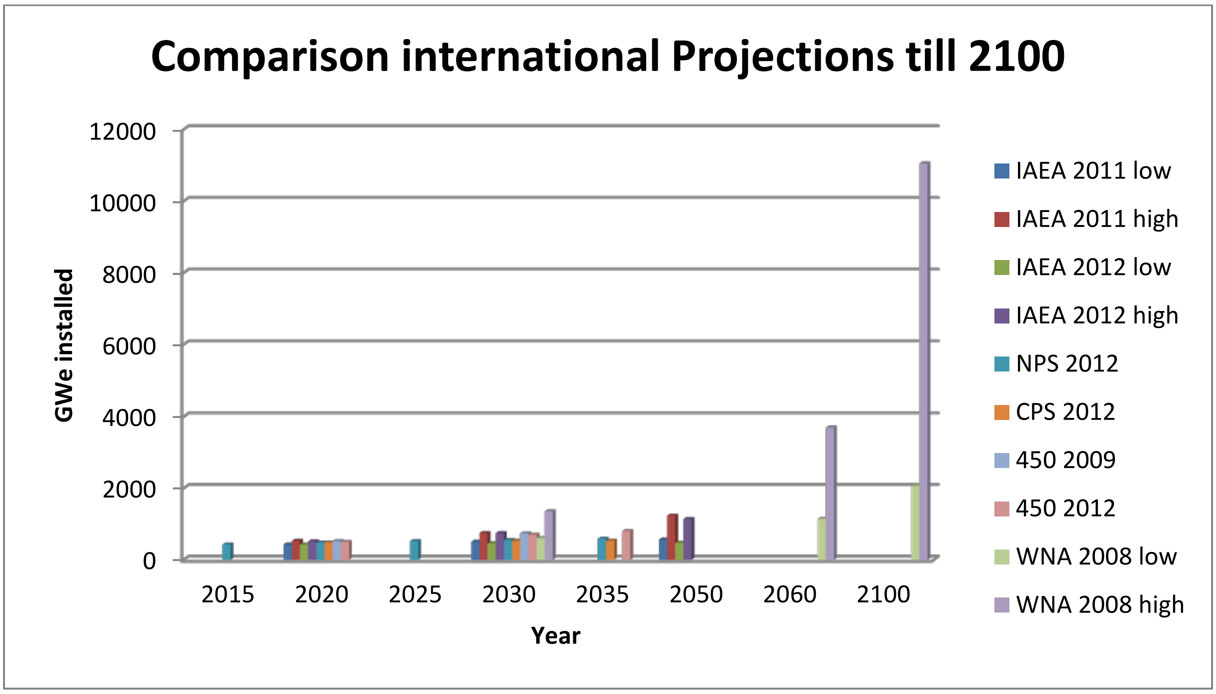


FIGURE 2: COMPARISON OF INTERNATIONAL PROJECTIONS UP TO 2100

The above described international projections are a selection of several projections and outlooks. There are several more projections created in the last decade. At the time when nuclear seemed to be the solution to the energy problems of mankind, there were made several projections by different Authorities. Those projections were very ambitious. Figure 3 inter-compares the historical projections and actual projections.

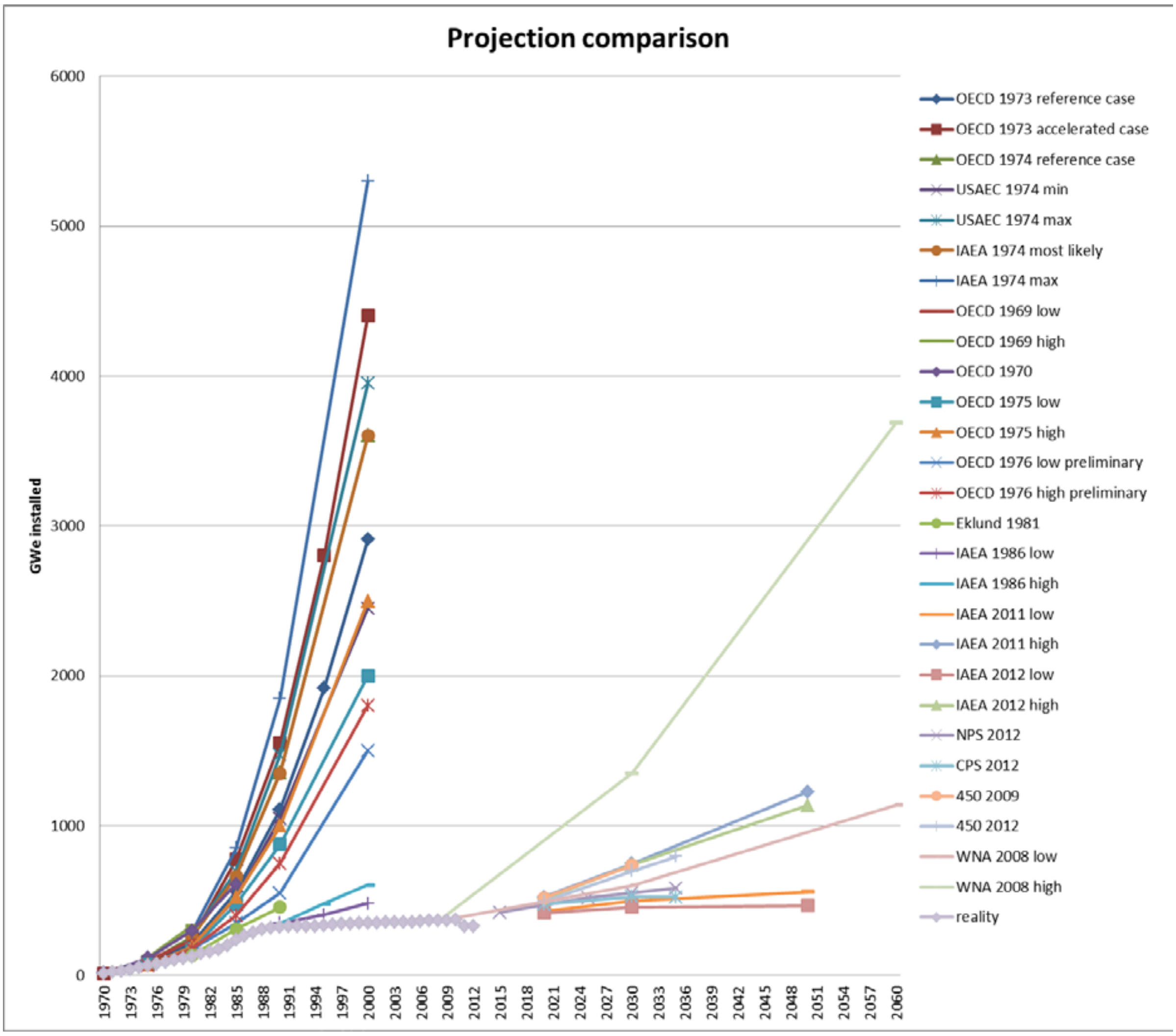


FIGURE 3: HISTORICAL AND RECENT PROJECTIONS COMPARED WITH THE REAL DEVELOPMENT

Figure 3 shows different projections from different years. The projections were decreased time by time, because the reality was not able to keep the pace of the projected growth. The WNA 2008 high scenario can be understood as in the tradition of projection in the 70s and 80s.

Another interesting fact shown in figure 3 is that the projections were always higher than reality, even in a short term (5-10 years). This fact was mentioned by Eklund (1981).

Eklund noted that “It is unfortunately much more difficult to interpret what the crystal ball indicates may happen in the energy field five to ten years from now”. (Eklund, 1981)

Figure 4 illustrates this finding. This was noted by Laue (Laue, 1982) who was observing a steady decline of projections for the short term and a dramatic decrease for the long term. Laue stated that even the oil crises in the mid-70s had only a little impact. He worked out that the projections for the year 1990 and 2000 in 1980 were at 1/3 to 1/5 of the value that they had in 1973/74 (Laue, 1982). Figure 4 makes this decrease more visible.

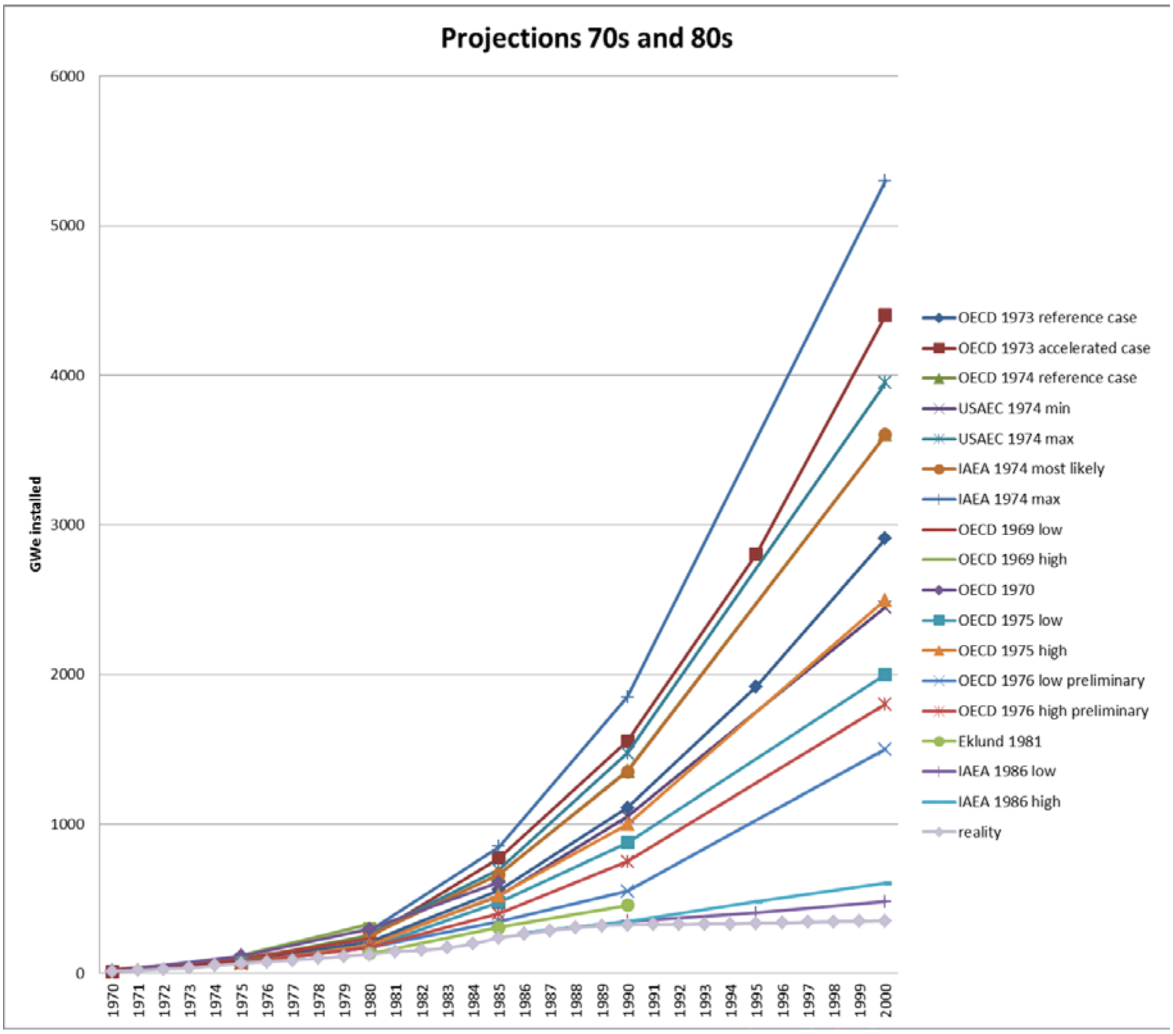


FIGURE 4: PROJECTIONS 70S AND 80S

The decrease is even stronger as Laue described (see Figure 4). Laue explained the dramatic reduction by three major reasons:

- The economic situation
- Lack of public confidence
- Proliferation risk (Laue, 1982)

For a certain period of time mainly the economic situation was the key driver for projections. Goodman and Krymm stated in 1975 that the theoretical forecast based purely on economic comparisons ran into constraints (Goodman and Krymm, 1975, p. 9). Those two identified constrains were:

- High capital costs and high content of advanced engineering
- Accidents, proliferation and public acceptance (Goodman and Krymm, 1975, pp. 9)

Nuclear fuel is not considered as a bottleneck, because the projections from the 70s and 80s consider a closed fuel cycle, by using breeders. Goodman and Krymm quoted the OECD/NEA-IAEA report from August 1973 were the nuclear capacity mix is projected. For the year 2000, in the reference case scenario, 856 GWe from breeders were predicted. (Goodman and Krymm 1975 , p. 14)

The variety of projections from different authorities combined with the high bandwidth of the projections made led the authors to the decision that it is necessary to create own scenarios to better understand the background and outcome of the projections. Based on the knowledge on past and recent projections work package 3 will carry the following tasks:

- Creation of three scenarios for the timeframe 2020 and 2030
- Identification of the world nuclear reactor park
- Identification of the main nuclear markets of the future
- Identification of regional differences regarding the development of nuclear power
- Identification of the nuclear development plans on a country by country base
- Identification of the gap between development plans and projections

2.4. DATABASE

Based on an existing database (flexRisk Project Database) a more elaborated and detailed database was created. The flexRisk database only contained European reactors operational in 2011. The database for EHNUR project contains all reactors worldwide, including units shut down, under construction, and in planning phase. Further there were added not only up to 650 reactors to the flexRisk database, but also many additional data. The EHNUR Database includes 834 commercial reactors at 313 sites worldwide.

For the EHNUR database each commercial reactor worldwide includes name, alternative name, site id, region, country, coordinates, units, thermal power, gross electrical power, net electrical power, fuel demand, unit type, reactor type detail, generation, construction start, operational status, startup year, shutdown year. Only commercial reactors were put into the database.

2.4.1. STRUCTURE OF THE DATABASE

Name: Name of the NPP

Alternative name: second name or alternative name of the NPP

Site ID: four letters site id for easier coding

Region: Five regions worldwide (Africa, Asia, Europe, North America, South America)

Country: Country in which the NPP is located

Units: Unit number or name

Thermal power: Thermal power of the unit

Electrical power gross: Gross electrical power of the unit

Electrical power net: Net electrical power of the unit

Fuel demand: Calculated fuel demand of the unit per year

Unit type: Reactor type general (PWR, BWR, PHWR, LWGR, GCR, FR, HTR, SGHWR, HWLWR)

Reactors type detail: Detailed reactors type description (i.e. Gidropress 6-loop VVER-440/212)

Generation: Generation of the reactor (Gen I, Gen II, Gen III, Gen III+, Gen IV)

Construction start: Construction start of reactors in construction phase

Operational status: Status of the reactor (permanent shutdown, operational, under construction, planned)

Start-up year: Commercial operation year

Shutdown year: Year of (expected) shutdown

The database is composed in a Microsoft Excel ™ file, with the possibility to further export the data to any kind of database, which is intended for the short term future. The gathered data can be used in numerous different ways, and allows the user to make different kinds of analyses of the nuclear power fleet around the world.

92 reactor types were identified to be in operation, in construction or in planning phase. 27 designs were in permanent shutdown conditions around the world. The identified nuclear power plants were grouped according to their generation. The description of the background for the grouping into generations can be found in chapter 5 of the work package 4 report.

Annex 1 shows the different reactor type details identified in the database.

2.4.2. SOURCES FOR THE DATABASE

For the Database several different sources of information were used. This was needed due to the fact that not all information's needed were available in one source. Due to the fact that a country by country and unit by unit analysis was carried out, information's for each site and unit were needed. The scenarios include data from the following sources.

International Atomic Energy Agency, Power Reactor Information System

The Power Reactors Information System (PRIS) was developed and is maintained by the IAEA. The IAEA uses the PRIS database for two official publications a year. The IAEA describes the PRIS as:

"The Power Reactor Information System (PRIS) developed and maintained by the IAEA for over four decades, is a comprehensive database focusing on nuclear power plants worldwide. PRIS contains information on power reactors in operation, under construction or those being decommissioned.

The database covers:

o Reactor specification data (status, location, operator, owner, suppliers, milestone dates) and technical design characteristics.

o Performance data including energy production and energy loss data, outage and operational event information.

Monthly production and power loss data have been recorded in PRIS since 1970 and are complemented by information on nuclear-power generated energy provided to non-electrical applications such as district heating, process heat supply or desalination. Information relating to the decommissioning process of shutdown units is also available from PRIS.

A set of internationally accepted performance indicators has been developed for calculations with PRIS data. The indicators can be used for benchmarking, international comparison or for analyses of nuclear power availability and reliability according to reactor type, country or worldwide. The analyses can, in turn, be applied to evaluations of nuclear power's competitiveness compared to other power sources.

In 2009, the new, web-based PRIS-STATISTICS reporting system was developed, making PRIS reports globally available online. Global and plant specific reports and graphs are created in a few mouse clicks. An integrated mapping system is also included." (http://www.iaea.org/PRIS/About.aspx)

The PRIS database is a very powerful and helpful tool when it comes to the past and recent status of nuclear power around the world. There is also information available regarding NPPs under construction. The IAEA database does not include planned NPPs. In order to create a comprehensive database and the opportunity to make projections and create scenarios additional information was needed.

World Nuclear Association

The World Nuclear Association (WNA) is an international organization with the aim to promote nuclear energy use around the world. Additionally it supports many companies that comprise the global nuclear industry. On their website the WNA describes its mission

Today WNA serves its membership, and the world nuclear industry as a whole, through actions to:

- Provide a global forum for sharing knowledge and insight on evolving industry developments;
- Strengthen industry operational capabilities by advancing best-practice internationally ;
- Speak authoritatively for the nuclear industry in key international forums that affect the policy and public environment in which the industry operates.

(http://world-nuclear.org/WNA/About-the-WNA/Our-Mission/#.UbCP9EAqxKI)

The website of the WNA contains a lot of information regarding the status of the world's nuclear industry. The WNAs website is described by the organization as follow:

The WNA website serves as the world's leading information source on nuclear energy. Some 120 WNA information papers, frequently updated, appear prominently on Google searches, with the result that a WNA webpage is downloaded every five seconds by users inside and outside the industry. The WNA Information Library is the world's "base-load" generator of comprehensive, accurate information on nuclear energy. (http://world-nuclear.org/WNA/About-the-WNA/Our-Mission/#.UbCP9EAqxKI)

In the "Information Library" all countries around the world dealing with nuclear energy production, from the mining to the decommissioning are described. The country profiles contain not only information on operating and shut- down reactors, but also on NPPs under construction and in planning phase (even if in a very early stage). The country profiles are updated regularly. As the WNA is – by mission – an organization promoting the use of nuclear power, some information in the country profiles are biased by that mission.

Country and utility reports and presentations

The quality assurance the plausibility check for the data by the IAEA and the WNA were performed by reviewing country and utility reports as well as presentations on conferences. The used data were:

Artisyuk, Vladimir (2012): Russia´s National Approaches in Developing Nuclear Program, Tokaimura Japan

Davies, Lukas W. (2012): Prospects for Nuclear Power, Journal of Economic Perspectives, Vol.26,No. 1 ,p. 46-66

Hirschberg et al. (2012): Bewertung aktueller und zukünftiger Kernenergietechnologien, Erweiterte Zusammenfassung des Berichts „Current and Future Nuclear Technologies, Bern 2012

Hou, Chunlin (2010): Nuclear Regulations in China, Status of Sanmen NPP Construction and Experience gained at NRC, 2010

IAEA (2010): Nuclear Energy Development in the 21st century: global scenarios and regional trends, IAEA NUCLEAR ENERGY SERIES No. NP-T-1.8, IAEA Vienna 2010

Mingguang, Zheng (2012): AP1000/CAP1400, Introduction of AP1000 Localized Standardisation and CAP1400 development, Hangzhou 2012

Moore, John (2013): NPP Construction Activities, IAEA Vienna 2013

OECD/NEA (2012): The economics of Long-Term Operation of Nuclear Power Plants, Paris 2012

Sailer, Michael (2007): Renaissance der Kernenergie?, Zürich 2007

Sun, Yuliang (2013): HTR Development Status in China, IAEA TWG-GCR, Vienna 2013

Utility websites

Regulator websites

Vendor websites

2.5. SCENARIO DEVELOPMENT

In order to perform an in depth analysis for the potential role of nuclear power in tackling climate change and reducing CO_2 emissions, different scenarios for the future development of nuclear power generation capacity were created.

The scenarios are based on the above described database. Therefore the scenarios are very accurate until 2020, and become fuzzier by approaching 2030.

As Eklund noted "It is unfortunately much more difficult to interpret what the crystal ball indicates may happen in the energy field five to ten years from now". (Eklund, 1981) Laue (Laue, 1982) observed a steady decline of projections for the short term and a dramatic decrease of a long term. The worked out that the projections for the year 1990 and 2000 in 1980 were at 1/3 to 1/5 of the value that they had in 1973/74 (Laue, 1982).

Work package 3 approaches the difficult task in a different way, as other projections did so far. Only existing plans for new nuclear installations are included in the scenarios. The authors choose to not include speculative idea but they only collect facts.

Within work package 3 those scenarios focus on two timeframes. The first timeframe is the time period until 2020, and the second time frame until 2030. Four different scenarios were developed for the described time horizons.

The four scenarios are:

1. Best possible pre Fukushima
2. Best possible post Fukushima
3. ISR Scenario 1
4. ISR Scenario 2

The four scenarios are built on different backgrounds. The main database is the same, but adjustments regarding reactors in operation, shutdown dates, planned grid connections and planned construction starts were performed.

The scenarios within work package 3 are other than the projections available in the open literature. Projections by international authorities and agencies are based on fundamental assumptions like

- Economic growth
- Correlation of economic growth and energy use
- Technology performance and costs
- Energy resources availability and future fuel prices
- Energy policy and physical, environmental and economic constraints. (IAEA, 2011, p. 6)

Other projections include additional other factors like

- Climate Targets (CO_2 reduction Goals)
- New technologies
- Policy driven changes (IEA, 2012)

The aim of work package 3 is to describe the development of the installed nuclear power capacity in short (2020) and mid (2030) term. As mentioned above, the authors used only data available by 2013. No assumption regarding potential new sites and reactors not announced by 2013 were included. For the mid-term the scenarios can only indicate the need for additional plants in order to reach the different target by other authors. In cooperation with the work package five “bottlenecks” a plausibility check can be performed.

The good quality for the short term outlook is assured due to the selected approach and some basic facts as construction and planning time. Moore (2013) worked out the median construction time of NPPs. He concluded that the median NPP construction time between 1970 and 1995 was 80 months (6.67 years). From 1996 up to now it was 83 months (6.92 years). The shortest construction period for a 1350 MWe unit from first concrete pouring to commercial operation were 49 months, for a 1000 MWe unit 47 month (Moore 2013). The construction time in China seemed to be a special case, as the construction time for existing designs were mostly in schedule, but with the Fukushima accident and the introduction of several “new” designs the construction time in China increased. In 2005 it was planned to start construction of AP 1000 units at Sanmen in 2007 and to be operational in 2011 (www.cnnc.com.cn). In 2010 Huo presented (Huo, 2010) the timetable for the construction of two AP1000 at the Sanmen site. Initially it was planned to have a construction time of 55 month. The construction started with a delay of two years – in 2009. Recent information indicates that the planned construction time will not be achieved, and that the reactor will be operational only in 2014, with a construction time of 61 months, if the time schedule can be fulfilled (world-nuclear.org). For other Chinese projects construction times up to 6 years can be found in the literature. Those data were used if no official data were available, by taking into account regional differences as good as possible. Further delays are always possible and likely – The EHNUR Scenarios reflect this fact. For projects in planning phase, but with a design decision taken, the IAEA Nuclear Energy Series No. NP-T-2.7 time schedule was used. It indicates that typically five years are needed from the pre-project phase to the first concrete pouring (IAEA, 2012a pp. 23).

The scheduled and planned shutdown dates were identified as a very crucial fact, when it comes to scenarios and projections. For the different scenarios, it was necessary that different assumptions for the unspecified shut down dates were made. The discussion on long term operation and life time extension is an on-going one. Therefore data provided by the OECD NEA study on "The economics of long-term operation of nuclear power plants" from 2012 (OECD/NEA, 2012) were used. The study of the OECD/NEA asked the member states to answer a questionnaire. Many countries sent the questionnaires back, and presented their plans on long term operation (LTO) and life time extension. For countries that did not take part in the questionnaire or did not respond, other sources of information were used. If no information was available, or in case that the life time extension was planned but not performed, the authors used similar plants to estimate the shutdown date of a certain NPP. This was done on a reactor per reactor base.

The scenarios developed for work package 3 are based on six main factors that vary from scenario to scenario. The six factors were weighted differently in each of the scenarios. The analyses and the scenario development were done on a country by country and unit by unit base, which means that the assumption for delays, LTO, etc… were performed for each reactor separately.

The six factors identified to be the most relevant factors for short- and mid-term development are:

- National nuclear development strategies
- Construction delays
- Planning delays
- National strategy for LTO and life time extension
- National strategy for Phase out
- Construction and planning stops

As described previously the scenarios were created on a unit by unit and country by country base. The global assumptions of the scenarios determine the case by case approach. The global assumptions for each scenario are described in the following section. In order to guarantee the transparency the identified factors were ranked from 1 (no implications) to 4 (strong implications), when describing the scenarios.

Change of national nuclear development strategies

The commitments of governments, utilities and vendors to their announced plans are of crucial importance for the fulfillment of the nuclear development strategy. (Rogner 2009) The governments are not only setting the targets, but by loan guarantees they influence the development of the strategy. Public acceptance and public option are crucial factors for potential changes in the strategies. Such changes could be observed in Germany and Italy after the Fukushima Daiichi nuclear accident.

TABLE 7: NATIONAL NUCLEAR DEVELOPMENT STRATEGIES AND IMPLICATIONS FOR THE SCENARIOS

Rank	Implication for the scenarios
None	Fukushima did not happen. Governments and utilities are strongly committed to nuclear energy use, and that they support the national programs heavy. Public option is in favors of nuclear.
Weak	Fukushima happened. Governments still support the nuclear industry but less than they would do if Fukushima would not have happened. Public option is still in favor of nuclear, even if public acceptance is decreasing and concerns rising.
Moderate	Fukushima happened. Governments do not treat nuclear as renewable technology, but are still supporting nuclear. Public acceptance is low.
Strong	Fukushima happened. Governments are looking for other energy technologies. Public acceptance for nuclear is very low.

Construction delays

Construction delays can affect the short term development of the installed nuclear capacity. Examples in Europe are Flamanville III and Olkiluoto III. In Asia construction delays can be observed in India and China. Those delays were not only affected by the accident at Fukushima, but are partially inherent when it comes to first of a kind NPPs.

TABLE 8: CONSTRUCTION DELAYS AND IMPLICATIONS FOR THE SCENARIOS

Rank	Implication for the scenarios
None	All constructions are in time and will be operational at the scheduled date.
Weak	Some constructions are delayed, but most constructions are in time.
Moderate	Several constructions are delayed, but the delays are moderate
Strong	Several constructions are delayed, and the delays are strong.

Planning delays

The Fukushima accident not only caused construction delays, but also delays for projects in planning phase. After the accident –globally– designs were re-evaluated which caused some delays. Further the global financial and economic crises caused further delays. In the US the low gas prices (IEA, 2012) caused additional delays, due to the business competition. Planning delays can be observed in China at the Sanmen site, in the US and in the UK.

TABLE 9: PLANNING DELAYS AND IMPLICATIONS FOR THE SCENARIOS

Rank	Implication for the scenarios
None	All planned future capacities are in time the construction will start at the scheduled time.
Weak	Many future capacities are in time the construction will start at the scheduled time.
Moderate	Some planned future capacities are delayed and the construction will start with a small delay
Strong	Some planned future capacities are delayed and the construction will start delayed

National strategy for LTO and life time extension

National strategies for life time extension and long term operation play a central role when analyzing the future installed nuclear capacity. If a life time extension of up to 60 years or beyond (80 years) is taken into account (global pre-Fukushima discussion) the amount of units to be replaced is much lower, than it would be when the lifetime is limited to 40-50 years. Major changes can be observed in France, Belgium and Germany.

TABLE 10: NATIONAL STRATEGY FOR LTO AND LIFE TIME EXTENSION AND IMPLICATIONS FOR THE SCENARIOS

Rank	Implication for the scenarios
None	A strong commitment to lifetime extension over 60 years.
Weak	Commitment to lifetime extension up to 60 years.
Moderate	Commitment to lifetime extension to 40-50 years.
Strong	Commitment to lifetime, depending on the reactor generation from 30-40 years.

National strategy for phase out

The accident at the Fukushima Daiichi nuclear power plant caused a change in several national strategies. Four months before the accident at Fukushima Germany adopted a new law in order to implement a life time extension program. Two months after the accident in Japan Germany shut down several of its reactors and announced its phase out strategy. Italy shut down all its reactors as a reaction to the Chernobyl accident and the following referendum.

TABLE 11: NATIONAL STRATEGY FOR PHASE OUT AND IMPLICATIONS FOR THE SCENARIOS

Rank	Implication for the scenarios
None	Fukushima did not happen. No phase outs are implemented
Weak	Fukushima happened. Implications on national phase out strategies. Germany and others phase out. Japan restarts all reactors exempt Fukushima Daiichi I-VI.
Moderate	Fukushima happened. Implications on national phase out strategies. Germany and others phase out. Japan restarts most of its reactors, but damaged ones remain shut down.
Strong	Fukushima happened. Implications on national phase out strategies. Germany and others phase out. Japan restarts up to 50% of its reactors.

Construction and planning cancellations

Construction and planning stops are no new phenomena. Such actions can be observed from the 70s up to now. Reactors in Austria, the Philippines, Cuba, Germany, Eastern Germany, Bulgaria, etc… were not finished or did never go into operation. Similar phenomena could also be observed in Italy, were a referendum for the return to nuclear energy production was planned, but the plan failed with the negative referendum.

TABLE 12: CONSTRUCTION AND PLANNING CANCELLATIONS AND IMPLICATIONS FOR THE SCENARIOS

Rank	Implication for the scenarios
None	Fukushima did not happen. All planned reactors are going to be built.
Weak	Fukushima happened. Some reactors will not be further planned and built.
Moderate	Fukushima happened. Several reactors will not be further planned and built.
Strong	Fukushima happened. Many reactors will not be further planned and built.

2.5.1. MAIN ASSUMPTIONS OF THE CREATED SCENARIOS

The scenarios are based on the database and the above described factors on a unit by unit and country by country base. The results are shown in chapter 4 of the report. The next section describes the main assumptions on a global perspective and on a regional level. For a better visibility the six factors are grouped and evaluated with different factors from 1-none to 4-strong implications.

TABLE 13: OVERVIEW OF SCENARIO DRIVERS

	Best pre	Best post	ISR Scenario 2	ISR Scenario 1
Change of National nuclear development strategies	None	Weak	Moderate	Moderate
Construction delays	None	Weak	Moderate	Strong
Planning delays	None	Weak	Moderate	Strong
National strategy for LTO and life time extension	None	Weak	Moderate	Strong
National strategy for Phase out	None	Weak	Moderate	Strong
Construction and planning cancellations	None	Weak	Moderate	Strong

1. Best possible pre Fukushima

The basic assumption of the best possible pre Fukushima scenario is that the accident at the Fukushima Daiichi NPP did not occur, and a very strong global trend towards nuclear energy capacity increase as mentioned in the nuclear renaissance is presumed to happen. Data used for this scenario were extracted before and shortly after Fukushima. For this scenario mainly old data were used, in order to fulfill the requirement of a best pre Fukushima scenario.

Europe: There are no delays in constructing and planning new nuclear power plants. The existing nuclear power plants built before 1980 will get the permission operate up to 60 years. The units built in 1980 or later will have a lifetime extension up to 80 years.

Asia: There are no delays in construction and planning of NPPs in Asia. 4 years is the assumed construction time for a reactor. New reactors in Japan will be built in 6 years; in Korea it will take 5 years and 6 years in India. The Korean design in the UAE will be in commercial operation as scheduled, and up to 4 units will be build.

CIS: The Russian nuclear program will be carried out as planned in 2010, with construction and planning in schedule. All Russian NPP of the second generation will have a lifetime of 80 years; the reactors from the first generation will have a lifetime of 50 years. The same assumptions are taken for the other CIS countries.

North America: All reactors in North America will have a lifetime of 80 years. The plans for planned new added capacity are in time and will be finished as planned in 2010.

South America: All reactors in South America will have a lifetime of 80 years. The plans for planned new added capacity are in time and will be finished as planned in 2010.

Africa: All reactors in Africa will have a lifetime of 80 years.

2. Best possible post Fukushima

The basic assumption of the best possible post Fukushima scenario is that the accident at the Fukushima Daiichi NPP occurred, and that the accident influences the global nuclear market in a slightly negative way. The influence is very different from region to region, but the global trend towards new nuclear power plants is still alive.

Europe: Germany will phase out as decided in 2011. Belgium and Switzerland will follow their strategy to phase out and not to replace existing capacities. New constructions and planned units will have a small delay before starting commercial operation. The existing nuclear power plants built before 1980 will get the permission to operate up to 50 years. The units built in 1980 or later will have a lifetime extension op to 60 years.

Asia: Deferred reactor plans in China inland will start construction in 2015-16, with up to 2 units built at the same time at the same site. One unit per site is going to commercial operation per year. 5 years is the assumed construction time for a reactor. New reactors in Japan will be built in 8 years; in Korea it will take 5 years and 6 years in India. The Korean design in the UAE will be in commercial operation as scheduled, and up to 4 units will be build there. Fukushima Daiichi and Fukushima Daiini will be decommissioned. All other units restart operation starting by 2014 over a period of 4 years. The lifetime of the Japanese reactors will be limited to 50 years (built after 1990), and to 40 years if built before 1990. (IEA, 2012, p. 190)

CIS: The Russian nuclear program will be carried out as planned in 2010, with construction and planning slightly behind schedule. Russian NPP of the second generation will have a lifetime of 60 years; the reactors from the first generation will have a lifetime of 50 years. The same assumptions are taken for the other CIS countries.

North America: All reactors in North America will have a lifetime of 60 years. The plans for new added capacity are behind the schedule intended in 2010, and not all of the new projects will be carried out.

South America: All reactors in South America will have a lifetime of 60 years. The plans for new added capacity are behind the schedule intended in 2010.

Africa: All reactors in Africa will have a lifetime of 60 years. The plans for new added capacity are behind the schedule intended in 2010.

3. ISR Scenario 1

The basic assumption of the ISR Scenario 1 is that the accident at the Fukushima Daiichi NPP occurred, and that the accident influences the global nuclear market in a moderate way. The influence is very different from region to region, but the global trend towards new nuclear power plants is alive, but much weaker than in the best post Fukushima Scenario.

Europe: Germany will phase out as decided in 2011. Belgium and Switzerland will follow their strategy to phase out and not to replace existing capacities. New constructions and planned units will have a decent delay before starting commercial operation. The lifetime of the existing nuclear power plants is limited to the published data in 2013.

Asia: The accident at Fukushima will have a decent influence on the planned new added nuclear capacity in Asia. China will not complete fully its plan of new builds. Deferred reactor plans in China inland will start construction in 2015-16, with up to 2 units built at the same time at the same site. 6 years is the assumed construction time for a reactor, if detailed information is not available. New reactors in Korea it will take 6 years and 7 years in India. The Korean design in the UAE will be in commercial operation later than scheduled. Japan will build no new NPPs. Fukushima Daiichi, Fukushima Daiini, and other NPPs damaged by the earthquake will be decommissioned. Not all other reactors will restart, as their assumed life time expires before a potential restart could take place. The lifetime of the Japanese reactors will be limited to 50 years (built after 1990), and to 40 years if built before 1990. (IEA, 2012, p. 190) The lifetime of reactors in Asia is limited to the published data in 2013.

CIS: The Russian nuclear program will mostly be carried out as planned in 2010, with construction and planning behind schedule, with some projections not being completed. The lifetime of the nuclear power reactor fleet is limited to the data published in 2013.

North America: Reactors in North America will have a lifetime as publicly available in 2013. The plans for new added capacity are behind the schedule intended in 2010 and not all planned units will be constructed.

South America: Reactors in South America will have a lifetime as publicly available in 2013.

Africa: Reactors in Africa will have a lifetime as publicly available in 2013.

4. ISR Scenario 2

The basic assumption of the ISR Scenario 2 is that the accident at the Fukushima Daiichi NPP occurred, and that the accident influences the global nuclear market in a moderate way. The influence is very different from region to region, but the global trend towards new nuclear power plants is alive, but much weaker than in the best post Fukushima Scenario.

Europe: Germany will phase out as decided in 2011. Belgium and Switzerland will follow their strategy to phase out and not to replace existing capacities. New constructions and planned units will have a decent delay before starting commercial operation. The existing nuclear power plants built before 1980 will get the permission to operate up to 40 years. The units built in 1980 or later will have a lifetime extension up to 50 years.

Asia: Deferred reactor plans in China inland will start construction in 2015-16, with up to 2 units built at the same time at the same site. 6 years is the assumed construction time for a reactor in China, if detailed information is not available. New reactors in Korea it will take 6 years and 7 years in India. The Korean design in the UAE will be in commercial operation later than scheduled. Japan will build no new NPPs. Fukushima Daiichi, Fukushima Daiini, and other NPPs damaged by the earthquake will be decommissioned. All other units restart operation starting by 2014 over a period of 4 years. The lifetime of the Japanese reactors will be limited to 50 years (built after 1990), and to 40 years if built before 1990. (IEA, 2012, p. 190)

CIS: The Russian nuclear program will be carried out as planned in 2010, with construction and planning behind schedule. Russian NPP of the second generation will have a lifetime of 50 years; the reactors from the first generation will have a lifetime as published in 2013. The same assumptions are taken for the other CIS countries.

North America: Reactors in North America will have a general lifetime of 60 years, but some reactors will have a shorter lifetime as stated in 2010. The plans for new added capacity are behind the schedule intended in 2010, and not all planned units will be constructed.

South America: All reactors in South America will have a lifetime of 40 years. The plans for new added capacity are behind the schedule intended in 2010.

Africa: All reactors in Africa will have a lifetime of 40 years. The plans for new added capacity are behind the schedule intended in 2010.

2.6. (PRINCIPLE) LIMITATIONS

There are several limitations regarding the short- and mid-term trends for the development of the nuclear landscape. Many scenarios and pathways (such as: IAEA 2012, IEA 2012, WNA 2011) make projections in the future up to the year 2030 and 2050. Those projections are mainly based on assumptions how nuclear energy production can possibly develop. These projections, especially those from the IAEA, are continuously adjusted. Figure 5 shows the projections by the IAEA at different point in time. It can be noted, that the projections fluctuate significantly.

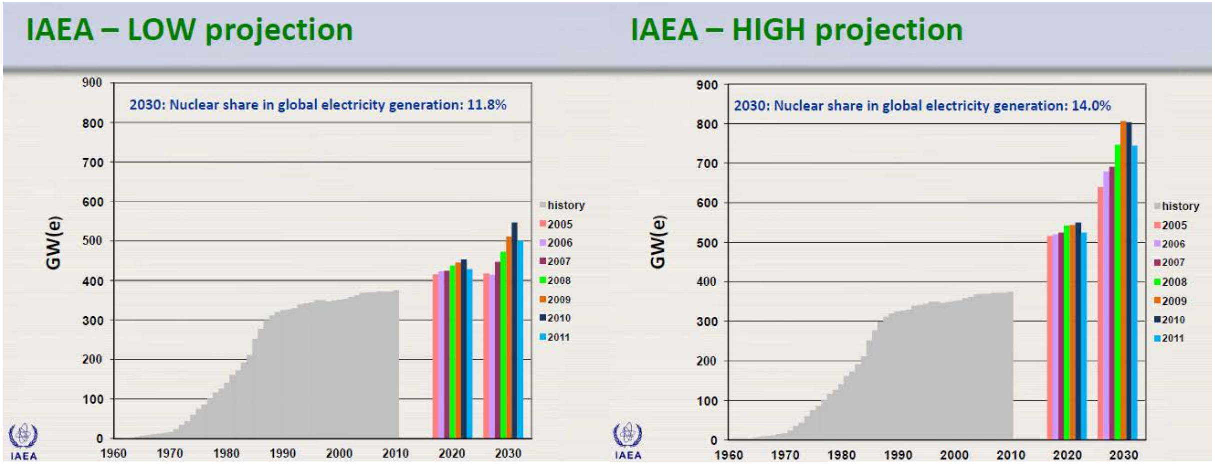


FIGURE 5: IAEA PROJECTIONS (ROGNER, 2012, P. 46)

An interesting fact is that the projections in the years 2005 and 2006 – in the IAEA Low projections – assume a decrease of the installed capacity from 2020 to 2030. The later projections assume an increase of the installed nuclear capacity in the time period from 2020 to 2030. This is parallel to the start of the discussion on a nuclear renaissance. Further an impact of the Fukushima accident can be observed, leading to a reduction of the projected installed nuclear capacity. The EHNUR project took the projections as benchmarks with the aim to check the own scenarios. Further one important fact was extracted from the IAEA projections, notably the fact that projections until 2030 are very insecure and speculative.

This fact was one constraining element which has been taken into account when developing the scenarios. Therefore only published data were used and considered. This leads to a specific limitation the EHNUR project was meeting. The availability of data is quite good for the timeframe up to 2020, but declines when approaching the year 2025 and 2030. The comparison with the IAEA projections made it clear, that the database of the project is good, and is very similar to the IAEA database and their assumptions for the year 2020. A significantly better database for 2020 is determined by the planning and construction horizon for nuclear projects. This time horizon is usually 6-12 years. Moore stated that the median of NPP construction time span between 1970 and 1995 was 80 month (6.67 years), and in the time span from 1996 up to now was 83 month (6.92 years). The shortest construction period for a 1350 MWe unit from first concrete pouring to commercial operation were 49 months, for a 1000 MWe unit 47 month (Moore, 2013). Schneider (2012) elaborated the differences between different countries when it comes to construction average construction times. The stated that the average construction time (over the last two decades) in Japan was 4.4 years, in Korea 4.6 years and in China 5.8 years. The UK started the unit after 6.1 years and France after an average of 9.4 years. (Schneider 2012) Based on the IAEA Nuclear Energy Series No. NP-T-2.7 typically five years are needed from the pre-project phase to the first concrete pouring. (IAEA, 2012a , pp. 23)

For the mid-term trend towards 2030 a lack of available data must be stated. Only a few countries have published a long term nuclear strategy, including site and design of for the planned reactors. The EHNUR project only included nuclear projects, if the sites and the design of the reactor were approved and available by August 2011. China, Russia, India have published their short- and mid-term strategies, meeting the need of the project. In many cases plans were too fuzzy and could not be used.

Other limitations, beyond the availability of data, are that construction delays and building freezes are a common challenge for the nuclear industry and the scenarios development. Therefore the scenarios were based on different assumptions regarding the two described challenges. Additionally the life time extension and long term operation programs have a big impact on the installed nuclear capacity. A big number of permanent shutdowns are envisaged for 2020 to 2030. Life time extension programs can shift those planned permanent shutdowns beyond the year 2030. Different strategies were included in the developed scenarios.

Another significant limitations for the mid- term time frame, is the potential change of policies in different countries. As seen after Fukushima (i.e. Germany, Switzerland), a nuclear phase out or a halt of nuclear projects is a political decision, not a technical one. Such changes cannot be well projected or foreseen.

3. TRENDS AND SCENARIOS

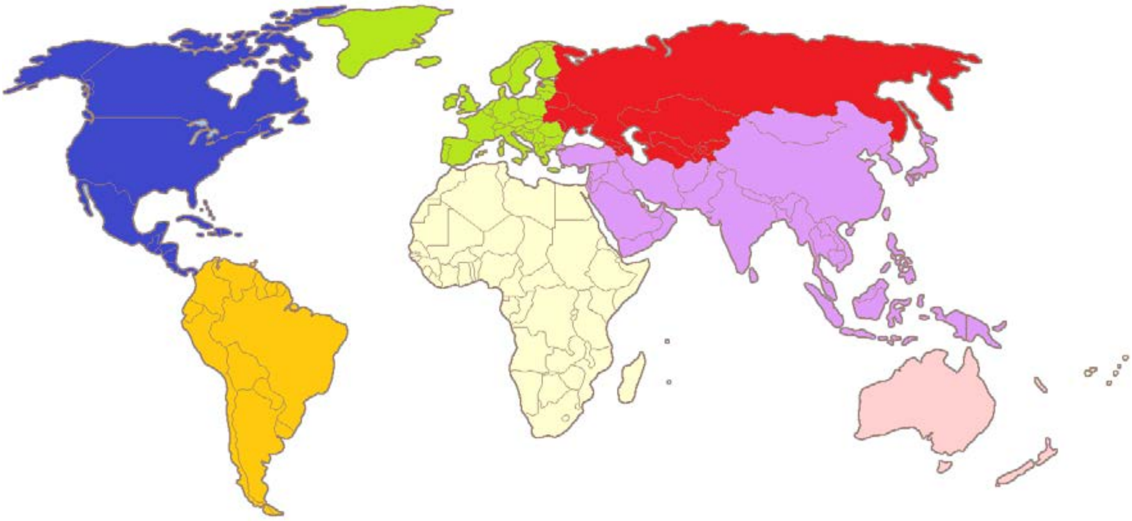


FIGURE 6: GLOBAL MAP WITH HIGHLIGHTED REGIONS

For an easier understanding the world was divided in seven regions, based on their geographical position. The seven regions are shown in the different graphs with the same colour as they are presented in the figure above. The regions are:

- North America (Blue)
- South America (orange)
- Europe (green)
- Africa (yellow)
- CIS (red)
- Asia (purple)
- Oceania (pink)

3.1. NUCLEAR LANDSCAPE IN 2013

By June 2013 according to the IAEA 436 nuclear power reactors were in operation (IAEA Pris, 2013). The installed nuclear capacity is about 372 GWe net (IAEA Pris, 2013). If excluding the 48 nuclear power reactors in Japan - still shut down due to the Fukushima Daiichi nuclear accident – 391 nuclear reactors are able to produce electricity by June 2013. The EHNUR database contains three more operational reactors, which by the IAEA were not considered as power reactors. This leads to a total of 439 operational power reactors in the database.

Globally there are 31 countries having nuclear power reactors. There are 61 units under construction in 13 countries around the world. Additionally there are 202 units in a planning phase in 18 countries. In 2011 the IAEA (2011a) noted that 65 reactors were in construction in 15 countries, and 151 reactors in 22 countries were in a planning phase (IAEA, 2011a). The distribution of the power reactors in 2013 is described in table 14. A total of 391 nuclear power reactors were operational by June 2013. The 48 reactors in Japan, shut down following the accident at Fukushima Daiichi, were considered separately.

TABLE 14: OPERATIONAL POWER REACTORS GLOBAL 2013

Region	Nr. operational units
South America	4
Africa	2
Asia	75
CIS	49
Europe	137
North America	124

The majority of the NPPs around the world are located in Europe. 137 reactors are operational there, followed by North America. If adding the 48 Japanese reactors in temporary shutdown conditions Asia would have 123 operational units. In the CIS region 49 reactors are operational by 2013.

TABLE 15: REACTORS IN PERMANENT SHUTDOWN CONDITIONS GLOBAL 2013

Region	Nr. Units permanent shutdown conditions
South America	
Africa	
Asia	9
CIS	11
Europe	88
North America	35

Europe is the region having most reactors in permanent shutdown conditions. North America is having 35 reactors, the CIS region 11 and Asia 9 reactors in permanent shutdown conditions. For the near term several units in Europe and North America will need decommissioning activities.

TABLE 16: REACTORS UNDER CONSTRUCTION OR PLANNED/PROPOSED GLOBAL 2013

Region	Under construction	Planned/proposed
South America	1	1
Africa		
Asia	42	136
CIS	8	43
Europe	6	3
North America	4	18

In Asia by 2013 there are 42 reactors under construction and up to 137 reactors are planned or proposed. In the CIS region 8 reactors are under construction and 43 are additionally planned or proposed (see Table 16). If summarizing the traditional nuclear markets – Europe and North America – there are 10 reactors under construction and up to 21 in a planned of proposed. The focus of the global nuclear market seems to shift towards Asia.

The world nuclear power reactor fleet is composed by 253 PWRs, 56 BWRs, 48 PHWRs, 16 GCRs, 15 LWGR and 3 Fast Reactors. The share of the PWR of the global nuclear power reactors fleet is of 65%, indicating the relevance PWR technology (see Figure 7).

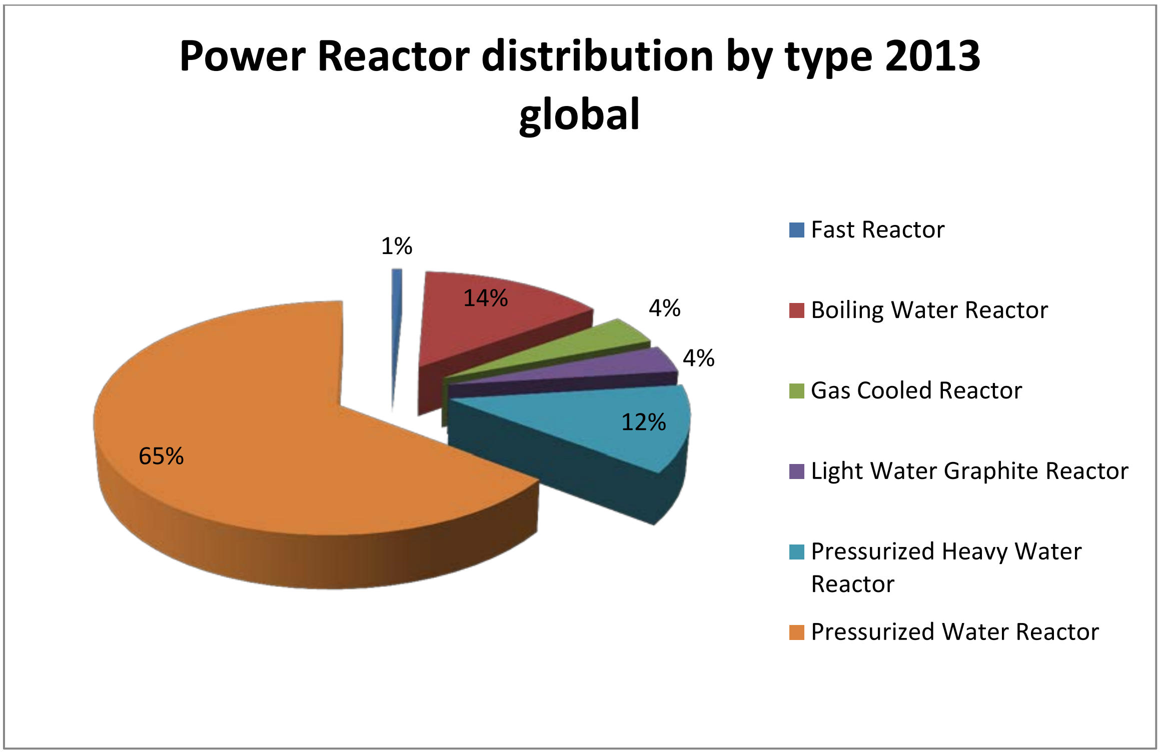


FIGURE 7: POWER REACTOR DISTRIBUTION BY TYPE 2013 GLOBAL

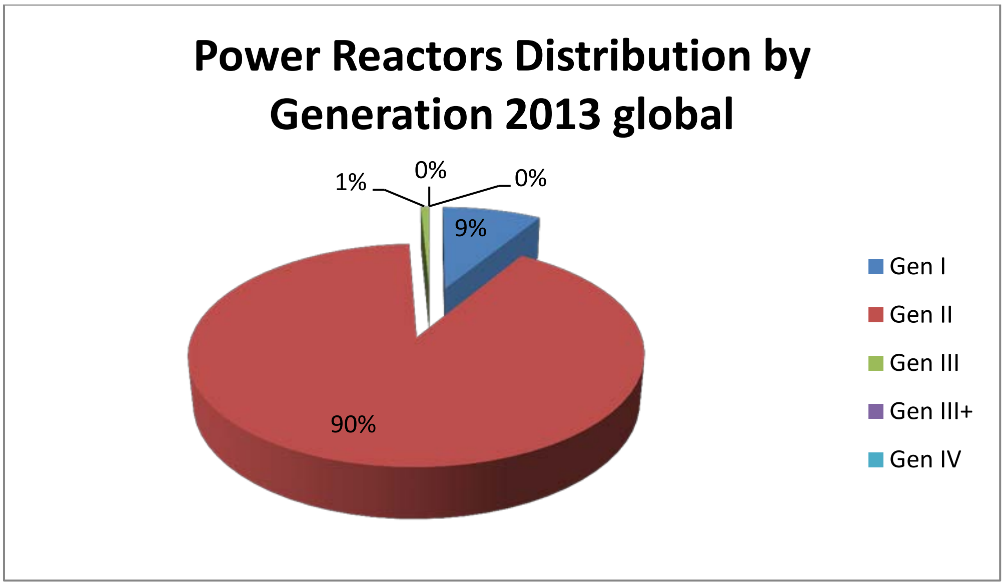


FIGURE 8: POWER REACTORS DISTRIBUTION BY GENERATION 2013 GLOBAL

The global distribution of reactors in 2013 shows that over 90% of the operational nuclear power stations are reactors of the second generation. 9% of the reactors are Gen I, and 1% of the reactors are Gen III reactors (see Figure 8). According to the different scenarios the distrubtion development will be shown in the following chapters not only an a global level, but also by regions.

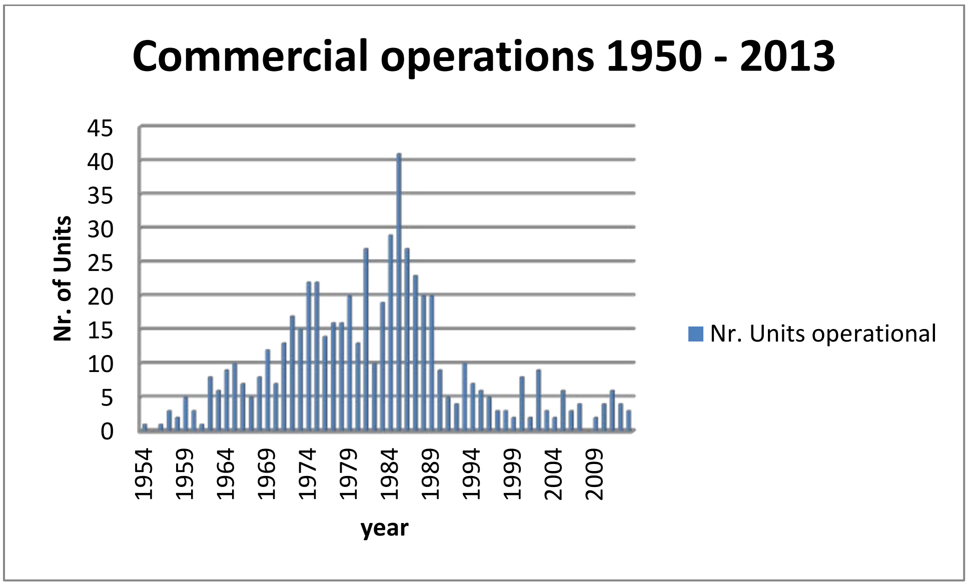


FIGURE 9: COMMERCIAL OPERATION STARTS 1950-2013

Figure 9 shows the number of units starting commercial operation from 1950 to 2013. Only the commercial operation date is taken into account not the year of the first grid connection. The Figure demonstrates that most units went operational before 1990. After 1990 the number of new units becoming operational significantly decreased.

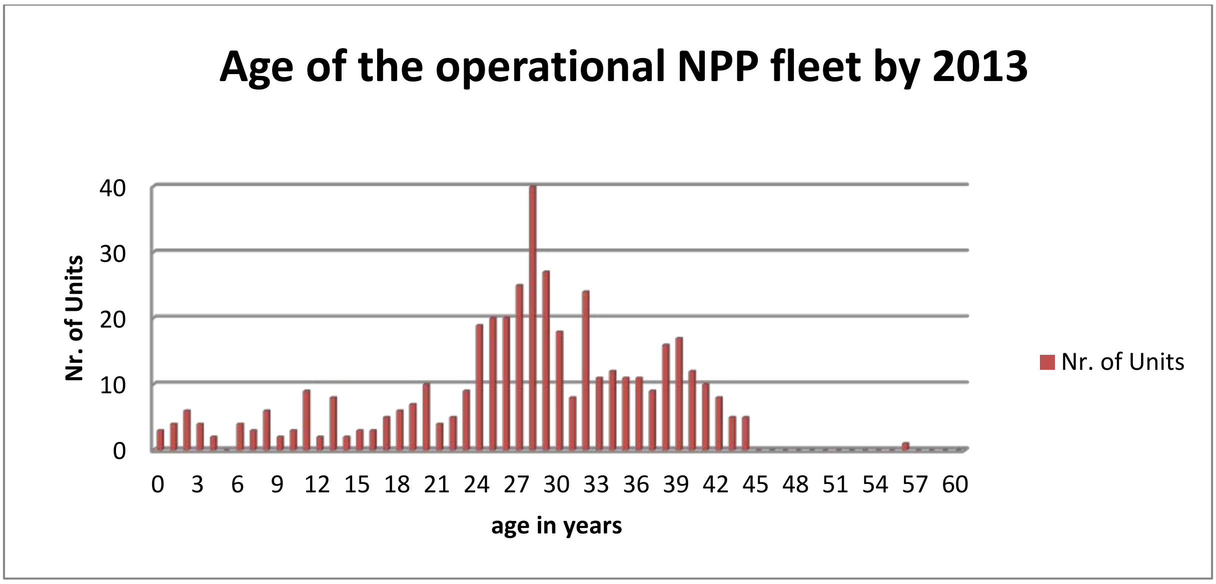


FIGURE 10: AGE OF OPERATIONAL NPP FLEET BY 2013

Figure 10 shows the age distribution of the nuclear power reactor fleet in 2013. The oldest operational nuclear power reactor is 56 years old. The average age of the nucler power reactor fleet in 2013 is 27.4 years.

3.2. BEST POSSIBLE POST FUKUSHIMA SCENARIO

The best possible post Fukushima Scenario was the second scenario to be constructed within the work package. The main approach is described in section 2.4 and the principle limitations are highlighted in section 2.5.

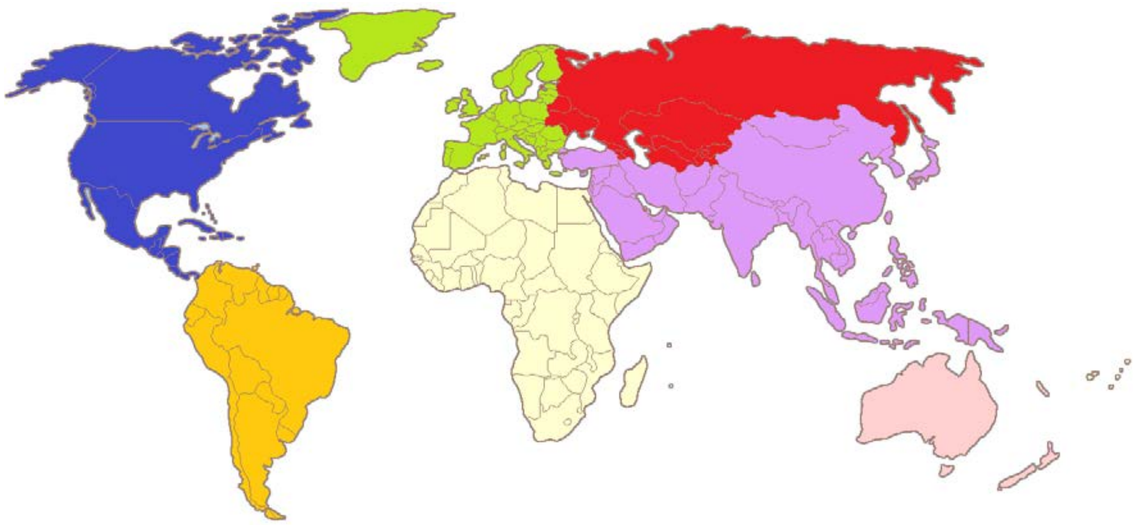


FIGURE 11: GLOBAL MAP WITH HIGHLIGHTED REGIONS

The scenario was created after the accident at the Fukushima Daiichi nuclear power plant. The scenario is based on data extrapolation. All relevant available data regarding national nuclear development strategies are taken into account. The data, on which the scenario is based on, were taken from the published information by the WNA, the IAEA, and by country reports. The main assumptions and the framework for the best possible post Fukushima Scenario are:

- Fukushima happened and had slight implications for the global nuclear development.
- The most ambitious plans by countries were taken into account.
- No delays in the planning and construction phase.
- Life time extension and long term operation for all reactors around the world up to 60 years.
- No shortages by fuel and heavy component supply.

The Information Box on p. 45 gives detailed information on the background and main assumptions for the scenario.

Based on these assumptions the best possible post Fukushima Scenario was created, and discussed and described on a global and regional level.

3.2.1. GLOBAL

The best Fukushima scenario indicates a growth of installed nuclear capacity from 378 GWe net in the year 2010 to 496 GWe net in the year 2020. In the year 2025 the installed capacity will be 516 GWe net and in the year 2030 the installed capacity will be 500 GWe net. As described in section 2.3 and 2.5 the quality of the available data is sufficient for projections until 2020, while decreasing towards 2030. Further section 2.4 describes the background of the scenario, and details can be found in the information box for the scenario best post Fukushima.

The scenario indicates a growth of 32.3% of installed nuclear capacity from 2005 to 2020. This is a significant increase, but the growth rate between 1980 and 1995 was 172.6%. When comparing the projected growth up to 2020 with the historical growth rates in the second phase of expansion the growth rate seems weak but significant. It seems clear that the nuclear renaissance projected in the years 2005 and beyond will not be as strong as in the 1980s.

Info Box: Background and assumptions of the best possible post Fukushima scenario
The basic assumption of the best possible post Fukushima scenario is that the accident at the Fukushima Daiichi NPP occurred, and that the accident influences the global nuclear market in a slightly negative way. The influence is very different from region to region, but the global trend towards new nuclear power plants is still alive. Europe: Germany will phase out as decided in 2011. Belgium and Switzerland will follow their strategy to phase out and not to replace existing capacities. New constructions and planned units will have a small delay before starting commercial operation. The existing nuclear power plants built before 1980 will get the permission to operate up to 50 years. The units built in 1980 or later will have a lifetime extension op to 60 years. Asia: Deferred reactor plans in China inland will start construction in 2015-16, with up to 2 units built at the same time at the same site. One unit per site is going to commercial operation per year. 5 years is the assumed construction time for a reactor. 5 years is the assumed construction time for a reactor. New reactors in Japan will be built in 8 years; in Korea it will take 5 years and 6 years in India. The Korean design in the UAE will be in commercial operation as scheduled, and up to 4 units will be build there. Fukushima Daiichi and Fukushima Daiini will be decommissioned. All other units restart operation starting by 2014 over a period of 4 years. The lifetime of the Japanese reactors will be limited to 50 years (built after 1990), and to 40 years if built before 1990. (IEA 2012 ,p. 190) CIS: The Russian nuclear program will be carried out as planned in 2010, with construction and planning slightly behind schedule. Russian NPP of the second generation will have a lifetime of 60 years; the reactors from the first generation will have a lifetime of 50 years. The same assumptions are taken for the other CIS countries. North America: All reactors in North America will have a lifetime of 60 years. The plans for planned new added capacity are behind the schedule intended in 2010, and not all of the new projects will be carried out. South America: All reactors in South America will have a lifetime of 60 years. The plans for planned new added capacity are behind the schedule intended in 2010. Africa: All reactors in Africa will have a lifetime of 60 years. The plans for planned new added capacity are behind the schedule intended in 2010.

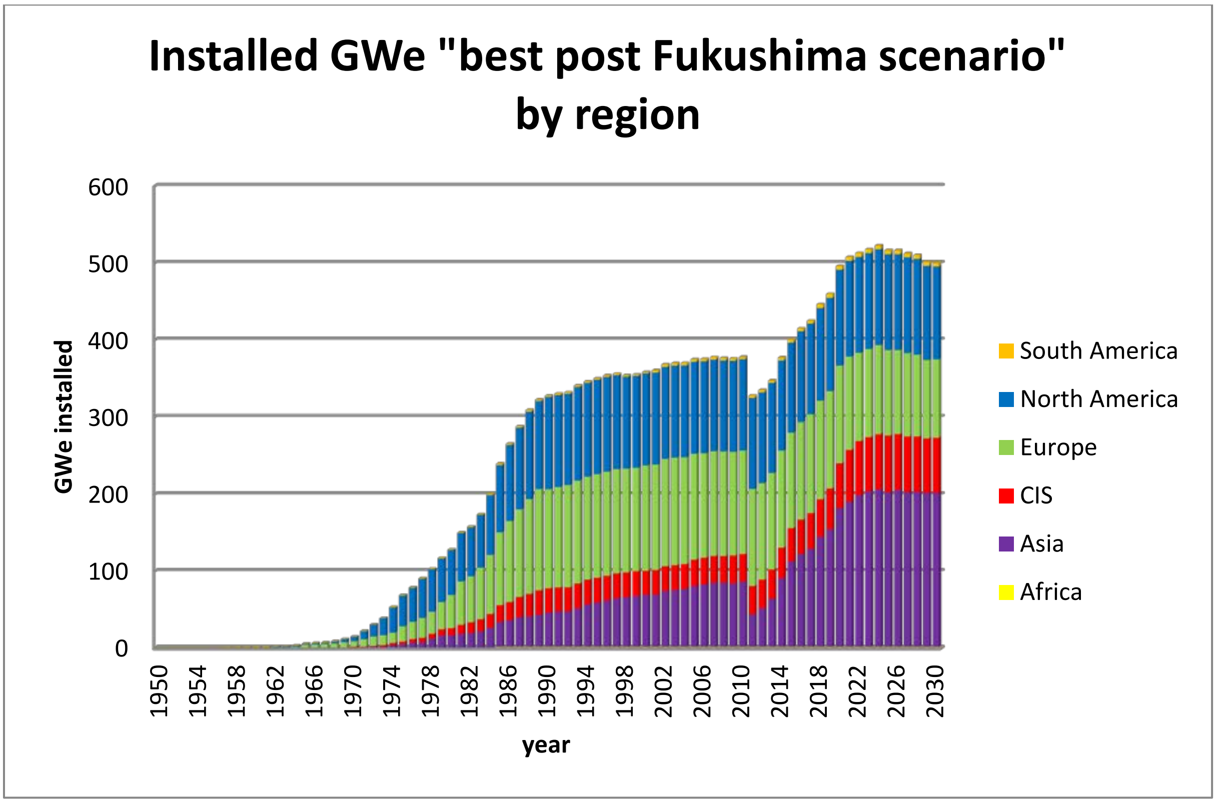


FIGURE 12: DEVELOPMENT INSTALLED NUCLEAR CAPACITY GLOBAL „BEST POST FUKUSHIMA"

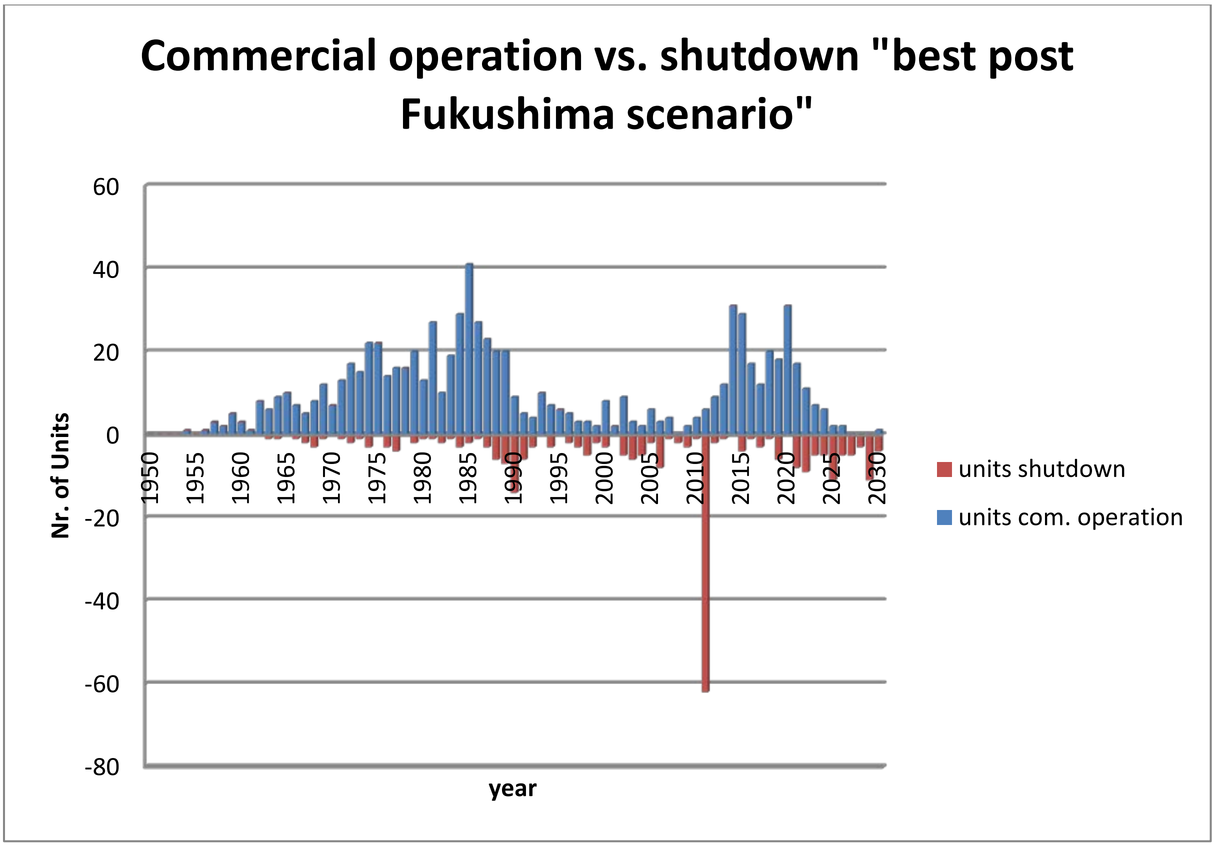


FIGURE 13: COMMERCIAL OPERATIONS VS. SHUTDOWN "BEST POST FUKUSHIMA" SCENARIO

Figure 13 shows the commercial operations and the shutdown from 1950 up to 2030. A strong growth from 1955 until 1990 can be observed. From 1990 to 2010 the new commercial operations and the shutdown are almost equilibrated. After Fukushima 61 reactors were shut down, but not all were shut down permanently. The scenario was built on the assumption that Japan will restart most of its reactors. This can be observed when looking at Figure 13. The number of commercial operations after 2012 is higher than the number of new grid connections due to the assumption for Japan. From 2019 on, a significant number of units are approaching the end of their lifetimes, and will be shut down permanently. This fact is reflected in figure 12 and explains the decrease of installed nuclear capacity from 2025 to 2030. Further there are only limited data available on plans regarding new builds after 2022.

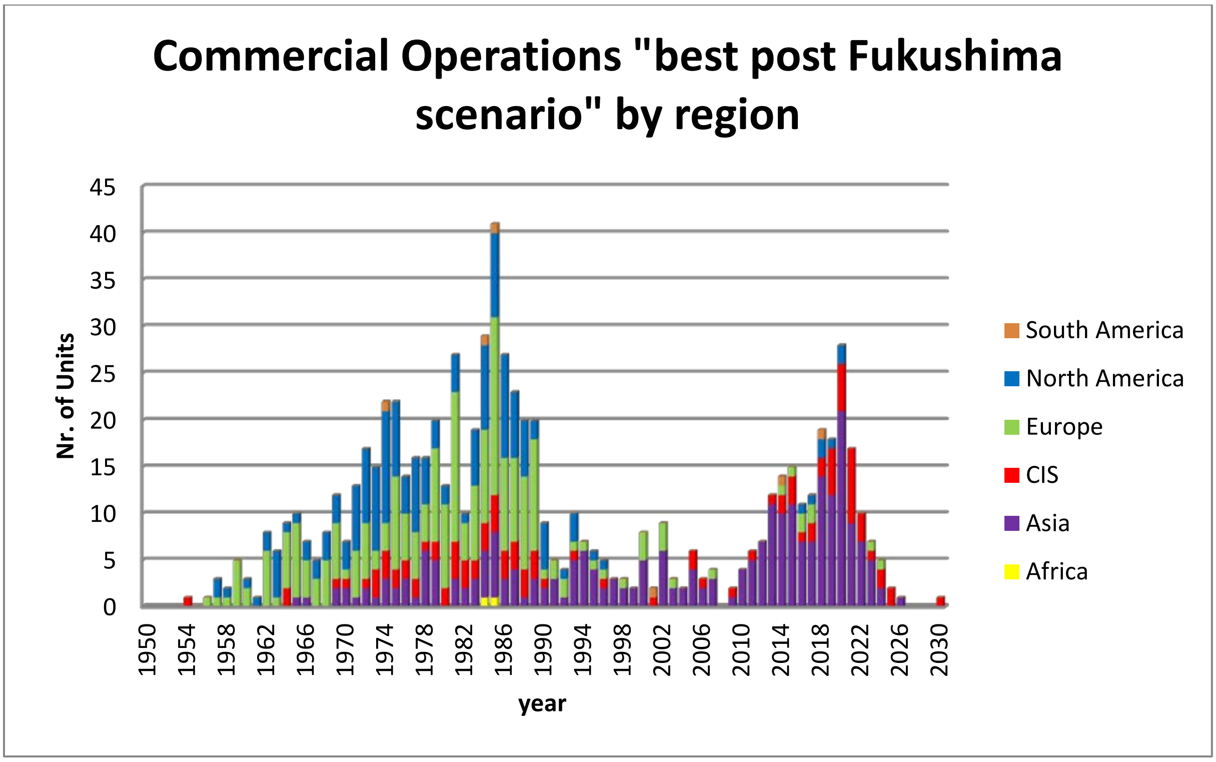


FIGURE 14: GRID CONNECTIONS GLOBAL „BEST POST FUKUSHIMA“ SCENARIO

The strong expansion of nuclear between 1980 and 1995 was mainly driven by the “traditional nuclear markets” namly North America and Europe. Asia and the CIS region saw some expansion between 1980 and 1995. The Scenario forsees a switch from the traditional markets towards the new markets until 2020. The main drivers of the third wave of nuclear expansion will be Asia and the CIS region. North America and Europe will only play a minor role in the future expansion of nuclear power.

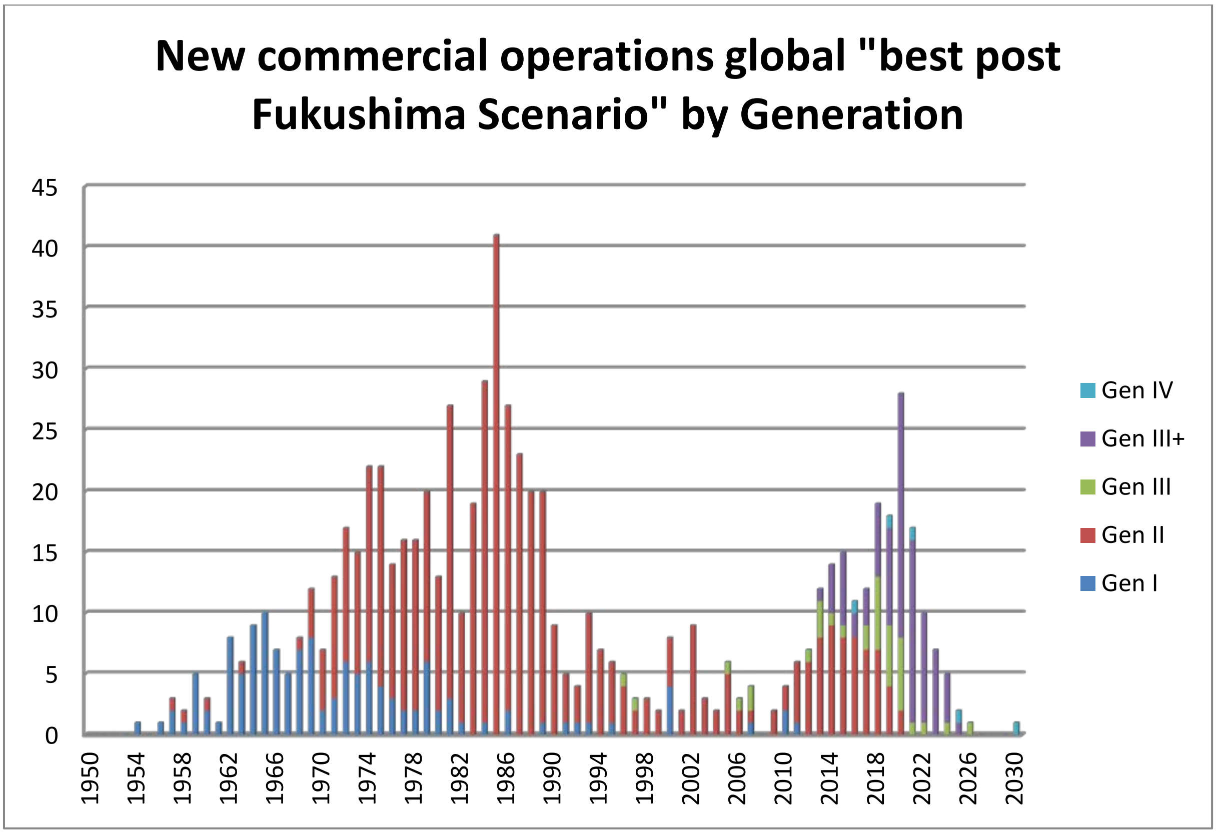


FIGURE 15: GRID CONNECTIONS GLOBAL „BEST POST FUKUSHIMA“ BY GENERATION

One promise of the nuclear renaissance was that the renaissance will rely on and will be driven by new designs of nuclear power plants. (McLellan, 2008) The new designs can be subsumed as Gen III, Gen III+ and Gen IV reactors. If looking at the historical development a transition phase from Gen I to Gen II can be observed around the year 1970. Starting from 1970 more Gen II that Gen I reactors were built. The next transition phase is projected around the year 2018. Around that year more Gen III, Gen III+ and Gen IV reactors than Gen II reactors will become operational.

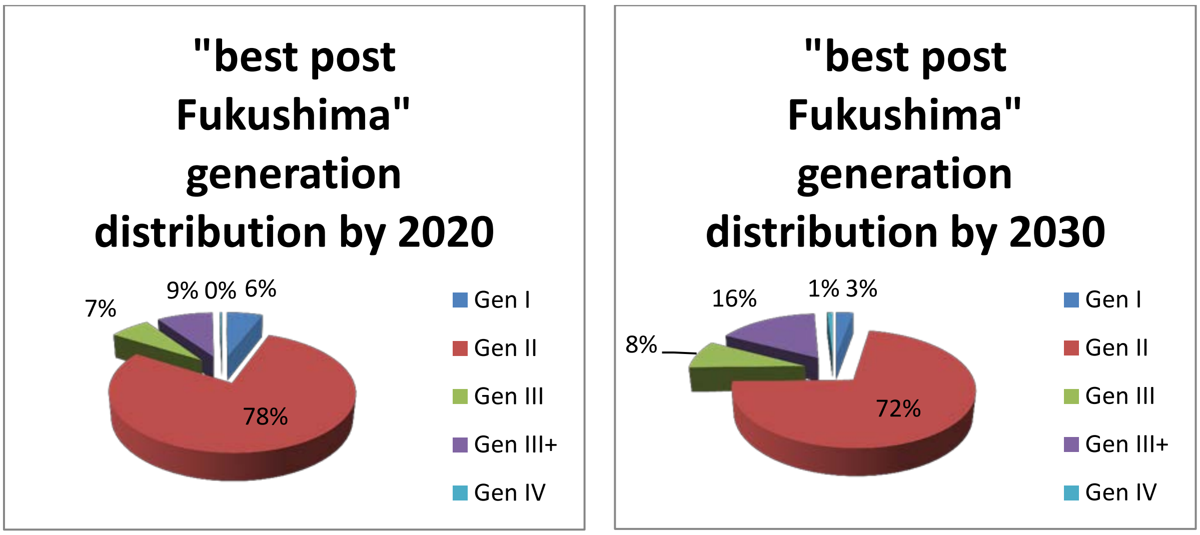


FIGURE 16: NUCLEAR POWER PLANTS DISTRIBUTION BY GENERATION IN 2020 AND 2030„BEST POST FUKUSHIMA“

Figure 16 shows the distribution of reactor generations in the year 2020. The majority (78%) of the operating nuclear power plants will be Gen II reactors. 7% of the global reactors will be Gen III reactors, slightly more than Gen I reactors – 6%. Gen III+ reactors will contribute 9% of the global nuclear fleet. In the year 2030 the global picture will change only slightly. Gen II reactors will still be the majority of the global reactor fleet with 72%. The share of Gen I reactors will significantly decrease compared to 2020, and the Gen III+ reactors will increase up to 16% of the global reactor fleet. Gen IV reactors will play only a marginal role.

3.2.2. EUROPE

Europe can be considered as traditional nuclear market. Starting in 1959 nuclear power generation became more and more relevant in Europe. In 1970 7.2 GWe net were installed in Europe. In the following 20 years the installed nuclear capacity rose to 128 GWe in 1990. In 2003 the installed nuclear capacity peaked in Europe. In 2003 140 GWe were installed. The future projections see a decrease of the installed nuclear capacity in Europe.

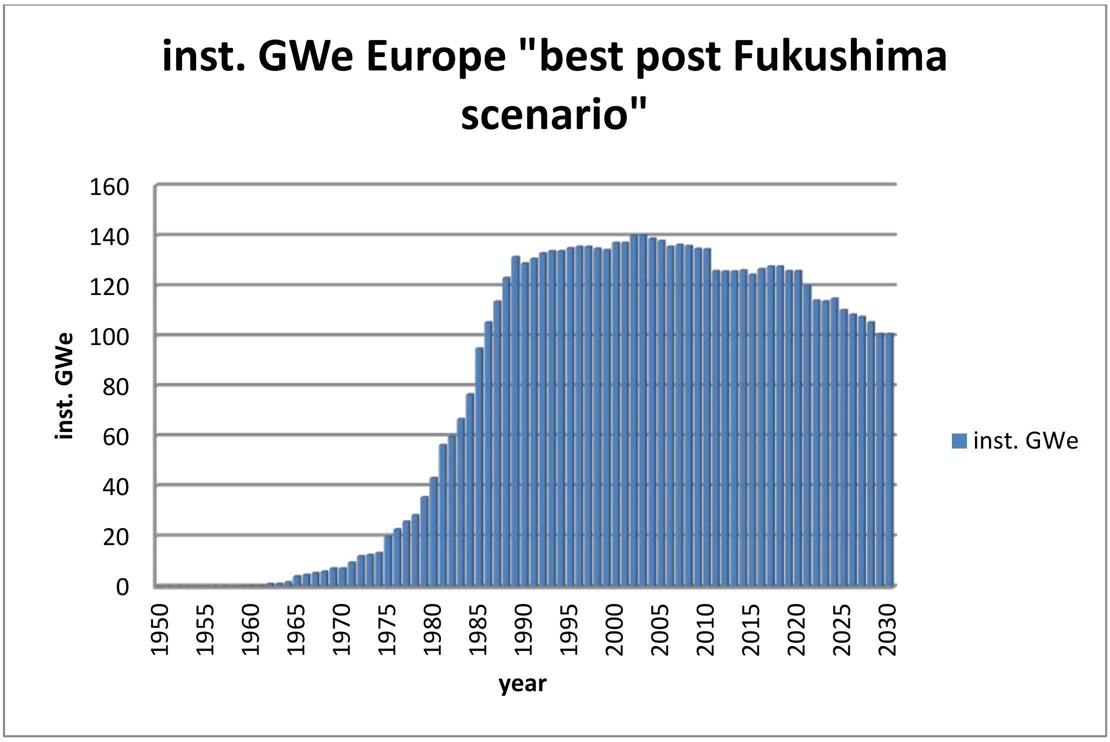


FIGURE 17: INSTALLED GWE EUROPE "BEST POST FUKUSHIMA SCENARIO"

The best post Fukushima Scenario indicates a reduction of the installed nuclear capacity in Europe from 140 GWe in 2003 to 125 GWe in 2020. In the year 2025 up to 110 GWe and in the year 2030 100 GWe will be installed. The reduction is caused by two facts. The post Fukushima phase out in some European countries, and the fact that the nuclear power reactor fleet gets older.

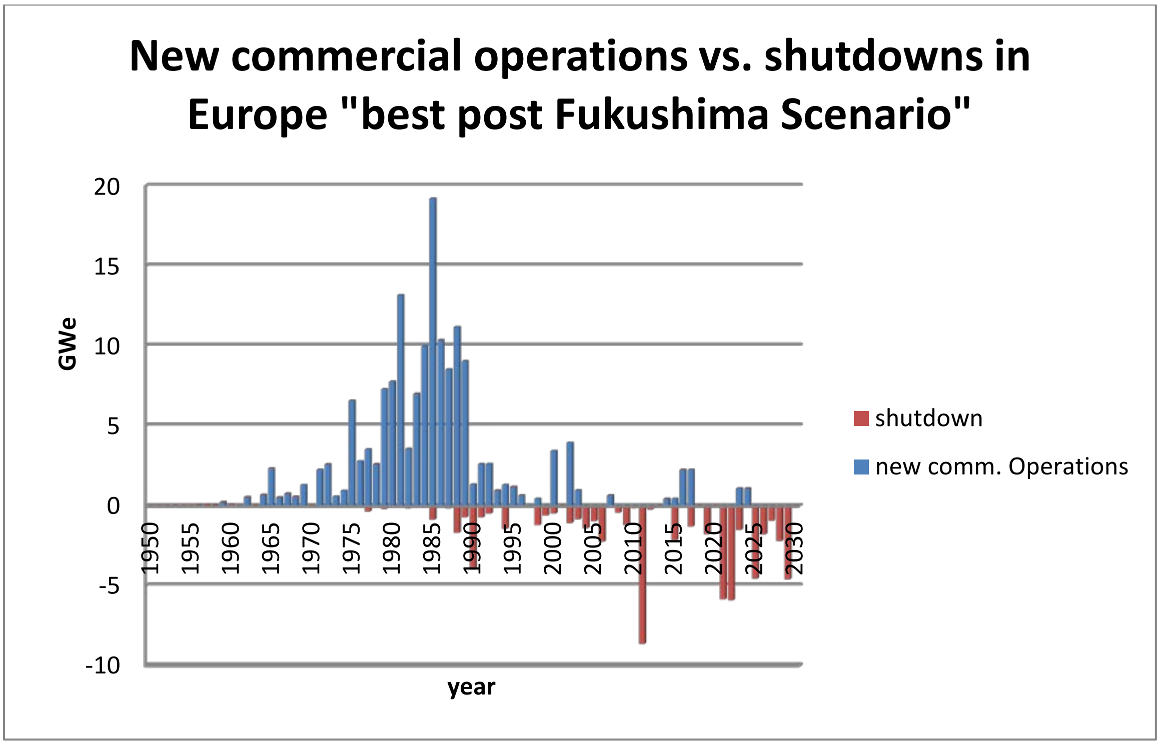


FIGURE 18: NEW COMMERCIAL OPERATIONS VS. SHUTDOWNS IN EUROPE "BEST POST FUKUSHIMA SCENARIO"

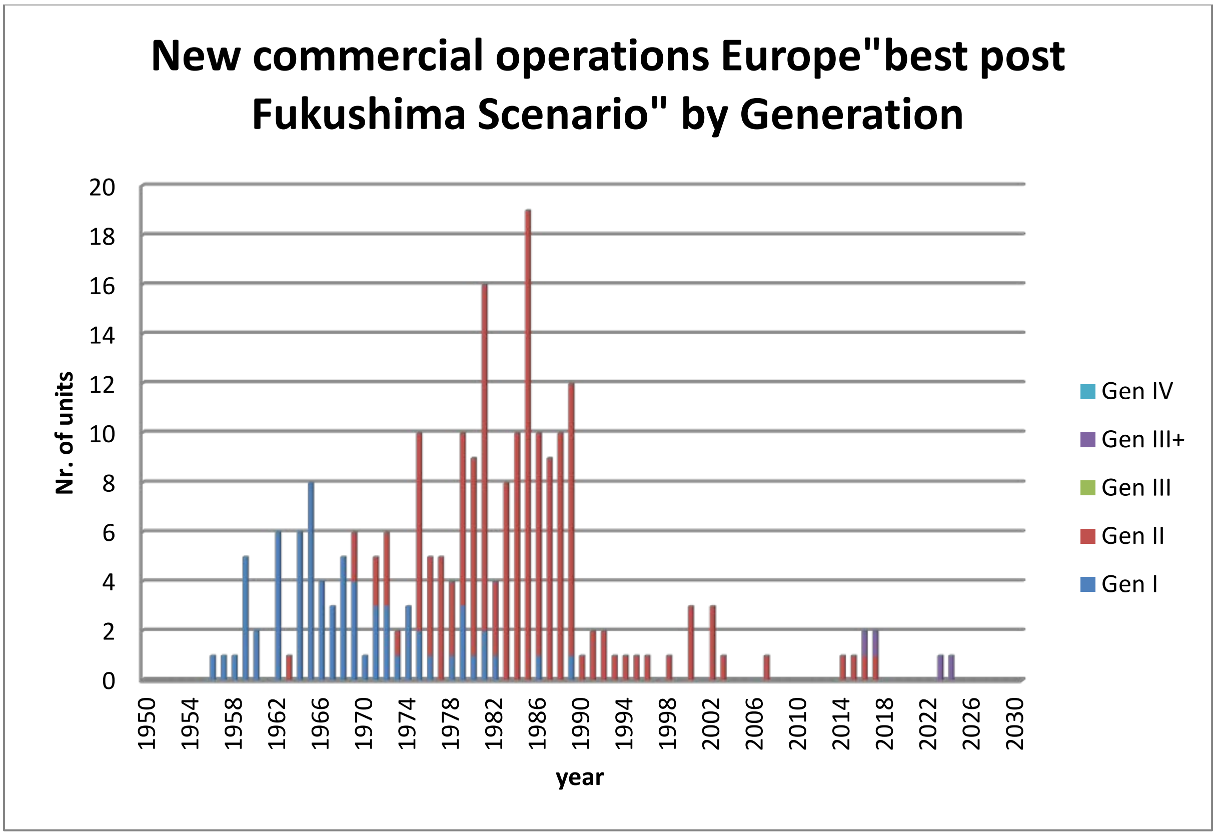


FIGURE 19: NEW COMMERCIAL OPERATIONS EUROPE "BEST POST FUKUSHIMA SCENARIO" BY GENERATION

As the European nuclear fleet gets older more and more units will be shut down in the timeframe up to 2030. The expansion of nuclear power in Europe can be observed in Figure 18. Most of the European NPPs were built up to 1990. Only some countries (France, Finland, Czech Republic, and Slovakia) have plans to build new reactors.

Similarly to the global trend, in the mid 70´s more Gen II than Gen I reactors were put into operation. The European nuclear power reactors fleet is mainly based on Gen II reactors. In 2013 only 4 Gen III+ reactors are planned to be build. The planned Gen III+ reactor types are the EPR and the MIR 1200.

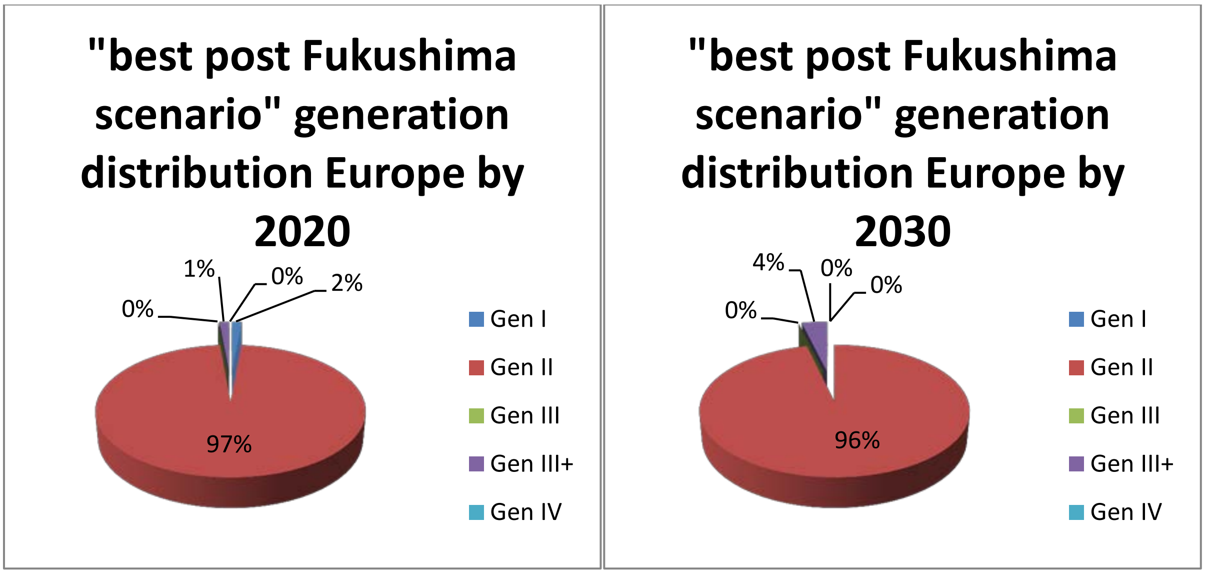


FIGURE 20: NUCLEAR POWER PLANTS DISTRIBUTION IN EUROPE BY GENERATION IN 2020 AND 2030 „BEST POST FUKUSHIMA“

In 2020 the nuclear power reactor fleet in Europe will consist by 97% of Gen II reactors. Only two Gen-II reactors and two Gen III+ reactors will be in operation. The picture of the nuclear fleet in Europe changes only slightly when looking at the year 2030. The majority 96% of the NPPs will consist of Gen II reactors. The one per cent decrease is mainly driven by shutdowns of Gen I and Gen II reactors.

3.2.3. CIS

The development in the CIS region can be described as a two-step development. The installed nuclear capacity rose very rapidly between 1970 and 1990. The Chernobyl accident in 1986 slowed down the addition of new nuclear capacities in the CIS region. The most severe impact was caused of course by the crash of the Soviet Union.

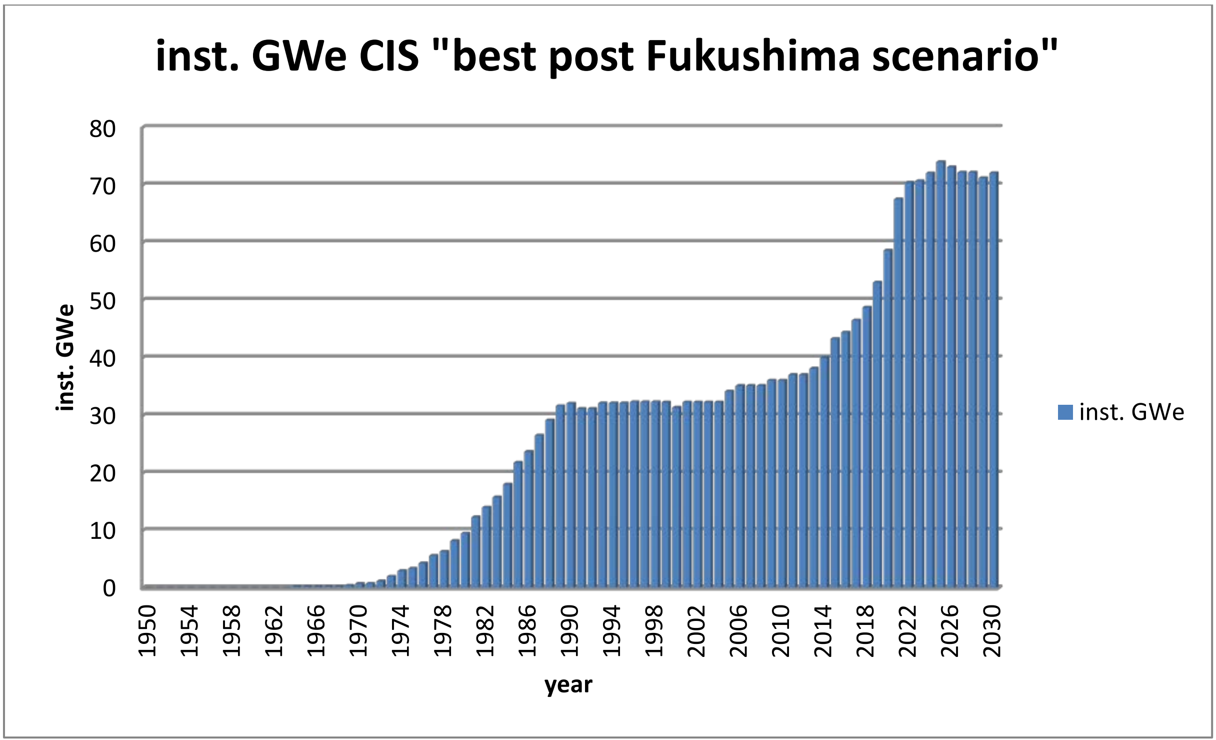


FIGURE 21: INSTALLED GWE CIS “BEST POST FUKUSHIMA SCENARIO“

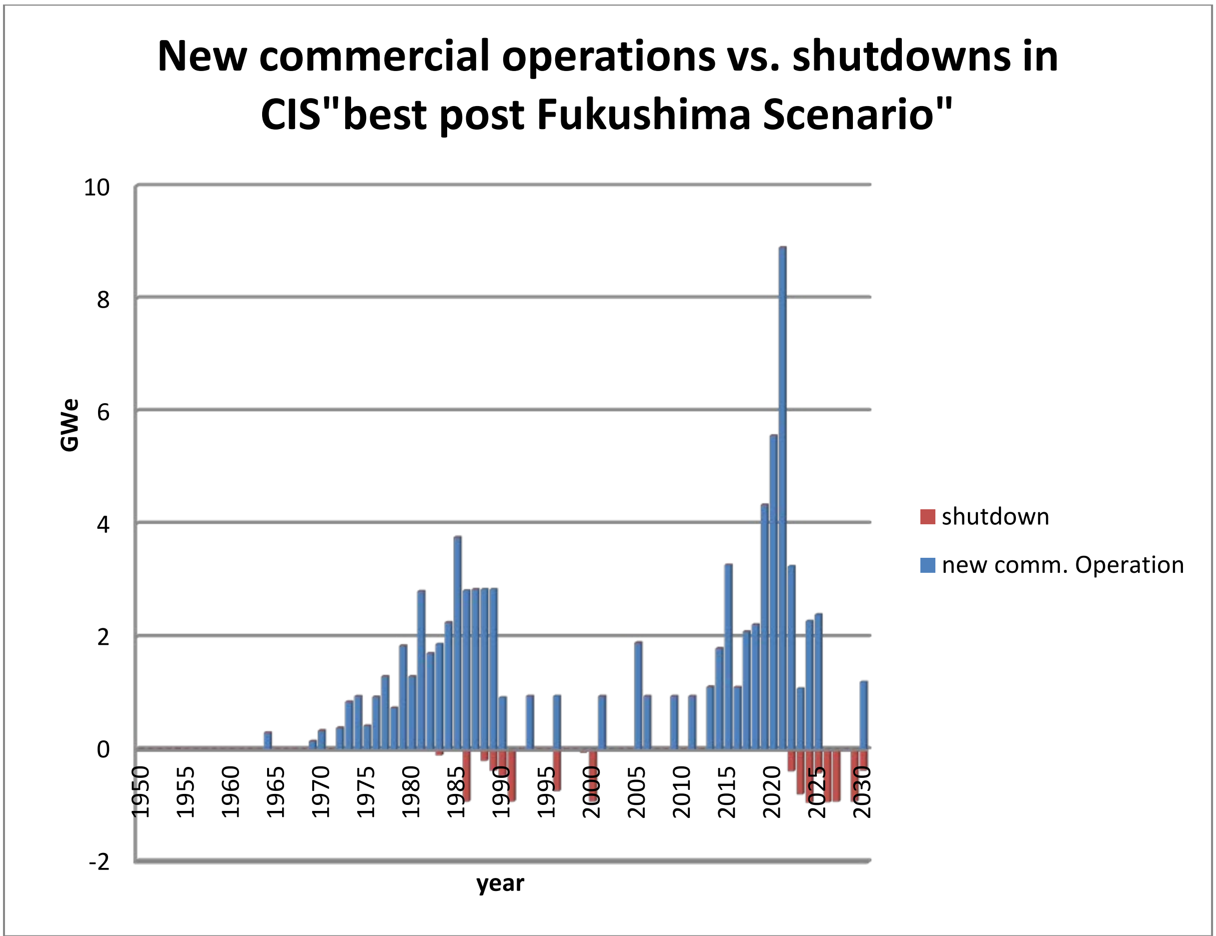


FIGURE 22: NEW COMMERCIAL OPERATIONS VS SHUTDOWS IN CIS “BEST POST FUKUSHIMA SCENARIO"

The installed nuclear capacity only increased slightly between 1990 and 2010. The projections to 2020 and 2030 see a strong increase of installed nuclear capacity in the CIS region, mainly driven by Russia. The time after 2013 can be described as the second phase of the nuclear development in the CIS region, as the growth of nuclear capacity is almost as high as in the 70´s and 80´s.

Between 1990 and 2010 only few new nuclear power plants went operational. This can be explained by the lack of financing during the years of the economic crises in Russia. The 70´s saw a steady increase of added nuclear capacity until 1986, and especially 1990 when several units were shut down. The projections for 2020 see a strong increase of installed nuclear capacity in the CIS region from 36 GWe in 2010 to 58 GWe in 2020 to 74 GWe in 2025. The scenario indicated 72 GWe for 2030, due to the experience of lifetimes of several reactors in the years between 2022 and 2030. The official plans for new added nuclear power reactors lack between 2025 and 2030. Those two facts explain the decrease between 2025 and 2030.

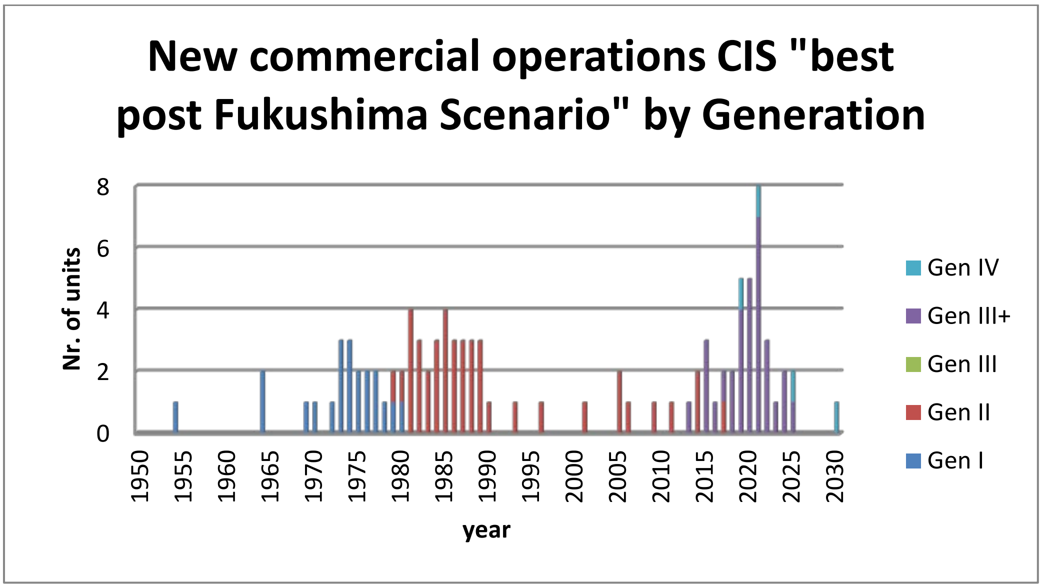
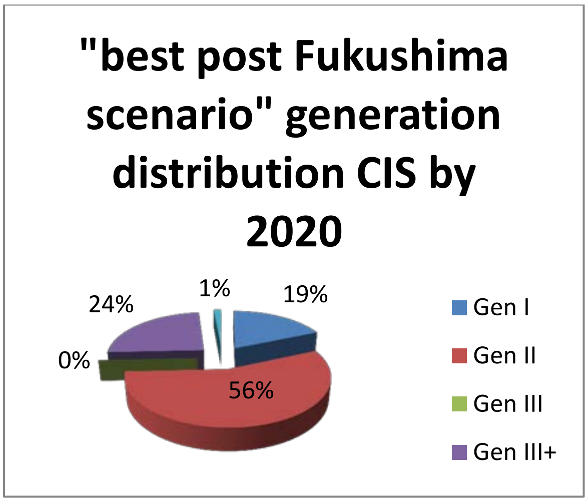


FIGURE 23: NEW COMMERCIAL OPERATIONS CIS “BEST POST FUKUSHIMA SCNEARIO” BY GENERATION

In the CIS region the development and installation of the different generations of nuclear power reactors can be observed in a continuous way. Until 1980 Gen I reactors went operational, after 1980 Gen II reactors. The next development step of the nuclear fleet in the CIS region will be the implementation of Gen III+ reactors – by 2016 this development will be significant. Furthermore Gen IV reactors will be put into operation in the CIS region.



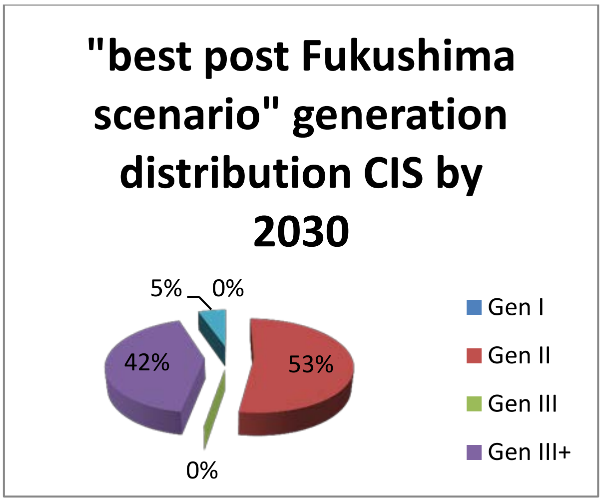


FIGURE 24: NUCLEAR POWER PLANTS DISTRIBUTION IN CIS BY GENERATION IN 2020 AND 2030 “BEST POST FUKUSHIMA”

By 2020 the majority of nuclear power plants operational in the CIS region will be Gen II reactors (56%). Gen I reactors will contribute 19% and Gen III+ reactors 24% of the NPP share. Additionally 1% of the nuclear fleet of the CIS region will be Gen IV reactors.

In 2030 no Gen I reactor will be in operation in the CIS region. The majority of NPP will still consist of Gen II reactors (53%), but Gen III+ reactors will see an increase to 42% of the nuclear fleet in the CIS region. Gen IV reactors will contribute 5% to the nuclear fleet of the CIS region in 2030.

3.2.4. ASIA

The development of nuclear power in Asia is continuous. The installed nuclear capacity rose from the 70´s to the year 2011. In 2011 with the accident at the Fukushima Daiichi nuclear power plant all nuclear power plants in Japan were shut down. This had a strong impact on the produced nuclear power in Asia.

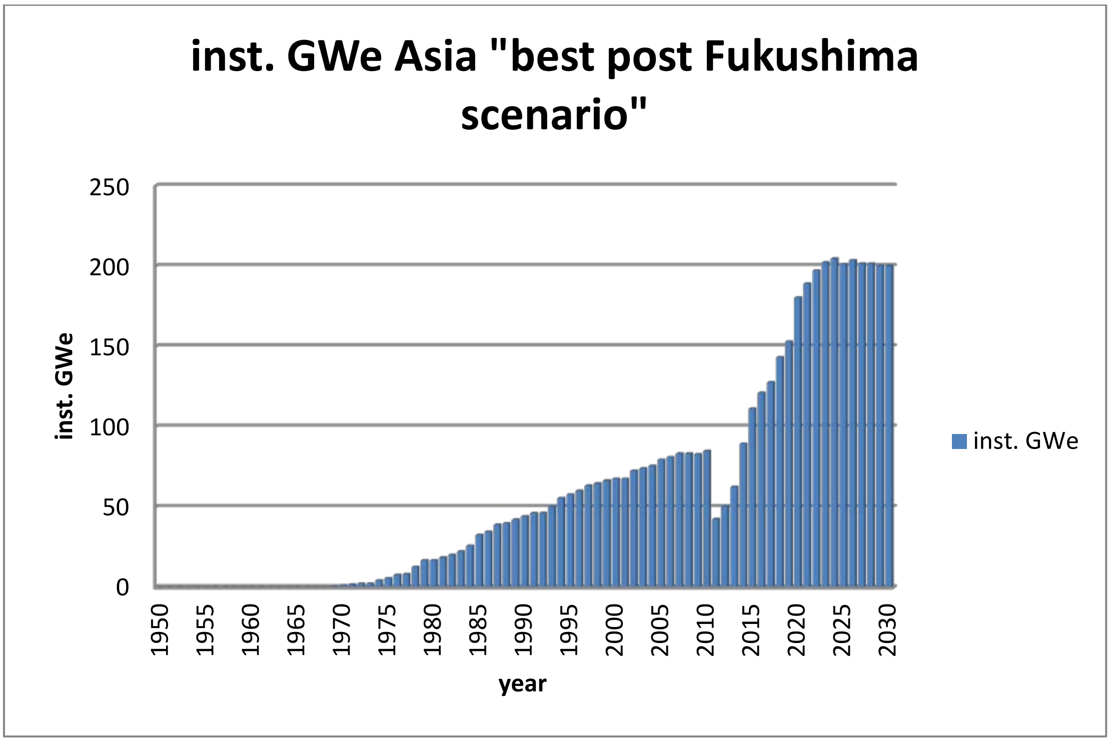


FIGURE 25: INSTALLED GWE ASIA "BEST POST FUKUSHIMA SCENARIO"

In 1970 1.1 GWe of nuclear capacity was installed in Asia. By 2010, 84.7 GWe were installed. The accident at Fukushima, and the related shutdowns in Japan decreased the operational installed capacity to 43 GWe. One assumption of the scenario "best post Fukushima" was the restart of most of the Japanese Nuclear power plants. The lifetime of the Japanese reactors was limited to 50 years (built after 1990), and to 40 years if built before 1990. (IEA 2012 ,p. 190) This assumption had an implication on the potential restart in Japan, because some reactors will not restart according to the assumption. The strong increase of installed nuclear capacity is not only driven by the restarts in Japan, but due to the progressive nuclear development program in China, India and Korea. The main actor for the development in Asia is China, were most of the nuclear capacity will be added until 2020 and 2030.

For 2020 an installed capacity of 180 GWe is projected. For 2025 the projections assume an installed nuclear capacity of 201 GWe and for 2030 200 GWe.

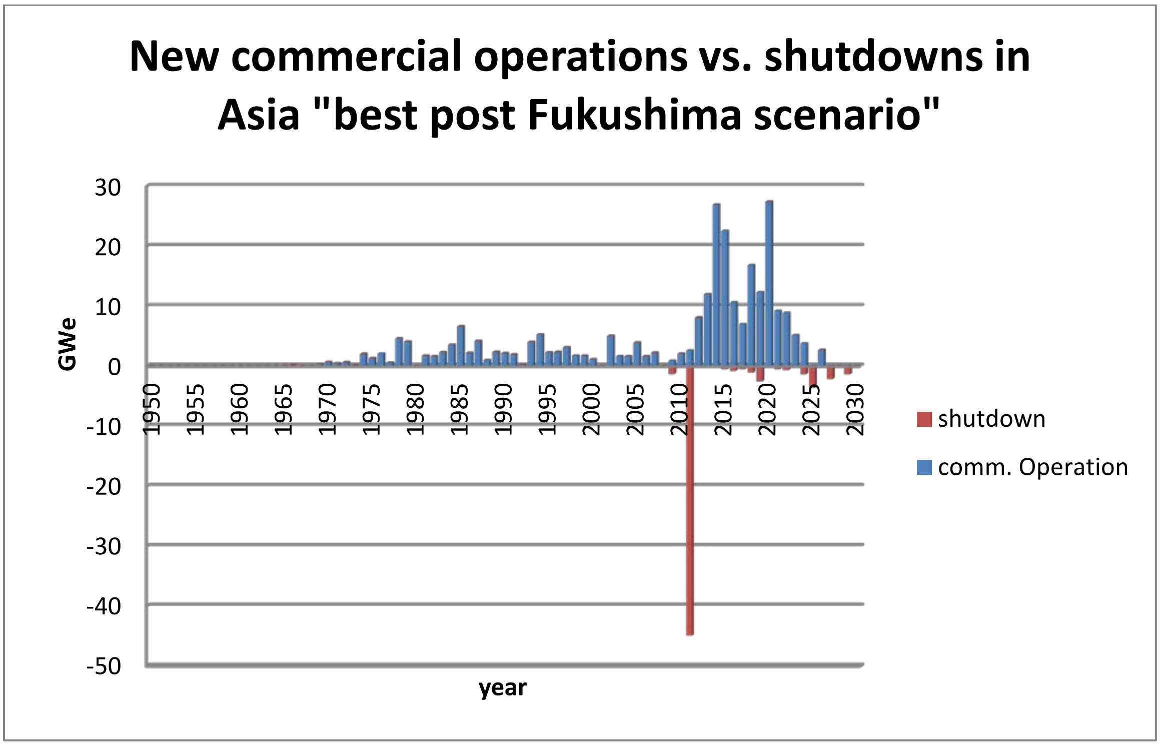


FIGURE 26: NEW COMMERCIAL OPERATIONS VS SHUTDOWNS IN ASIA "BEST POST FUKUSHIMA SCENARIO"

The stagnation of installed nuclear capacity between 2025 and 2030 can be explained by shutdowns and limited information available on new reactors in planning phase. If looking into the new commercial operations of NPPs and shutdowns of nuclear power stations, the year 2011 marks a very important date. After 2011 a strong commitment to nuclear can be observed, when looking at the plans for new grid connections in Asia. The development in the period between 1970 and 2010 seems marginal, when projecting into the future of nuclear power in Asia.

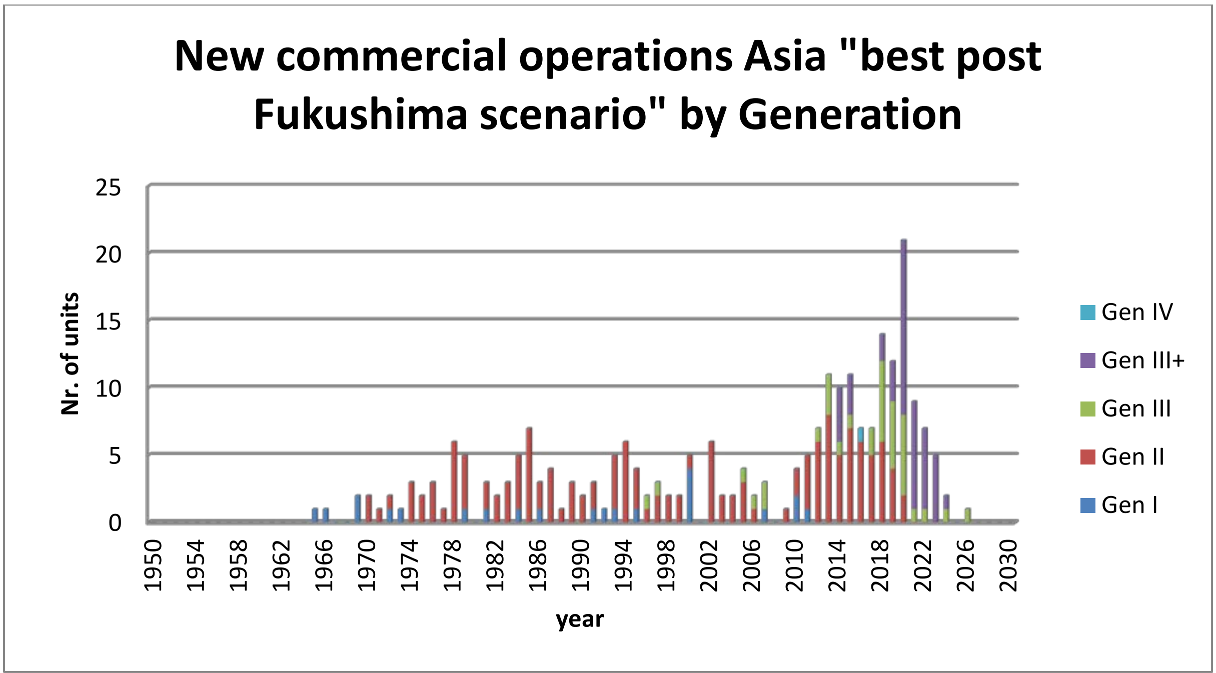


FIGURE 27: NEW COMMERCIAL OPERATIONS ASIA "BEST POST FUKUSHIMA SCENARIO" BY GENERATION

From 2018 on, the majority of the new grid connected nuclear power plants will be reactors of Gen III and Gen III+. Gen III plants in Asia play a certain role since the mid 2000´s. This can explained by the construction of reactors in Japan and Korea, which startet in the end of the 1990´s and beginning of the new century.

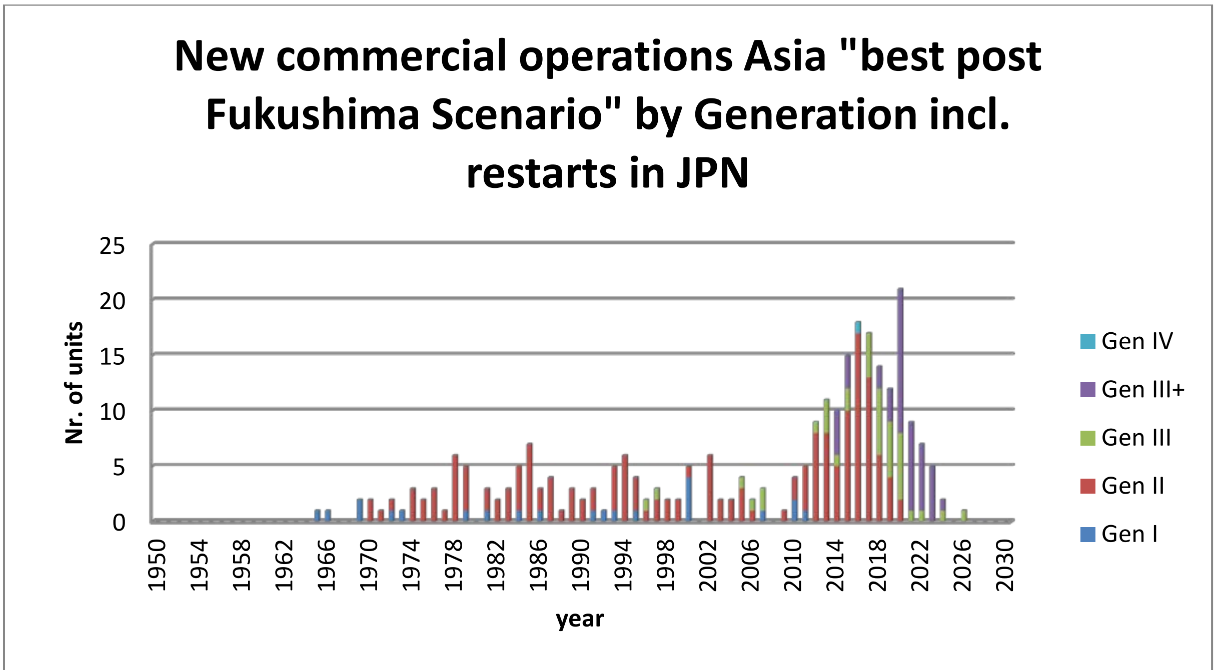
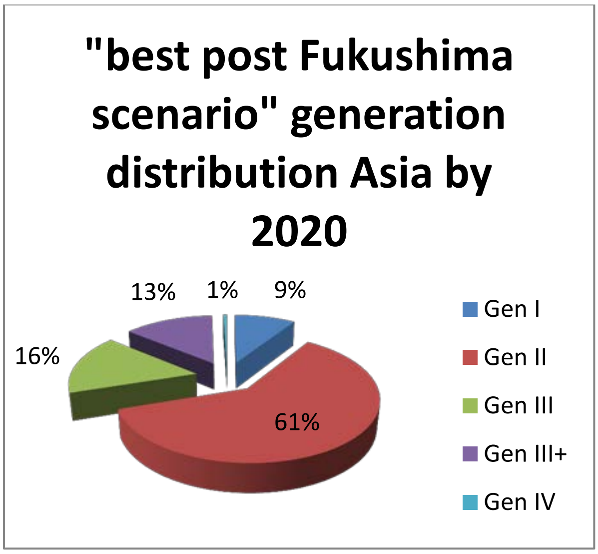


FIGURE 28: NEW COMMERCIAL OPERATIONS ASIA "BEST POST FUKUSHIMA SCENARIO" BY GENERATION INCL. RESTARTS IN JAPAN

If taking into account the restarts in Japan the picture of the grid connections by generation changes only marginally. The restarted plants in Japan are mainly Gen II plants, but 2018 seem to be the year when Gen III and Gen III+ reactors will be designs to be built at most.



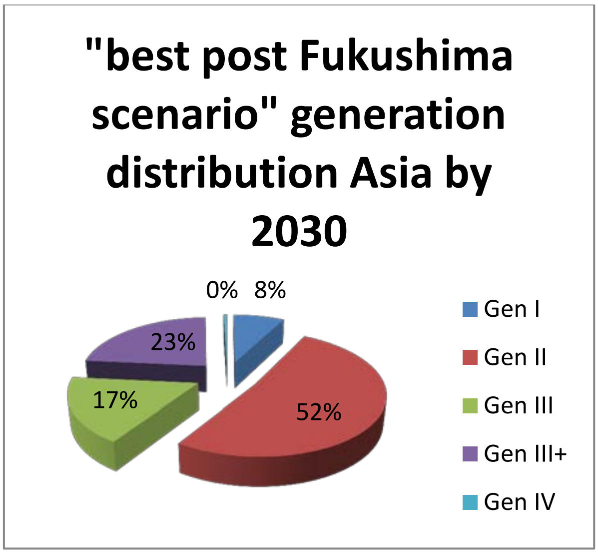


FIGURE 29: NUCLEAR POWER PLANTS DISTRIBUTION IN ASIA BY GENERATION IN 2020 AND 2030 "BEST POST FUKUSHIMA"

The nuclear reactor fleet in Asia by 2020, according to the "best post Fukushima scenario", will be composed as follow:

Gen I – 9%

Gen II – 61%

Gen III – 16%

Gen III+ – 13%

Gen IV – 1%

The majority of NPPs in 2020 are going to be reactors of the second generation. The trend towards Gen III and Gen III+ in the second half of the 2010´s is affecting the distirbution of reactor generations only marginally.

In 2030 the distribution of generations changes significantly compared to the distribution in 2020. This is caused due to the fact that the new NPPs are reactors of Gen III and Gen III+ and that older reactors are shut down. The majority (52%) of the reactors will still be Gen II reactors. 8 % of the reactors fleet will be reactors from the first generation. The new generation reactors will reach 40% of the Asian power reactor fleet.

3.2.5. NORTH AMERICA

The installed nuclear capacity in North America saw a strong increase in the 70´s and 80´s until 1990. Due to the strong growth in this time period North America, similar to Europe, can be described as traditional nuclear market. In 1970 the installed nuclear capacity was 5.8 GWe. In 1980 58.5 GWe and in 1990 119 GWe nuclear capacity was installed in North America.

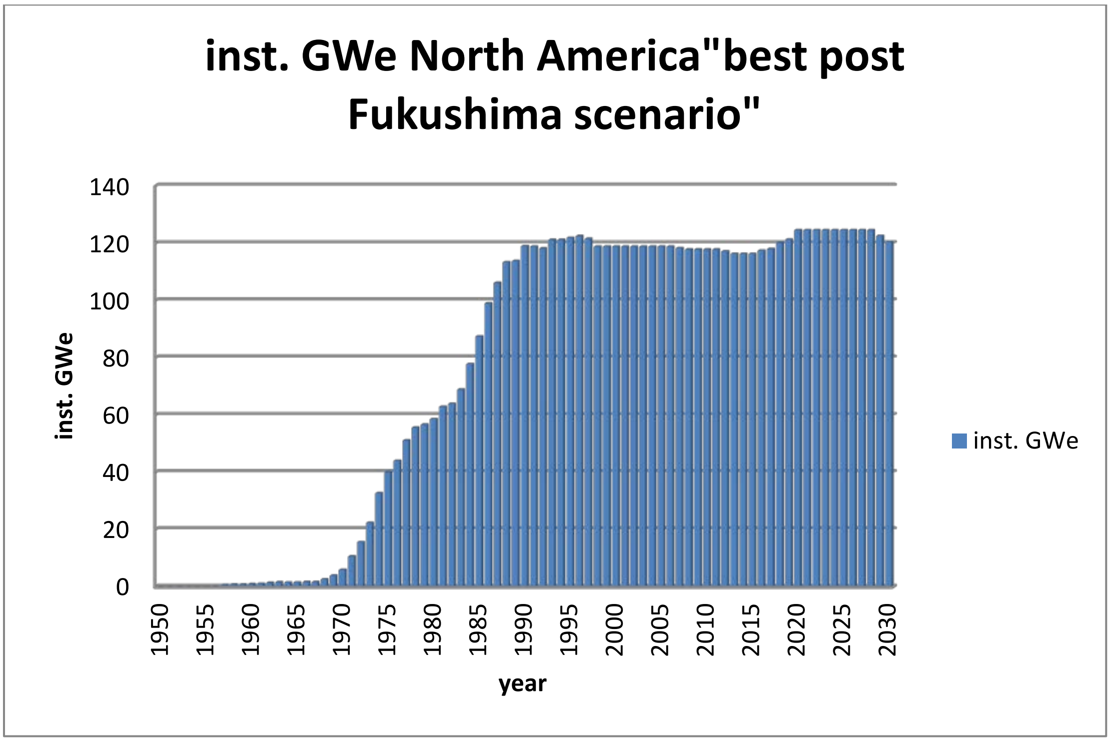


FIGURE 30: INSTALLED GWE NORTH AMERICA “BEST POST FUKUSHIMA SCNEARIO”

Between 1990 and 2000 there was a marginal decrease in the installed capacity from 119 GWe to 118 GWe, which continued until 2010 when 117 GWe were installed. The projections for North America indicate an increase of the installed nuclear capacity for 2020 to 124 GWe and a decrese from 2020 to 2030 to 120 GWe.

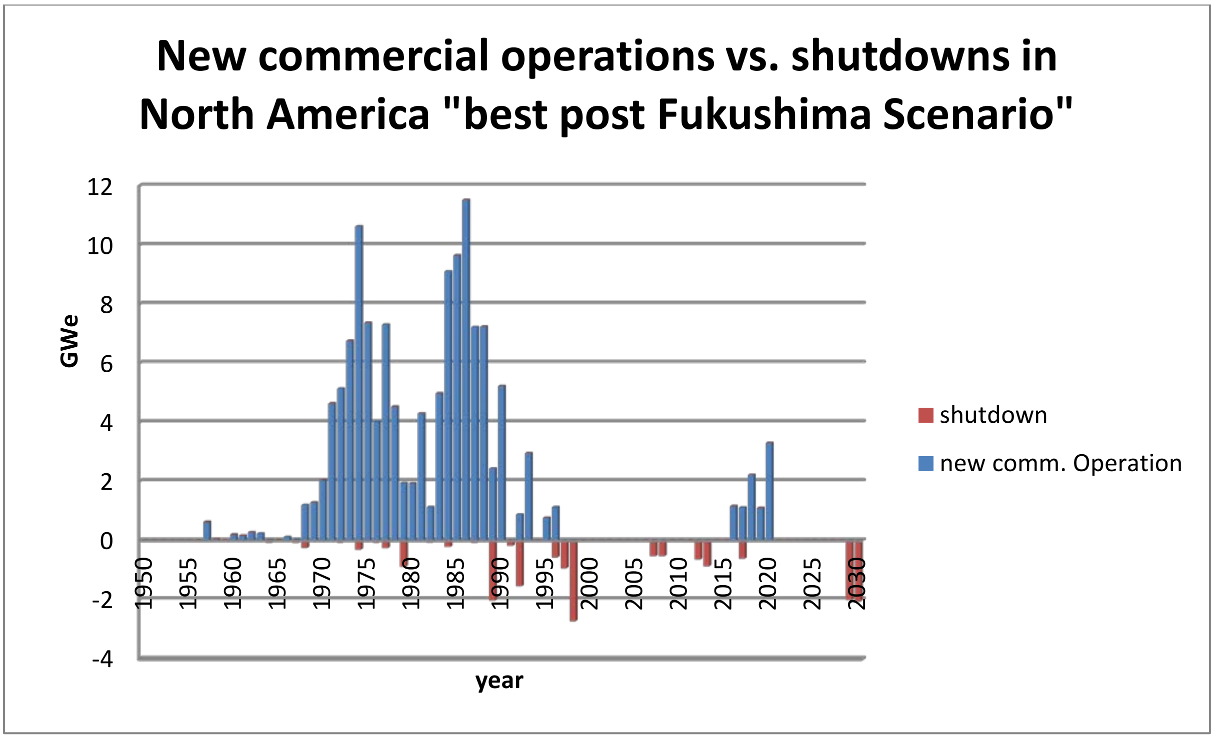


FIGURE 31: NEW COMMERCIAL OPERATIONS VS SHUTDOWNS IN NORTH AMERICA "BEST POST FUKUSHIMA SCENARIO"

Two waves of nuclear power development can be observed in North America. In the beginning of the 70´s a peak of new grid connections is indicated in the graphic, and a second peak in the mid 80´s. Between 1995 and 2016 no nuclear reactors are to be built in North America. The discussion on a nuclear renaissance in North America was triggered in the first years of the new century, at a time when no nuclear power plants went operational since 1996.

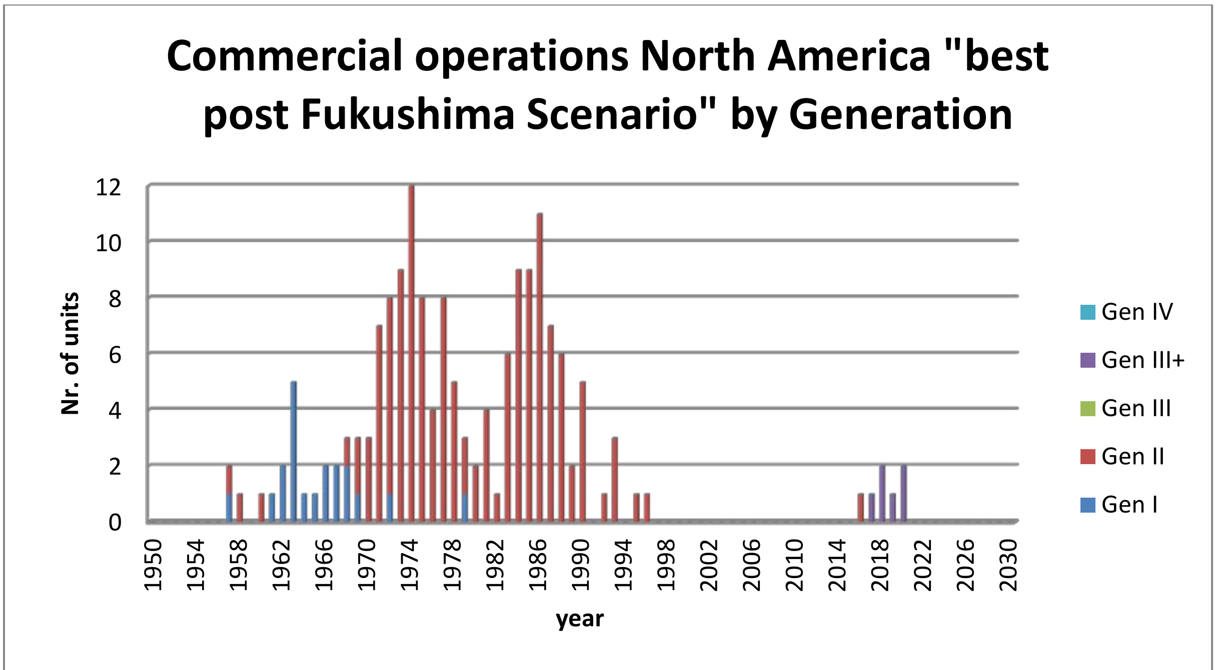


FIGURE 32: NEW COMMERCIAL OPERATIONS NORTH AMERICA "BEST POST FUKUSHIMA SCENARIO" BY GENERATION

The projections show that the reactors to be built in the second half of the 10´s will be mostly advanced reactors. There is one Gen II reactors which will be operational by 2015, but all other new builts are Gen III+ reactors.

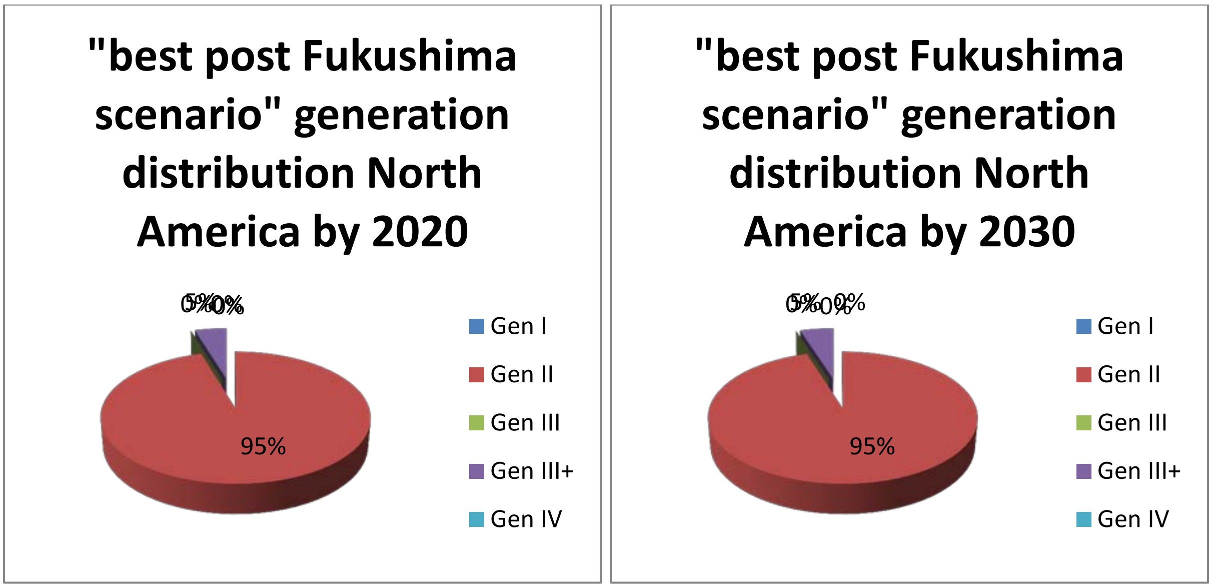


FIGURE 33: NUCLEAR POWER PLANTS DISTRIBUTION IN NORTH AMERICA BY GENERATION IN 2020 AND 2030 “BEST POST FUKUSHIMA”

The nuclear power reactor fleet in North America will be dominated by Gen II reactors. There will be no changes between 2020 and 2030. This special case can be explained by the equilibrium between new operations and shutdowns. Gen II reactors (95%) will be the majority of NPPs in North America. Advanced Reactors will only play a minor role in the scenario (5%).

3.2.6. SOUTH AMERICA AND AFRICA

South America and Africa will have no significant changes compared to 2010, and will therefore not be described in detail.

3.3.ISR 1 SCENARIO

One of the four scenarios is the ISR 1 Scenario. The main approach is described in section 2.4 and the principle limitations are highlighted in section 2.5.

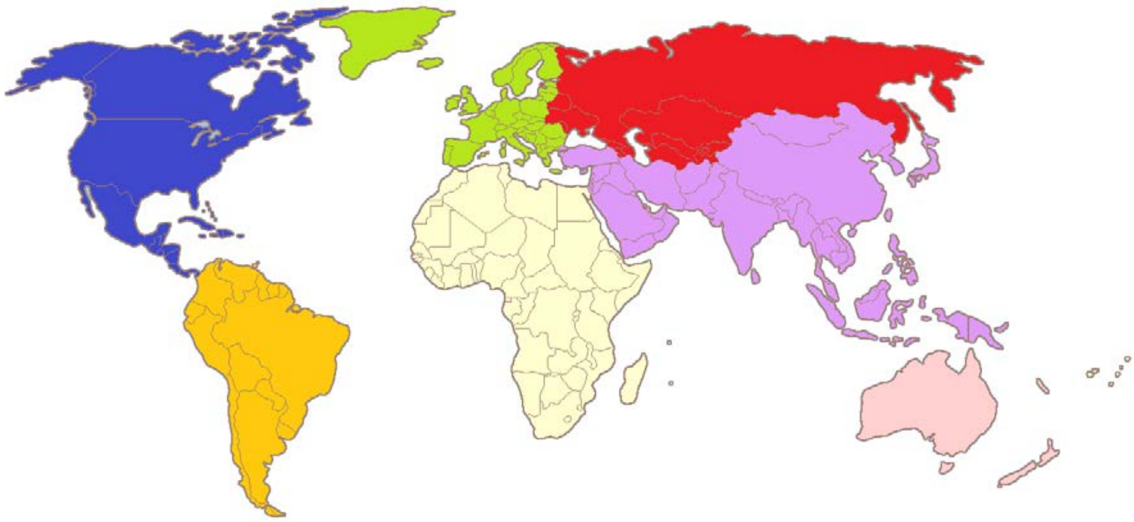


FIGURE 34: GLOBAL MAP WITH HIGHLIGHTED REGIONS

The scenario is based on data extrapolation. All relevant available data regarding national nuclear development strategies are taken into account. The data, on which the scenario is based on, were taken from the published information by the WNA, the IAEA, and by country reports. The main assumptions and the framework for the ISR 1 scenario are:

- Fukushima had implications for the global nuclear development
- The national nuclear development plans were reviewed and taken into account
- Several delays in the planning and construction phase were assumed
- Life time extension and long term operation for all reactors on a country by country base
- No shortages due to fuel and heavy component supply

Based on the assumptions summarized in the following infobox the ISR 1 scenario was created, discussed and described on a global and regional level.

Info Box: Background and assumption of the ISR 1 scenario
The basic assumption of the ISR Scenario 1 is that the accident at the Fukushima Daiichi NPP occurred, and that the accident influences the global nuclear market in a moderate way. The influence is very different from region to region, but the global trend towards new nuclear power plants is alive, although much weaker than in the best post Fukushima Scenario. Europe: Germany will phase out as decided in 2011. Belgium and Switzerland will follow their strategy to phase out and not to replace existing capacities. New constructions and planned units will suffer delays before starting commercial operation. The lifetime of the existing nuclear power plants is limited to the published data in 2013. Asia: The accident at Fukushima will have a decent influence on the planned new added nuclear capacity in Asia. China will not complete fully its plan of new builds. Deferred reactor plans in China inland will start construction in 2015-16, with up to 2 units built at the same time at the same site. 6 years is the assumed construction time for a reactor, if detailed information is not available. New reactors in Korea it will take 6 years and 7 years in India. The Korean design in the UAE will be in commercial operation later than scheduled. Japan will build no new NPPs. Fukushima Daiichi, Fukushima Daiini, and other NPPs damaged by the earthquake will be decommissioned. Not all other reactors will restart, as their assumed life time expires before a potential restart could take place. The lifetime of the Japanese reactors will be limited to 50 years (built after 1990), and to 40 years if built before 1990. (IEA 2012 ,p. 190) The lifetime of reactors in Asia is limited to the published data in 2013. CIS: The Russian nuclear program will mostly be carried out as planned in 2010, with construction and planning behind schedule, with some projections not being completed. The lifetime of the nuclear power reactor fleet is limited to the data published in 2013. North America: Reactors in North America will have a lifetime as publicly available in 2013. The plans for new added capacity are behind the schedule intended in 2010, and not all planned units will be constructed. South America: Reactors in South America will have a lifetime as publicly available in 2013. Africa: Reactors in Africa will have a lifetime as publicly available in 2013

3.3.1. GLOBAL

The ISR 1 scenario shows a moderate growth of installed nuclear capacity from 2011 to 2020. As described in section 2.4 and 2.5 the quality of the available data is sufficient for projections until 2020, while decreasing towards 2030.

According to the scenario the global installed nuclear capacity in 2020 will be at 411 GWe gross. This is a slight increase compared to the year 2010, when 378 GWe were installed. For the year 2030 the scenario indicates a decrease of the installed nuclear capacity to 370 GWe – less than in the year 2010. Due to assumptions regarding delays in several constructions of new capacities the quality of the data seems to be good until the year 2024, when up to 413 GWe will be installed.

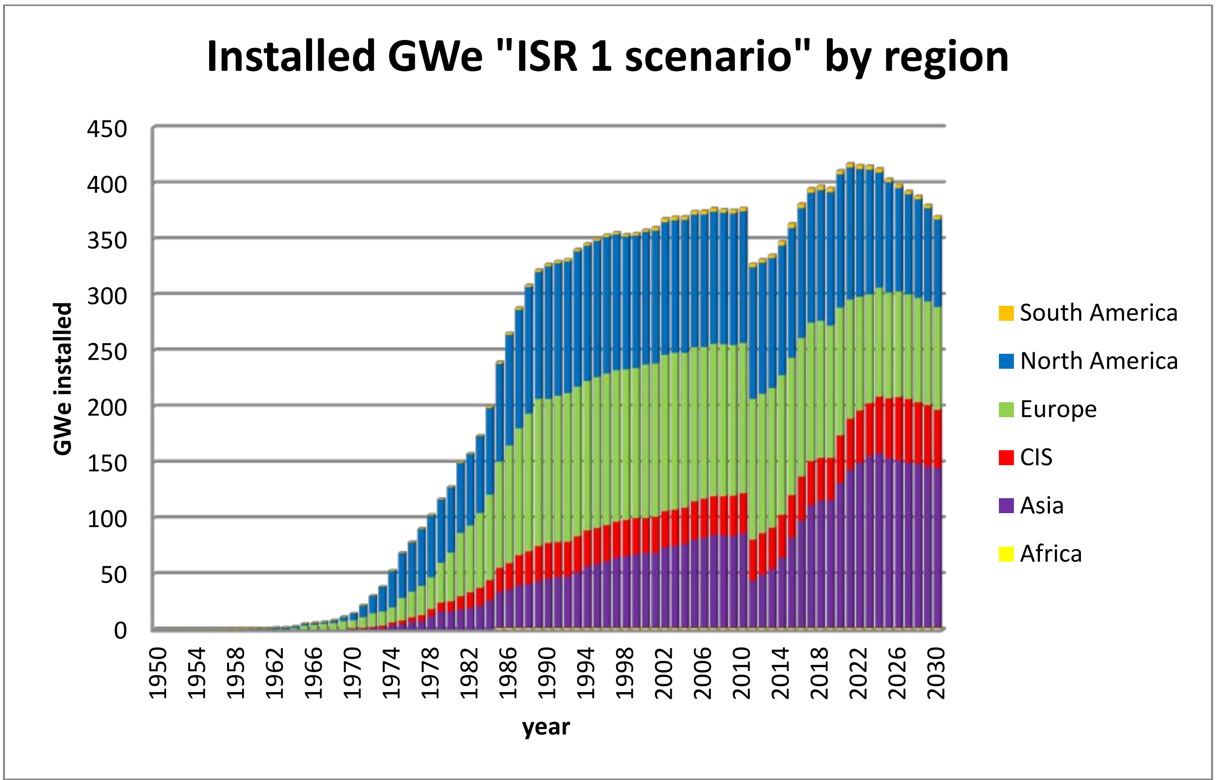


FIGURE 35: DEVELOPMENT INSTALLED NUCLEAR CAPACITY GLOBAL "ISR 1 SCENARIO"

The ISR 1 scenario shows an increase of the global installed nuclear capactiy of 8% between 2010 and 2020. For the period from 2020 to 2030 a decrease of 10% is indicated by the scenario. The comparision with the growth between 1980 and 1995 when a strong expasion of nuclear power was performed (+172.6%) the growth from 2010 to 2020 must be described as marginal. In the figure 35 the growth between 2011 and 2020 looks significant, but this can be explained by the shutdowns of NPPs in Japan after the Fukushima accident, and the assumed restart of several Japanese units till 2020. Therefore the growth rate is compared to the pre Fukushima status.

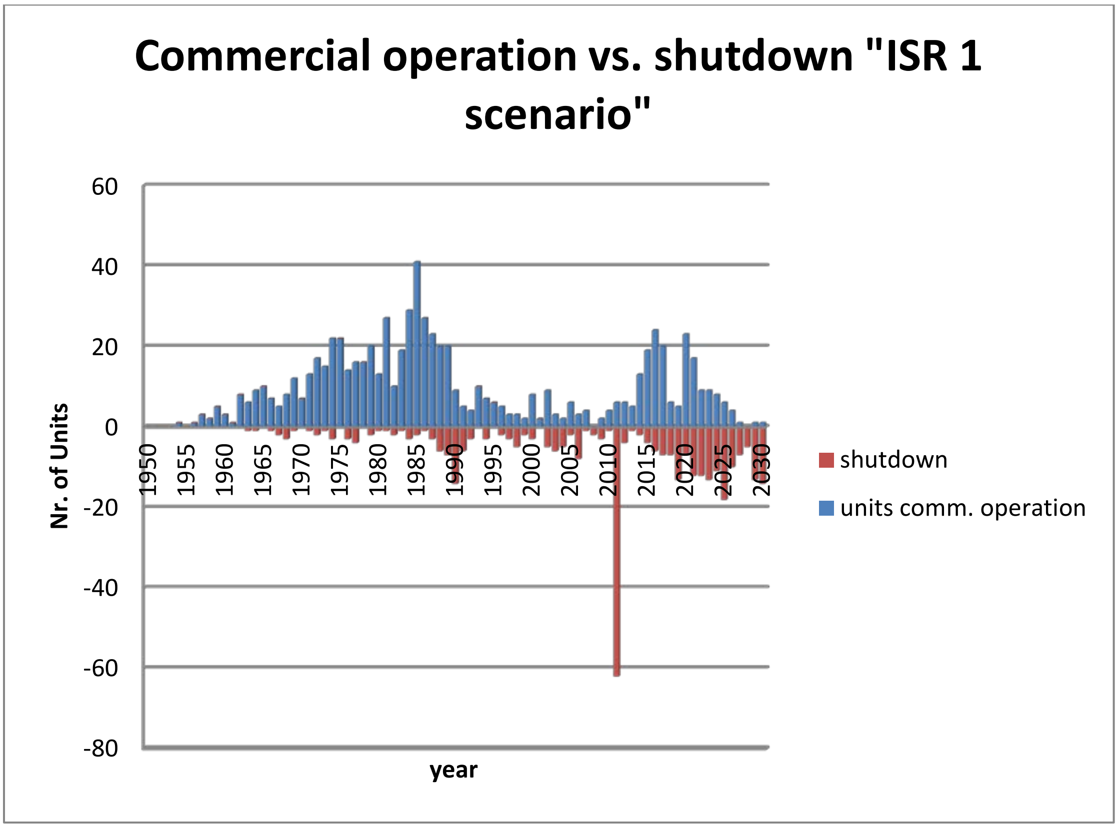


FIGURE 36: COMMERCIAL OPERATIONS VS SHUTDOWN "ISR 1 SCENARIO"

The detailled figure on assumed startups and shutdowns shows a large number of units being shutdown between 2020 and 2030, as figure 36 shows. The shutdowns are the main driver for the previously described decline in installed nuclear capacity between 2020 and 2030.

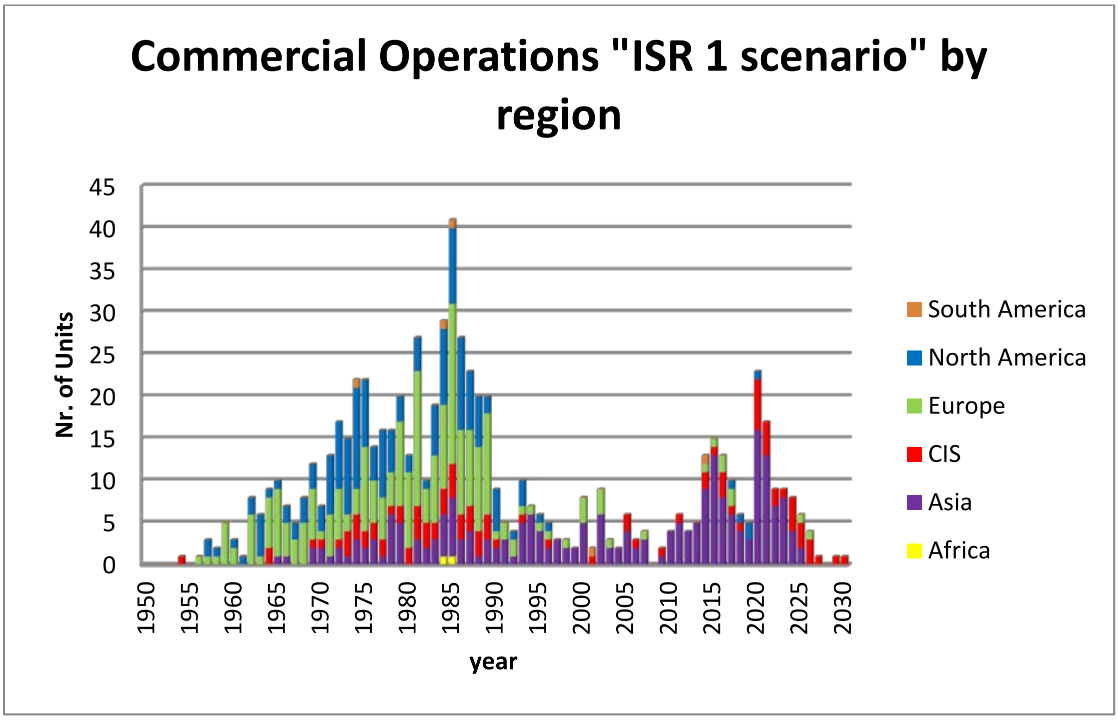


FIGURE 37: GRID CONNECTIONS GLOBAL "ISR SCENARIO"

Considering the shutdowns and the known plans for constructions and new grid connections, as shown in figure 36 and figure 37 the overall installed capacity is described in a detailled matter. The figure dealing with the new commercial operations indicates a shift in the global nuclear landscape, from the tradional nuclear market towards the new markets. Asia and the CIS region were identified as the main drivers for the future expansion of nuclear energy on a global level. North America and Europe will play only a minor role when it comes to new grid connections. In the following chapters this is elaborated on a region by region base.

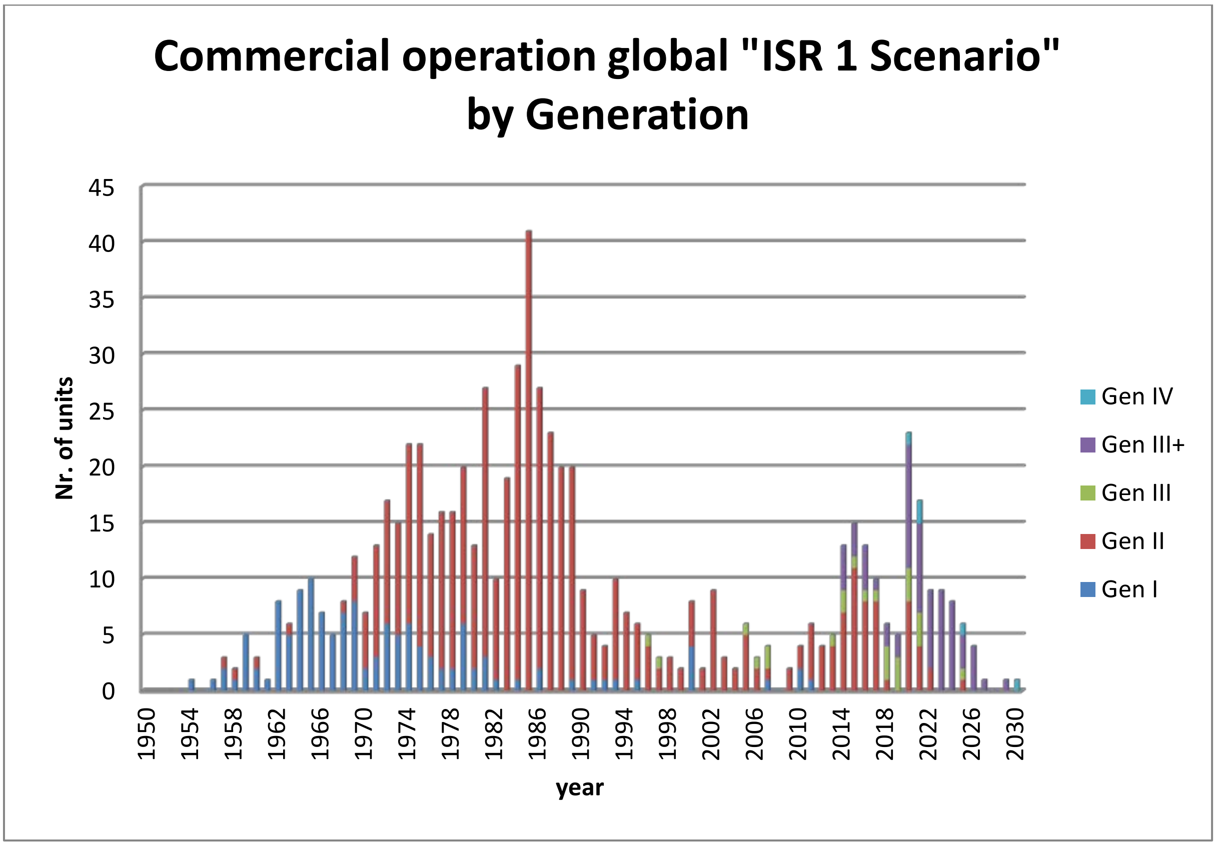


FIGURE 38: GRID CONNECTIONS GLOBAL "ISR 1 SCENARIO" BY GENERATION

If taking into account one promise of the nuclear renaissance, that the renaissance will rely on and will be driven by new designs of nuclear power plants (McLellan, 2008) a detailled look into the future plans shows that advanced generations of reactors will be installed mainly after 2018. Due to the delayed installation of advanced generation the picture of the nuclear landscape based on generations does not change signifantly to 2020. In 2010 91% of the operational reactors were reactors of the second generation.

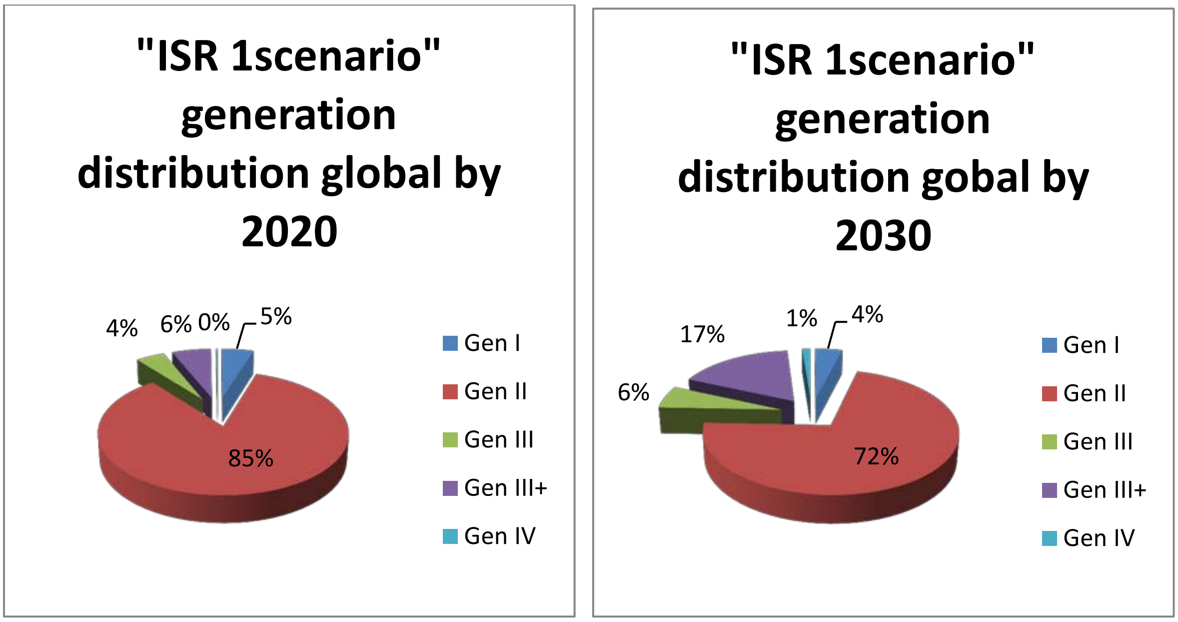


FIGURE 39: NUCLEAR POWER PLANTS DISTRIBUTION BY GENERATION IN 2020 AND 2030 "ISR 1 SCENARIO"

By 2020 85% of the global reactors will be reactors from the second generation. The picture changes slightly when looking into 2030. This shift can be explained by the decrease of the total number of operational units. Shutdowns of NPPs and the start of commercial operation of several advanced reactors are having an impact on the global distribution by generation. Nevertheless in the year 2030 the operational nuclear power reactor fleet will still consist of 72% reactors from the second generation.

3.3.2. EUROPE

The impact of the accident at the Fukushima nuclear power plant in the ISR 1 on Europe is strong. The installed capacity in 2010 was about 134 GWe. The peak was in 2003 with 140 GWe. The scenario indicates an installed capacity of 114 GWe by 2020 – a decrease of 15% compared to 2010. For 2030 the installed nuclear capacity is assumed to decrease to 91 GWe. This would imply that the level of installed nuclear capacity in Europe will be below the level of the year 1985.

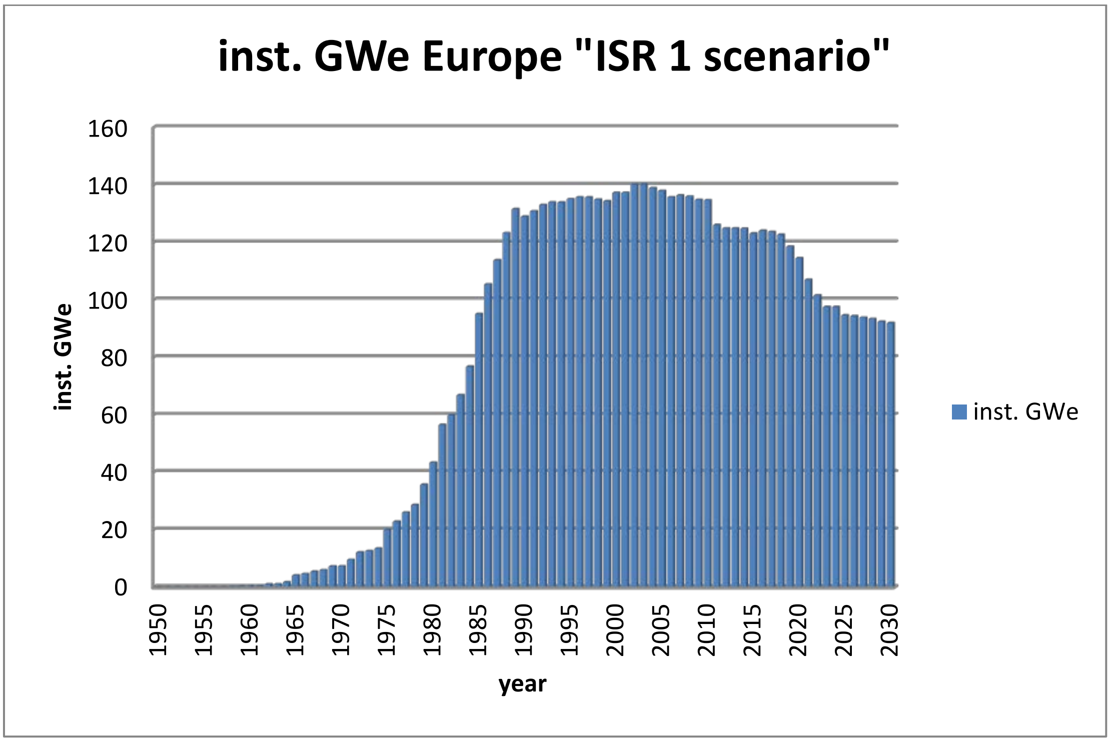


FIGURE 40: INSTALLED GWE EUROPE “ISR 1 SCENARIO”

The reduction of the installed capactiy is related to the main assumptions of the scenario, the shutdown dates published in 2013 were used. If no decision on lifetime extension of existing capacities was known in the beginning of 2013 the publicly available data were used.

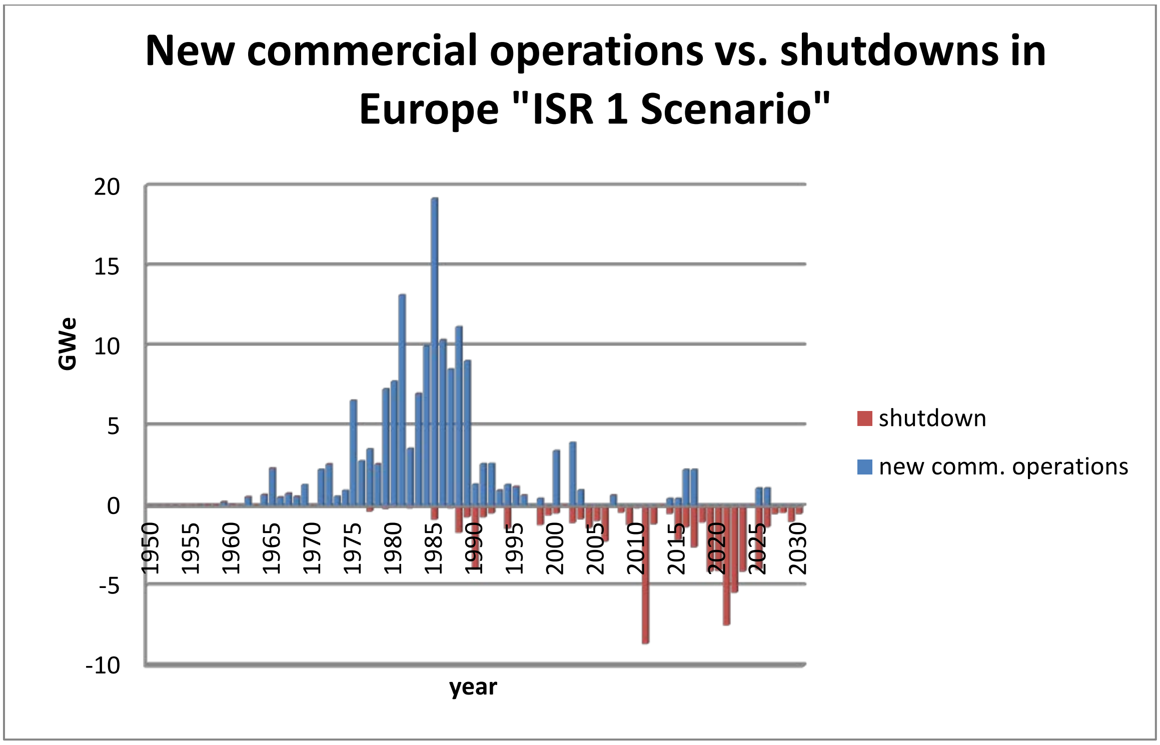


FIGURE 41: NEW COMMERCIAL OPERATIONS VS SHUTDOWNS IN EUROPE “ISR 1 SCENARIO”

The decrease of the installed nuclear capacity is well illustrated in figure 41. The number of shutdowns from 2015 on is much higher than the number of new built units. The role of nuclear power in the European energy mix will decline until 2020 and 2030.

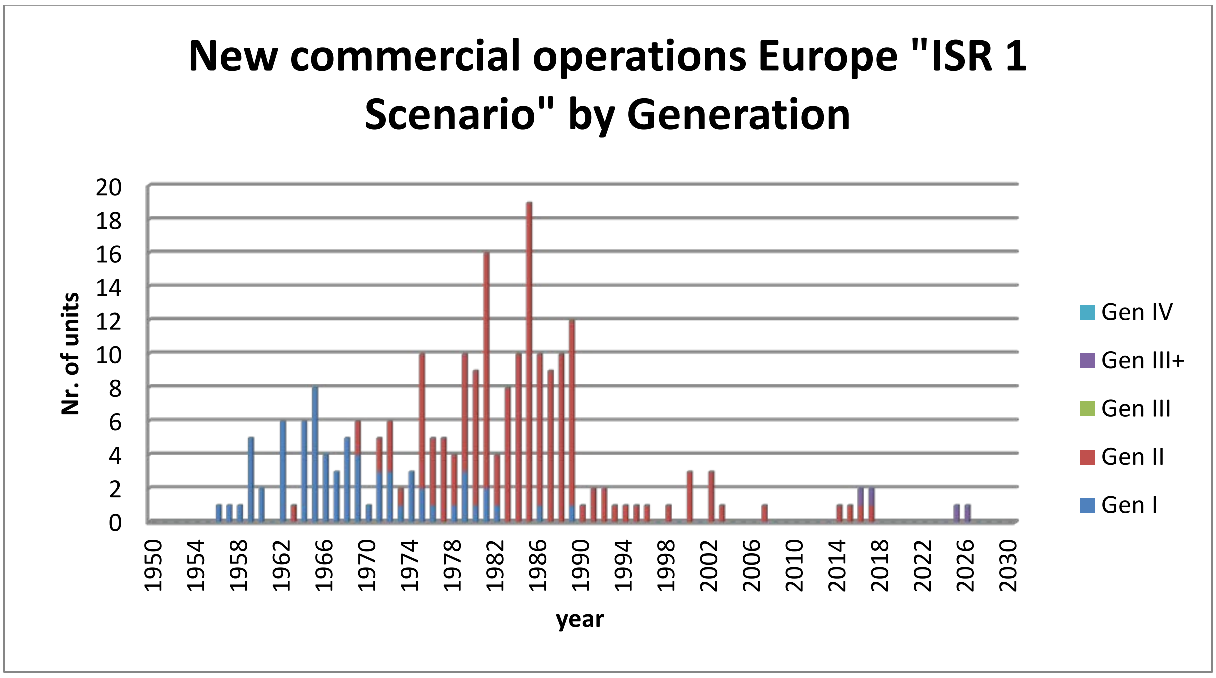


FIGURE 42: NEW COMMERCIAL OPERATIONS EUROPE “ISR 1 SCENARIO” BY GENERATION

The new reactors which will be built in Europe are reactors from the generation III+ (i.e. Flamanville 3, Olkiluoto 3, etc…) and reactors of the second generation (Mochovce NPP). The limited number of new reactors leads to fact, that the majority of reactors in Europe will be reactors of the second generation.

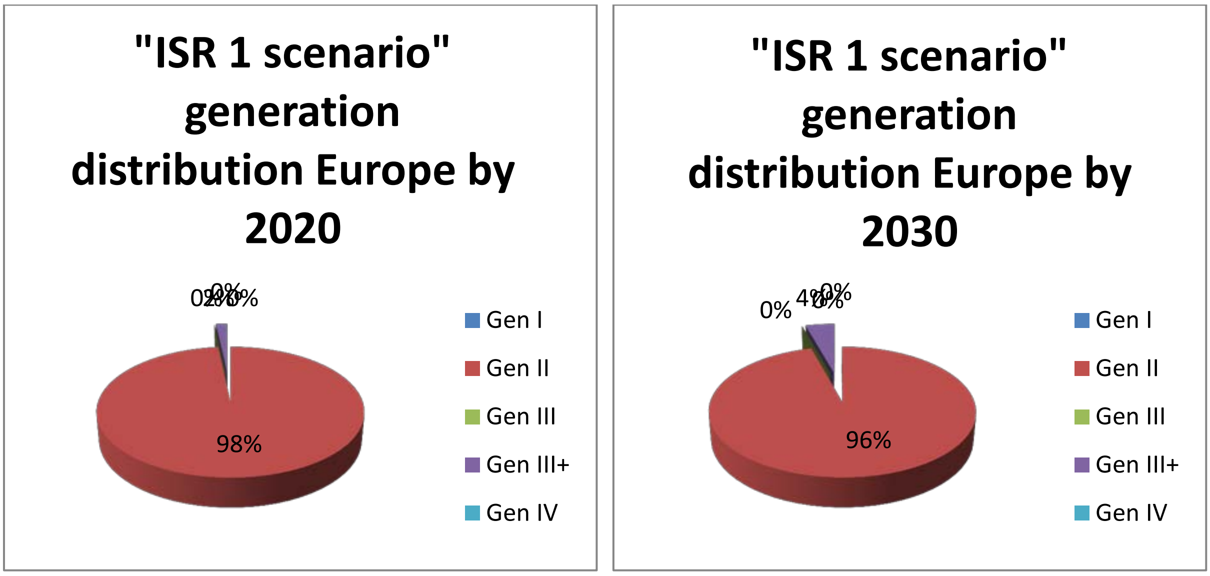


FIGURE 43: NUCLEAR POWER PLANT DISTRIBUTION IN EUROPE BY GENERATION IN 2020 AND 2030 "ISR 1 SCNEARIO"

The European power reactor fleet in 2020 will consist almost totally of reactors of the second generation. 98% of the reactors in Europe in the year 2020 are going to be reactors of the second generation. Nevertheless the reduction of NPPs in Europe up to 2030 the huge majority of reactors operational at that time will still be reactors of the second generation (96%).

3.3.3. CIS

The CIS region saw strong growth of installed nuclear capacity between 1970 and 1990 with a significant impact of the Chernobyl impact and the collapse of the Soviet Union.

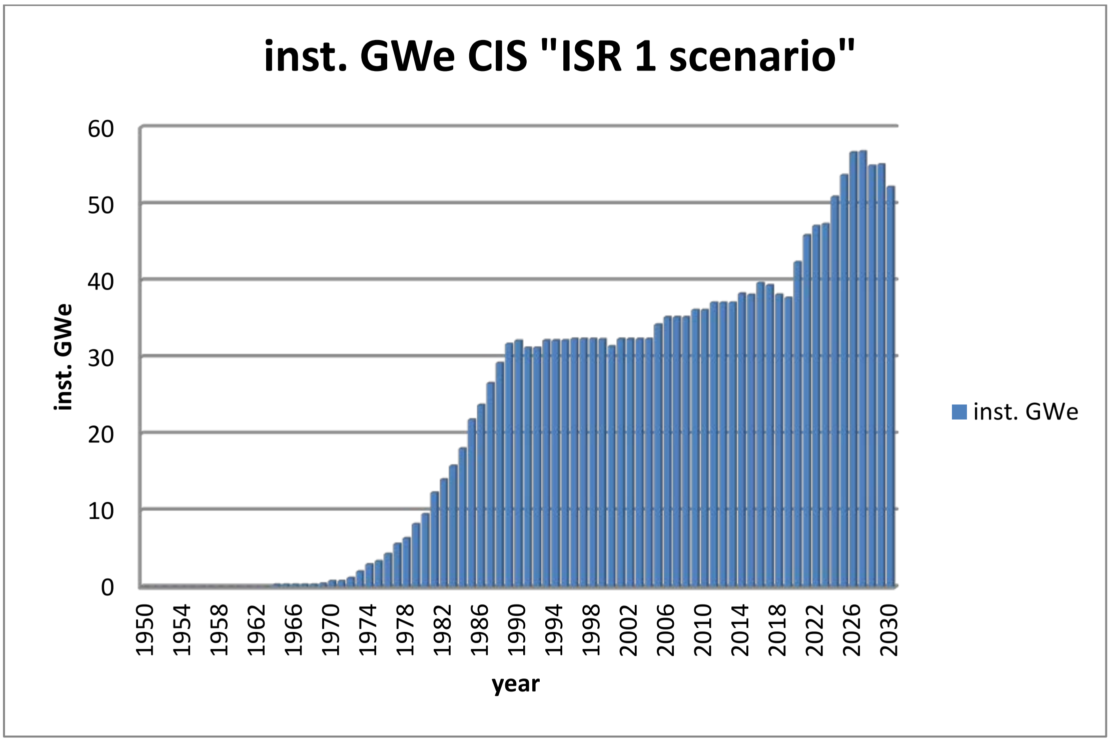


FIGURE 44: INSTALLED GWE CIS “ISR 1 SCENARIO”

The expected increase of installed nuclear capacity in the CIS region is mainly driven by Russia. The ISR 1 scenario indicates a significant increase of installed nuclear capacity up to 2025, with an expected slight decrease until 2030. Russia announced an ambitious nuclear program, in order to expand the nuclear power reactor fleet in Russia. Several nuclear power reactors are seeking for life time extension, but several will be shut down until 2030 due to age.

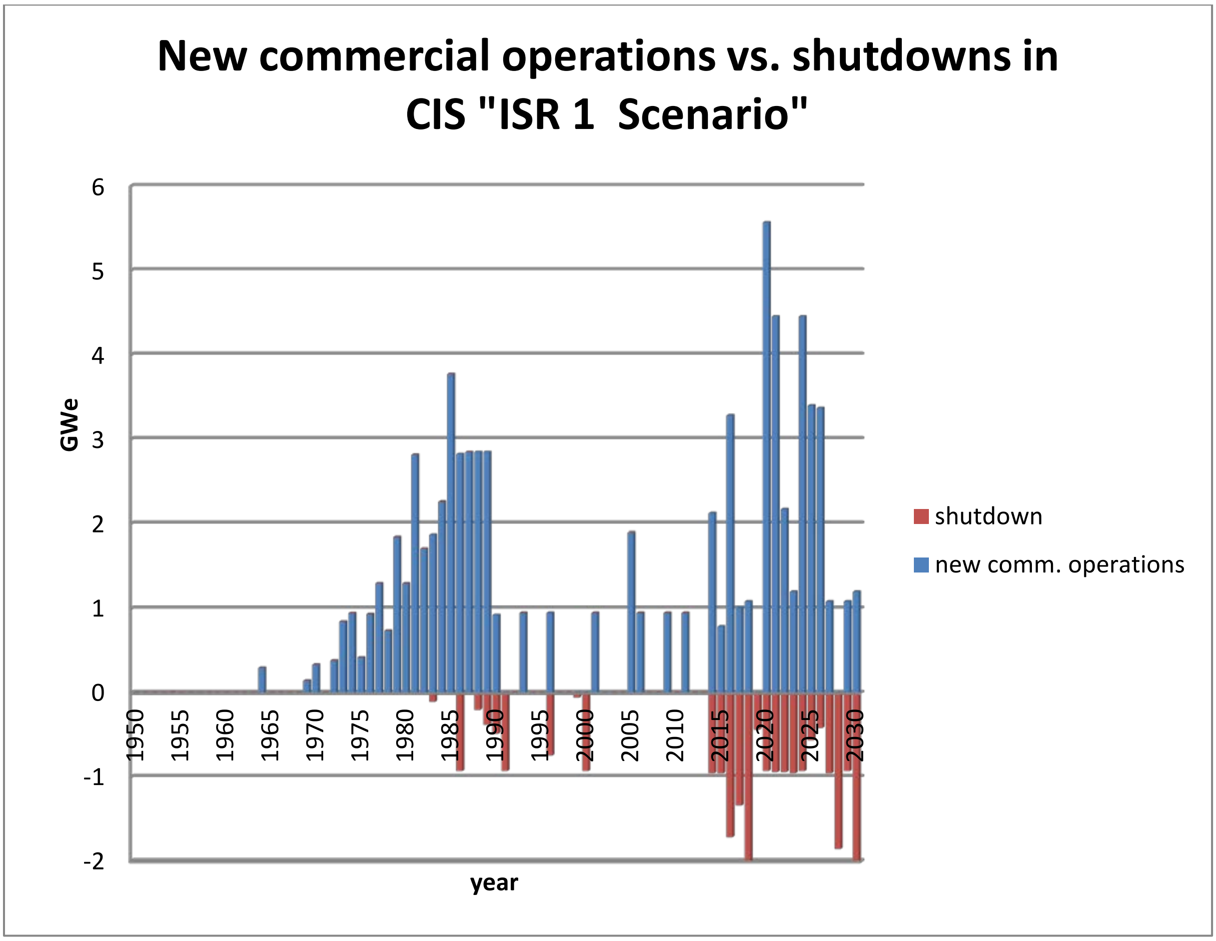


FIGURE 45: NEW COMMERCIAL OPERATIONS VS SHUTDOWNS IN CIS “ISR 1 SCENARIO”

Between 1990 and 2010 only a few new nuclear power plants went operational. This can be explained by the lack of financing during the years of the economic crises in Russia. The 70´s saw a steady increase of added nuclear capacity until 1986. After the Chernobyl accident several units were shut down. The projections for 2020 see an increase of installed nuclear capacity in the CIS region from 36 GWe in 2010 to 42 GWe in 2020 to 53 GWe in 2025. The scenario indicates 52 GWe for 2030, due to phase out of several reactors in the years between 2014 and 2030. The official plans for new added nuclear power reactors between 2025 and 2030 are not complete. Those two facts explain the decrease between 2025 and 2030. For the projections several projects were assumed to be delayed or cancelled.

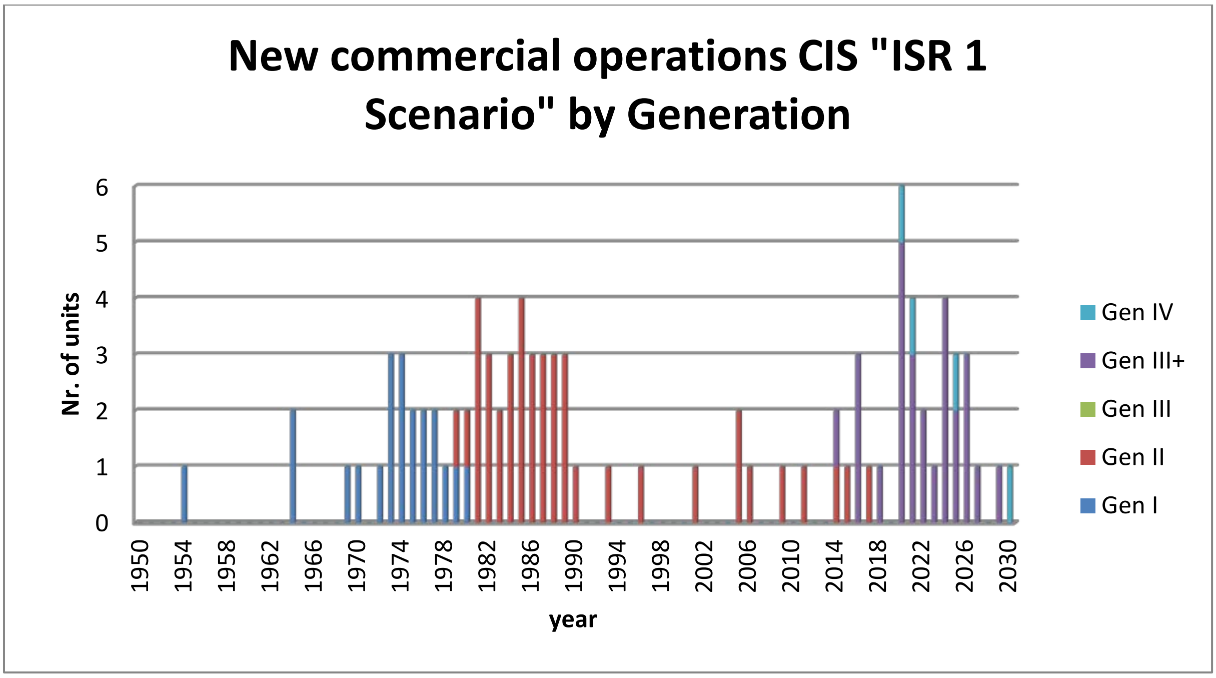


FIGURE 46: NEW COMMERCIAL OPERATIONS CIS “ISR 1 SCENARIO”

The future nuclear capacities which will be added in the CIS region will consist of reactors of advanced generations. Gen III+ and Gen IV reactors are the reactors which are intended to be built from 2018 on.

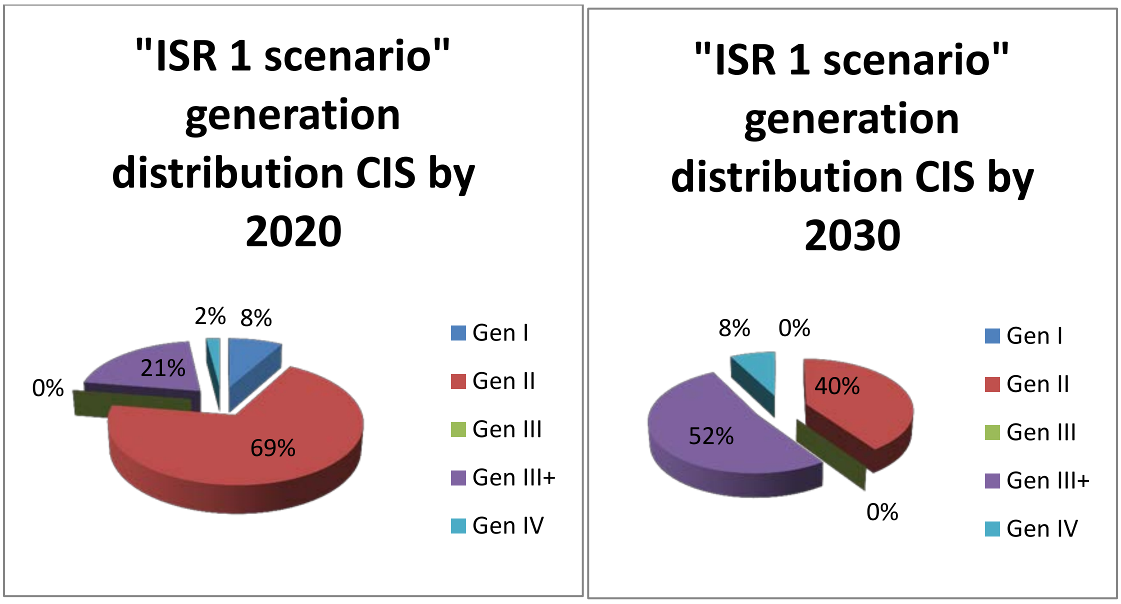


FIGURE 47: NUCLEAR POWER PLANTS DISTRIBUTION INS CIS BY GENERATION IN 2020 AND 2030 “ISR 1 SCENARIO”

The shutdown of several Gen II reactors between 2020 and 2030 leads to a change in the generation distribution picture. By 2020 the nuclear power reactors fleet in the CIS region will consist mainly by second generation reactors. For 2030 it is expected that the majority of the reactors – 52% - will be Gen III+ reactors.

3.3.4. ASIA

The accident at Fukushima has a decent influence on the planned new added nuclear capacity in Asia. China will not complete fully its plan of new builds. The deferred reactor plans in China (inland) will start construction in after 2015. The assumed construction time for a reactor is 6 years, if detailed information is not available. New reactors in Korea it will take 6 years and 7 years in India. The Korean design in the UAE will be in commercial operation later than scheduled. Japan will build no new NPPs. Fukushima Daiichi, Fukushima Daiini, and other NPPs damaged by the earthquake will be decommissioned. Not all other reactors will restart, but many Japanese reactors are back online in 2017. The lifetime of reactors in Asia is limited to the published data in 2013.

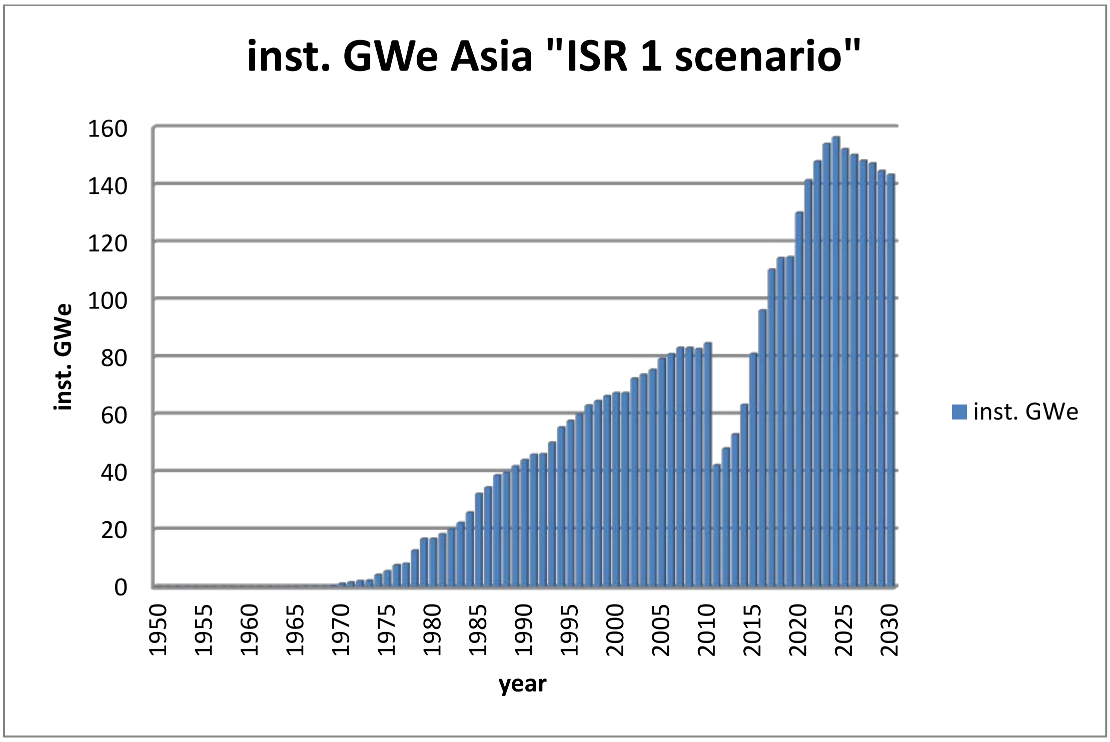


FIGURE 48: INSTALLED GWE ASIA “ISR 1 SCENARIO”

In 1970 1.1 GWe of nuclear capacity was installed in Asia. By 2010 84.7 GWe were installed. The accident at Fukushima, and the related shutdowns in Japan, decreased the operational installed capacity to 43 GWe. One assumption of the scenario “ISR 1” was the restart of most of the Japanese Nuclear power plants. The lifetime of the Japanese reactors was limited to 50 years (built after 1990), and to 40 years if built before 1990. (IEA 2012 p.190) This assumption had an implication on the potential restart in Japan, because some reactors will not restart according to the assumption. The strong increase of installed nuclear capacity is not only driven by the restarts in Japan, but due to the progressive nuclear development program in China, India and Korea. The main actor for the development in Asia is China, were most of the nuclear capacity will be added until 2020 and 2030.

According to the ISR 1 scenario by 2020 130 GWe will be operational. By 2025 the installed nuclear capacity will reach 152 GWe and by 2030 143 GWe.

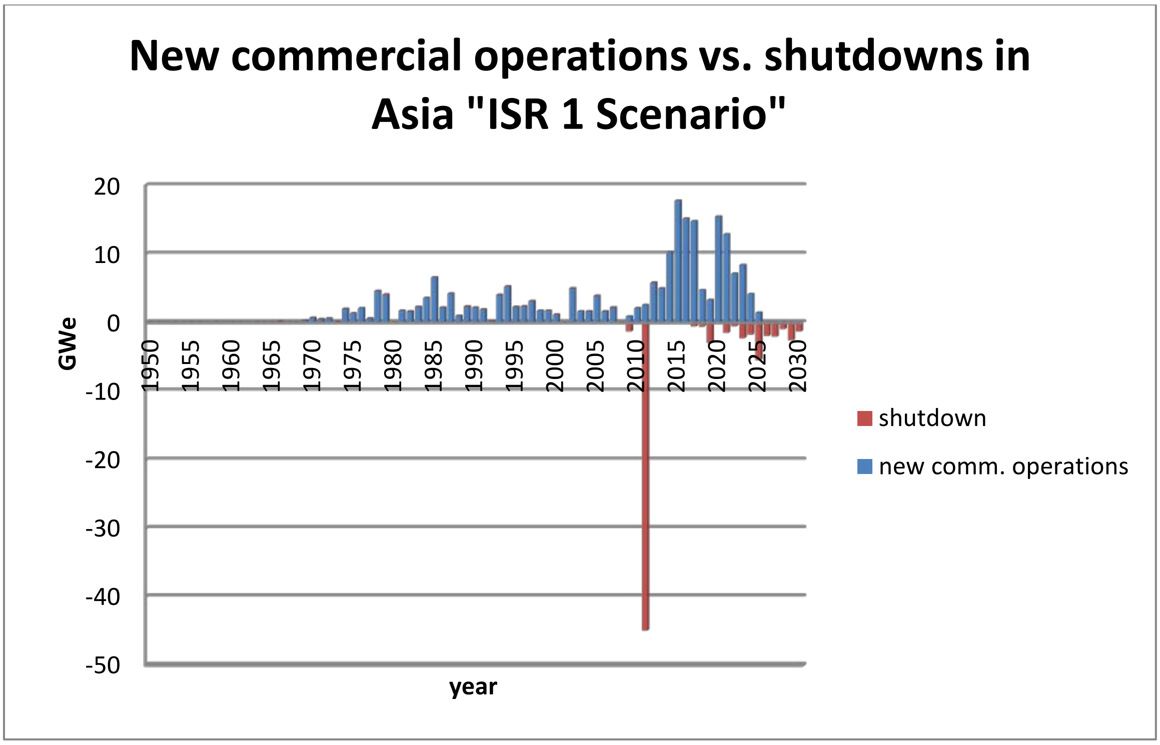


FIGURE 49: NEW COMMERCIAL OPERATIONS VS SHUTDOWNS IN ASIA "ISR 1 SCENARIO"

Figure 49 shows the impact of the Fukshima Daiichi nuclear accident. For the time period between 2020 and 2030 several shutdowns are scheduled according to the plans in 2013. More new NPPs are projected go online than shut down until 2030.

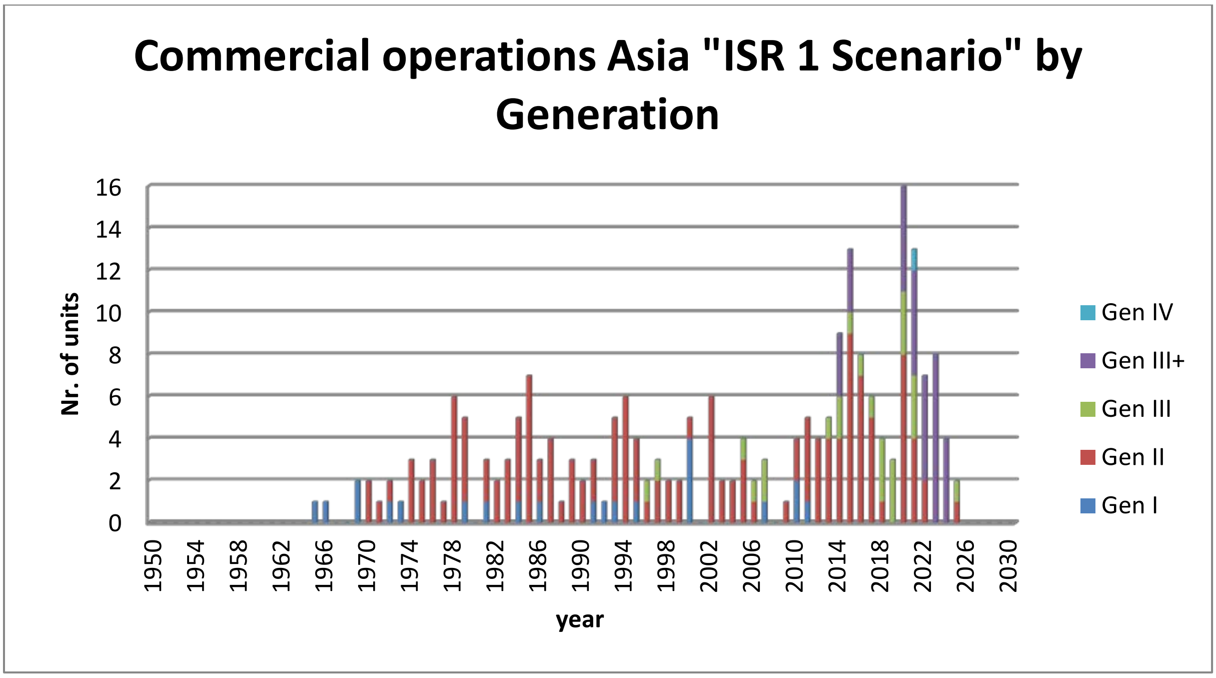
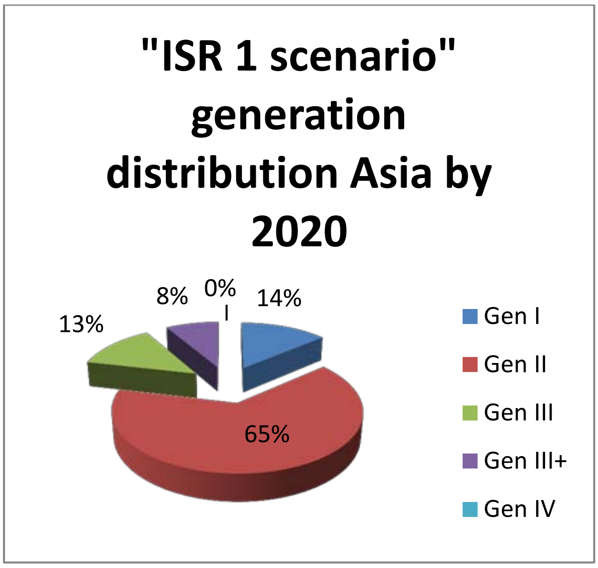


FIGURE 50: NEW COMMERCIAL OPERATIONS ASIA "ISR 1 SCENARIO" BY GENERATION

Until 2017 the new grid connected units will consist mainly of reactors from the second generation. A shift towards advanced generation reactors is visible from 2021 on.



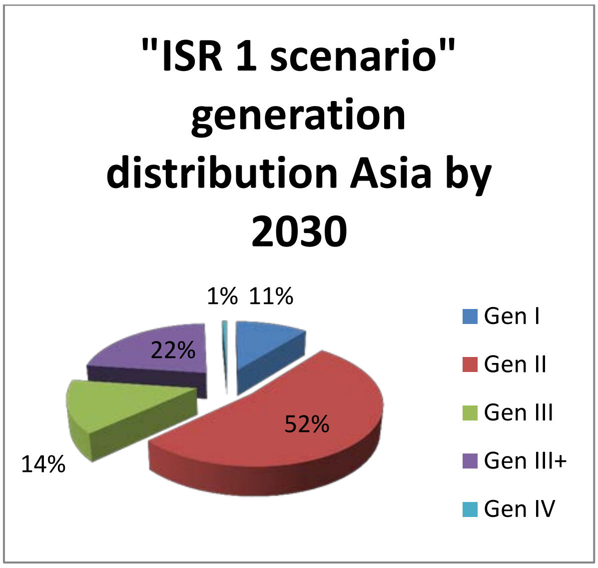


FIGURE 51: NUCLEAR POWER PLANTS DISTRIBUTION IN ASAI BY GENERATION IN 2020 AND 2030 "ISR 1 SCENARIO"

The distrubution of the generation in Asia is projected to shift from second generation units towards advanced generation units between 2020 and 2030. The majority of the operational reactors in 2030 are going to be reactors from the second generation. The share of reactors of the third generation and the third generation plus will rise to 14 respectively 22 percent. The share of reactors of the first generations will be reduced to 11 percent. The impact of the strong expansion of nuclear energy production on the share of advanced generation reactors is lower than might be expected.

3.3.5. NORTH AMERICA

The installed nuclear capacity in North America saw a strong increase in the 70´s and 80´s until 1990. Due to the strong growth in this time period North America, similar to Europe, can be described as traditional nuclear market. In 1970 the installed nuclear capacity was 5.8 GWe. In 1980 58.5 GWe and in 1990 119 GWe nuclear capacity was installed in North America. Between 1990 and 2000 there was a marginal decrease in the installed capacity from 119 GWe to 118 GWe, which continued until 2010 when 117 GWe were installed

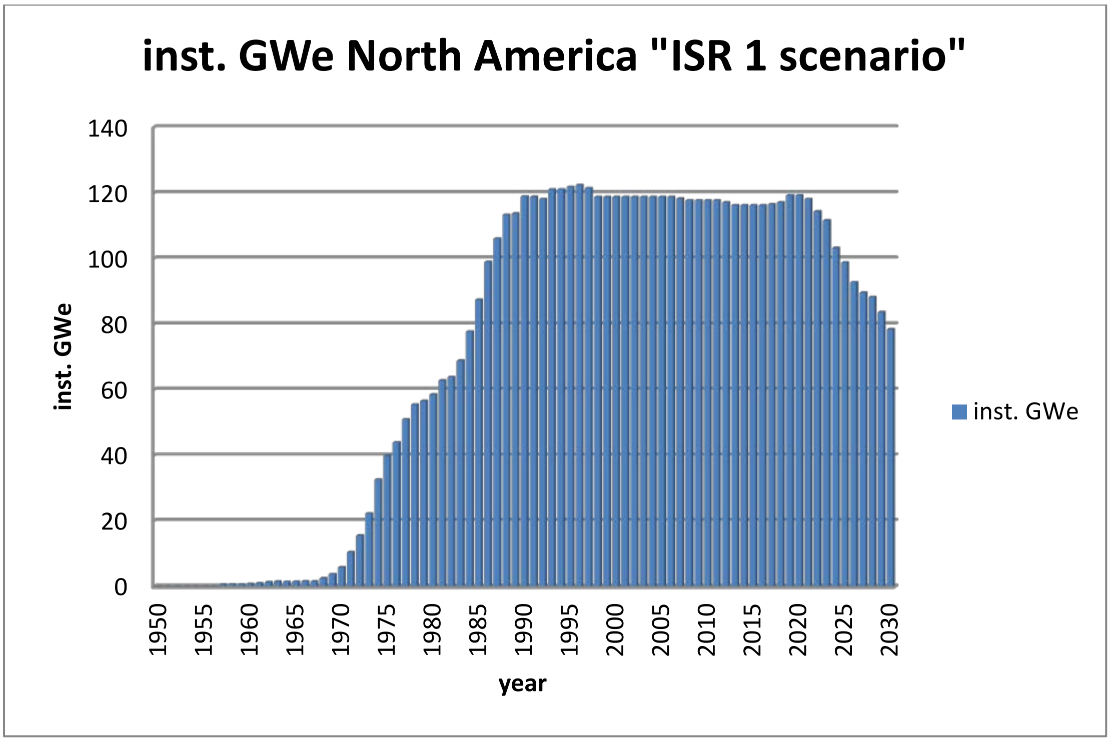


FIGURE 52: INSTALLED GWE NORTH AMERICA “ISR 1 SCENARIO”

The assumptions for North America are the following:

Reactors in North America will have a lifetime as publicly available in 2013. The plans for new added capacity are behind the schedule intended in 2010, and not all planned units will be constructed.

The assumptions lead to the projections for North America which indicate an increase of the installed nuclear capacity for 2020 to 119 GWe and a strong decrese from 2020 to 2030 to 78 GWe.

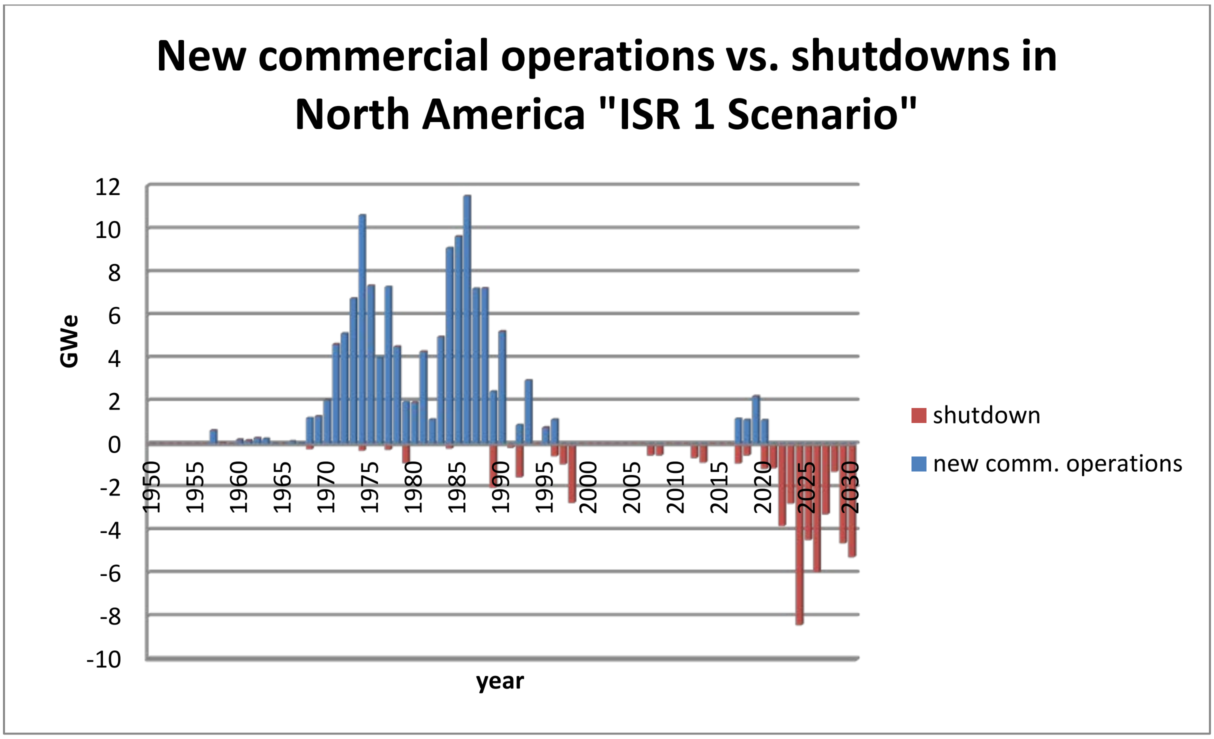


FIGURE 53: NEW COMMERCIAL OPERATIONS VS SHUTDOWNS IN NORTH AMERICA "ISR1 SCENARIO"

Two waves of the nuclear development can be observed in North America. In the beginning of the 70´s a peak of new grid connections is indicated in the graphic, and a second peak in the mid 80´s. Between 1995 and 2016 no nuclear reactors are to be built in North America. The discussion on a nuclear renaissance in North America was triggered in the first years of the new century, at a time when no nuclear power plants went operational since 1996. There are several shutdowns expected between 2020 and 2030. This leads to a strong decrease of installed nuclear capacity in North America.

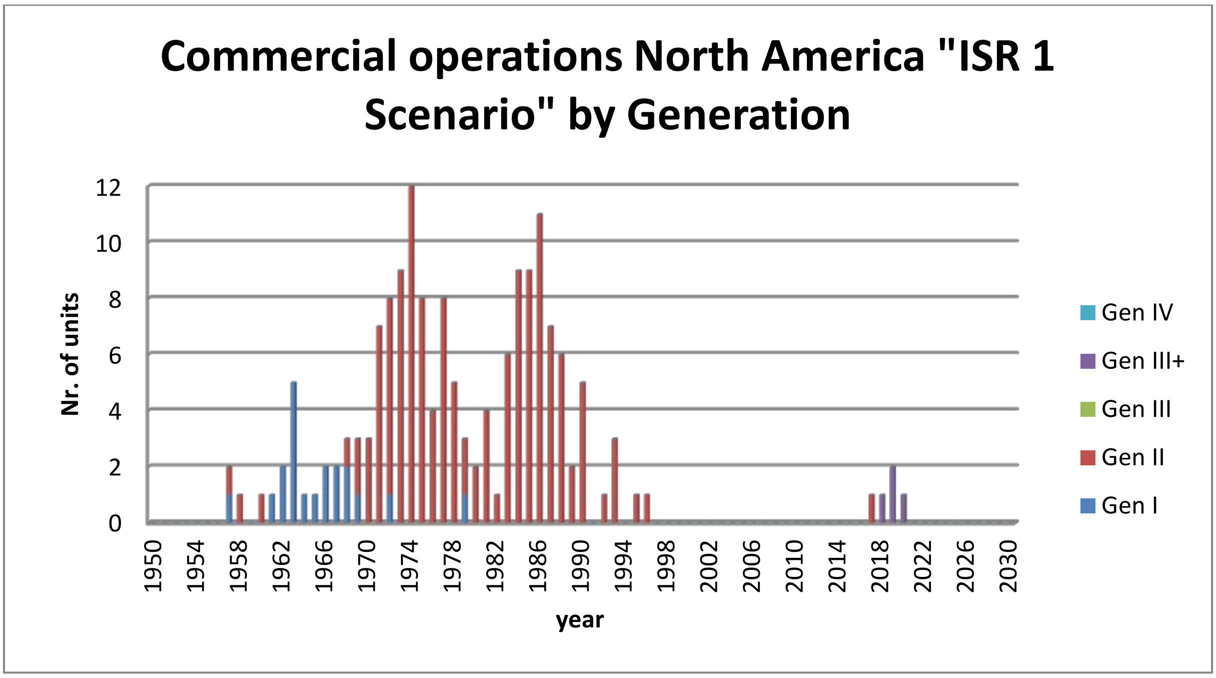
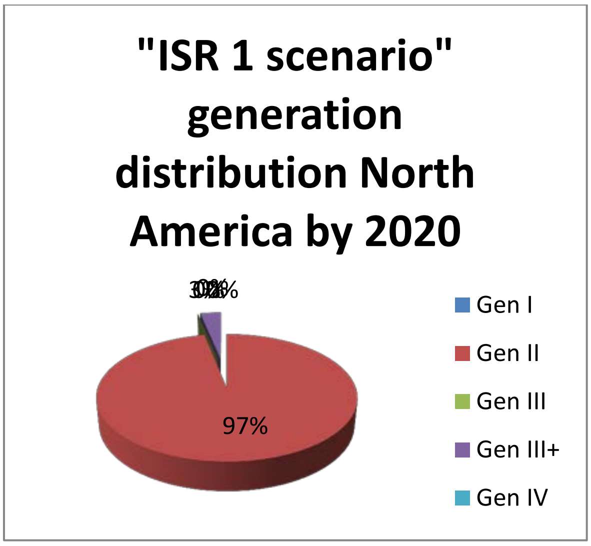


FIGURE 54: NEW COMMERCIAL OPERATIONS NORTH AMERICA “ISR 1 SCENARIO” BY GENERATION

The projections show that the reactors to be built in the second half of the 2010´s prevailingly will be advanced reactors. There is one Gen II reactors which will be operational by 2017, but all other new builts are Gen III+ reactors.



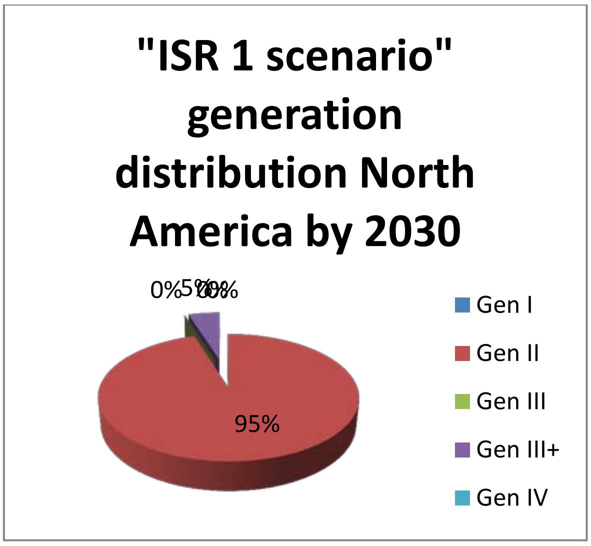


FIGURE 55: NUCLEAR POWER PLANTS DISTRIBUTION IN NORTH AMERICA BY GENERATION IN 2020 AND 2030 “ISR 1 SCENARIO”

The nuclear power reactor fleet in North America will be dominated by Gen II reactors. There will be no changes between 2020 and 2030. This special case can be explained by the equilibrium between new operations and shutdowns. Gen II reactors (95%) will be the majority of NPPs in North America. Advanced Reactors will only play a minor role in the scenario (5%).

3.3.6. SOUTH AMERICA AND AFRICA

South America and Africa will have no significant changes compared to 2010, and will therefore not be described in detail.

3.4. BEST POSSIBLE PRE FUKUSHIMA SCENARIO

One of the four scenarios is the best possible pre Fukushima Scenario. The main approach is described in section 2.4 and the principle limitations are highlighted in section 2.5.

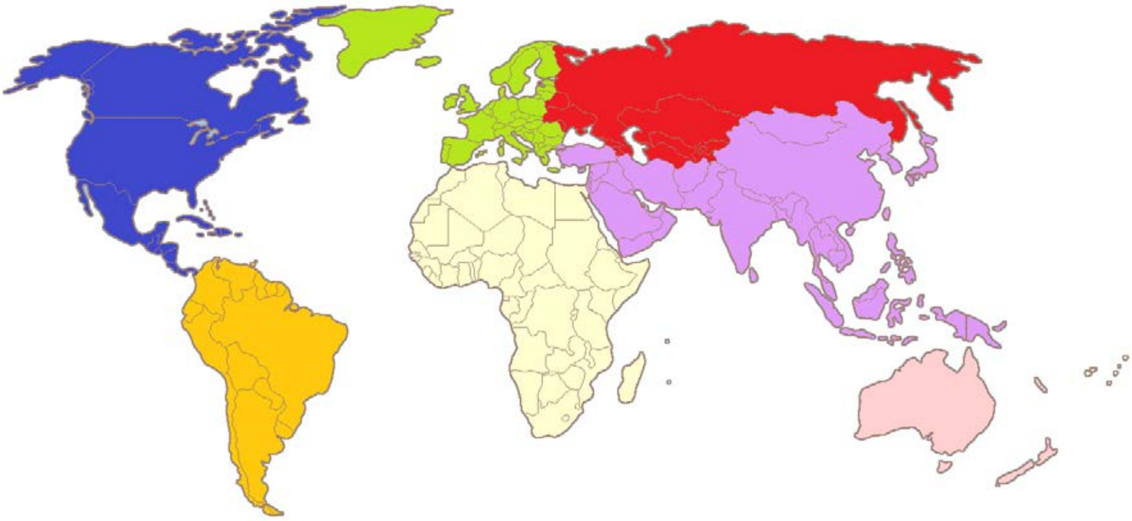


FIGURE 56: COLOURS PER REGIONS

The scenario was created before the accident at the Fukushima Daiichi nuclear power plant. The scenario is based on data extrapolation. All relevant available data regarding national nuclear development strategies are taken into account. The data, on which the scenario is based on, were taken from the published information by the WNA, the IAEA, and by country reports. Because one major assumption was, that the Fukushima accident did not happen, an additional dataset was created, where the EHNUR database was reset to February 2011. The main assumptions and the framework for the best possible pre Fukushima Scenario are:

- Fukushima never happened, and had therefore no implications for the global nuclear development
- Very ambitious national plans were taken into account
- No delays in the planning and construction phase
- Life time extension and long term operation for all reactors around the world up to 60 years
- No shortages by fuel and heavy component supply

Based on the assumptions summarized in the following infobox the best possible pre Fukushima Scenario was created, discussed and described on a global level.

Info Box: Background and assumption of the best possible pre Fukushima scenario
The basic assumption of the best possible pre Fukushima scenario is that the accident at the Fukushima Daiichi NPP did not occur, and a very strong global trend towards nuclear energy capacity increase as mentioned in the nuclear renaissance is presumed to happen. Data used for this scenario were extracted before and shortly after Fukushima. For this scenario mainly old data were used, in order to fulfill the requirement of a best pre Fukushima scenario. Europe: There are no delays in constructing and planning new nuclear power plants. The existing nuclear power plants built before 1980 will get the permission operate up to 60 years. The units built in 1980 or later will have a lifetime extension up to 80 years. Asia: There are no delays in construction and planning of NPPs in Asia. 4 years is the assumed construction time for a reactor. New reactors in Japan will be built in 6 years; in Korea it will take 5 years and 6 years in India. The Korean design in the UAE will be in commercial operation as scheduled, and up to 4 units will be build. CIS: The Russian nuclear program will be carried out as planned in 2010, with construction and planning in schedule. All Russian NPP of the second generation will have a lifetime of 80 years; the reactors from the first generation will have a lifetime of 50 years. The same assumptions are taken for the other CIS countries. North America: All reactors in North America will have a lifetime of 80 years. The plans for new added capacity are in time and will be finished as planned in 2010. South America: All reactors in South America will have a lifetime of 80 years. The plans for new added capacity are in time and will be finished as planned in 2010. Africa: All reactors in Africa will have a lifetime of 80 years.

3.4.1. GLOBAL

The best possible pre Fukushima scenario shows a strong growth of installed nuclear capacity from 2011 to 2020. As described in section 2.4 and 2.5 the quality of the available data is sufficient for projections until 2020, while decreasing towards 2030.

According to the scenario the global installed nuclear capacity in 2020 will be at 593 GWe. This is an increase of 56% compared to the year 2010. The increase of installed capacity from 1984 to 1988 was similar to this value with a 50% increase.

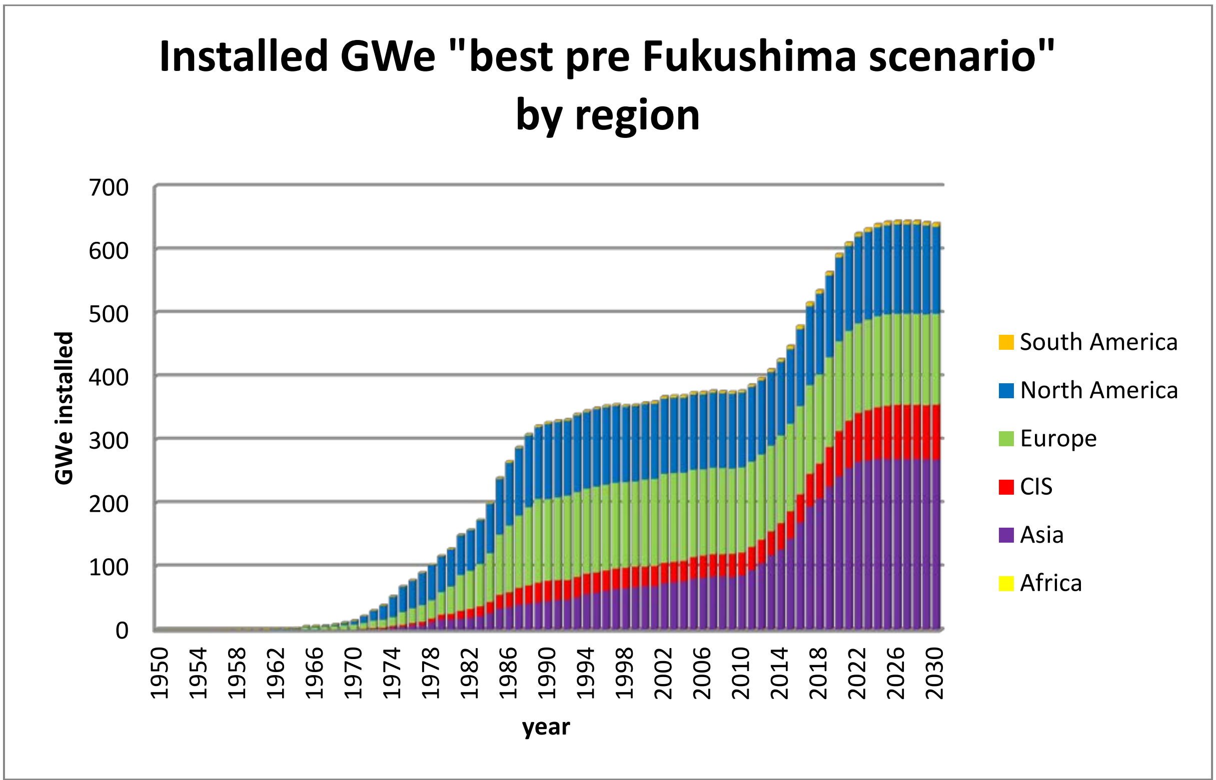


FIGURE 57: DEVELOPMENT INSTALLED NUCLEAR CAPACITY GLOBAL "BEST PRE FUKUSHIMA"

Figure 57 shows this increase. Further figure 57 clearly identifies the main drivers for this development. The "old traditional markets" Europe and North America have only a slight increase of installed nuclear capacity, the CIS region and Asia have a strong increase. The growth is triggered mainly by Asia and the CIS region.

South America will only have a slight increase of installed capacity, while the nuclear capacity in Africa will remain at the same level it was in 2010. The growth of installed nuclear capacity in the CIS region and in Asia can not only be observed in figure 57 but also in figure 58.

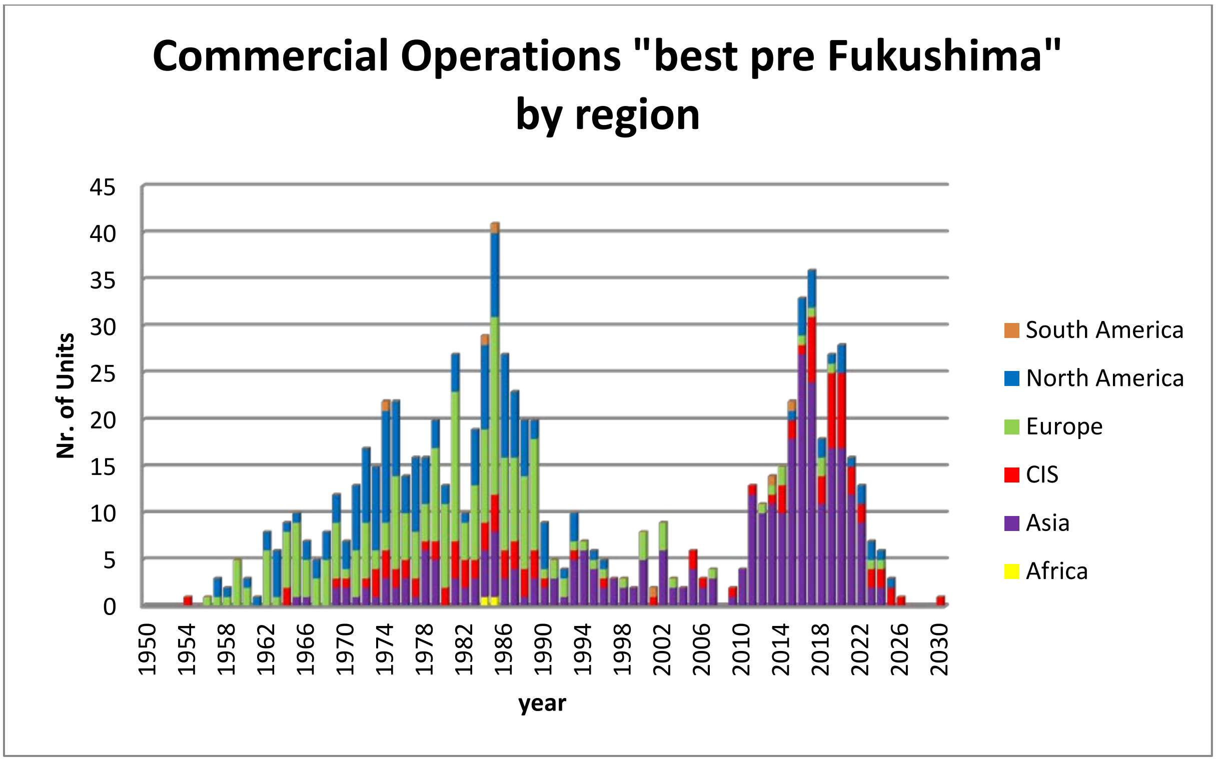


FIGURE 58: GRID CONNCETIONS GLOBAL “BEST PRE FUKUSHIMA” SCENARIO

Figure 58 shows the grid connections over a 80 year period. The best pre Fukushima Scenario indicates a strong raise of new grid connections in the time period between 2010 and 2020, similar to the development in the 70´s and 80´s. The main drivers for that development are located in Asia and in the CIS region.

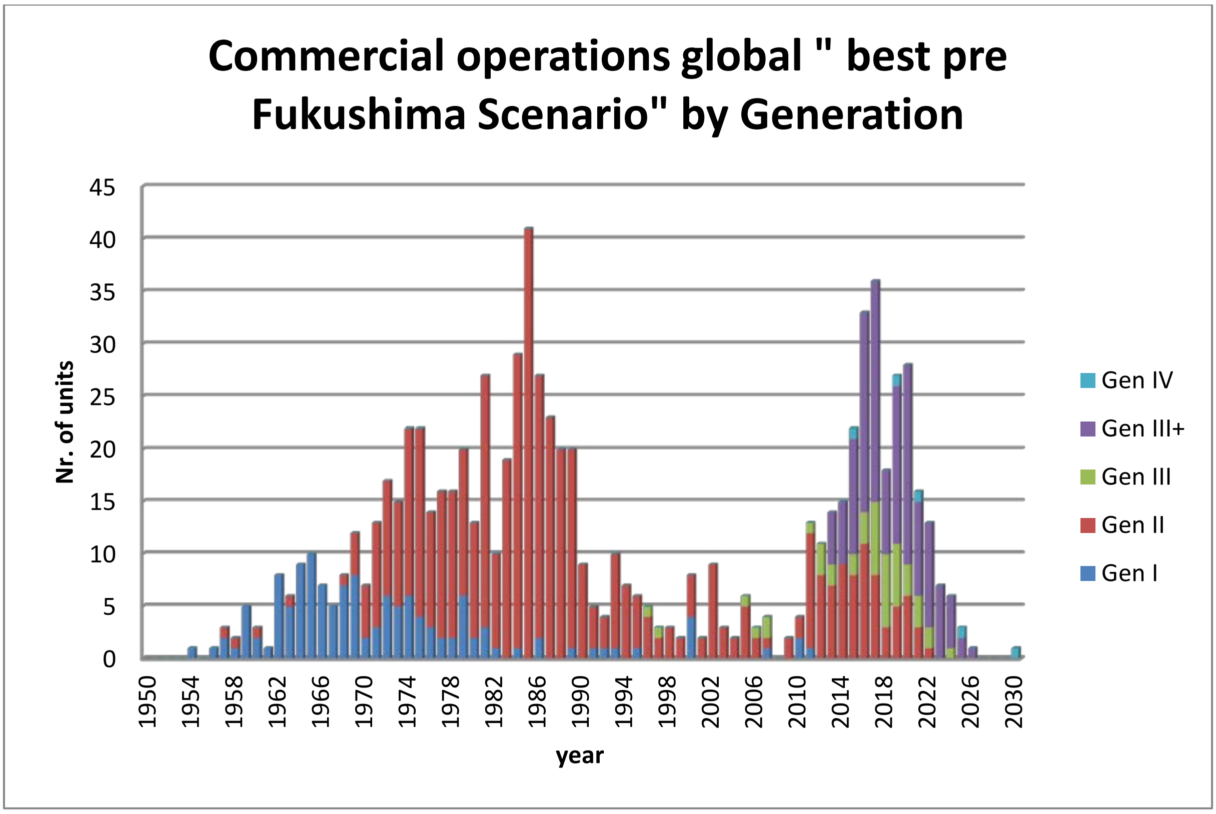
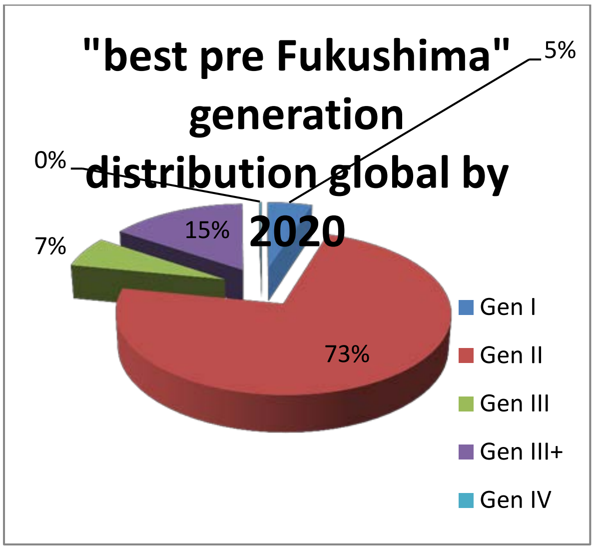


FIGURE 59: GRID CONNECTIONS GLOBAL "BEST PRE FUKUSHIMA" BY GENERATION

One promise of the nuclear renaissance was that the renaissance will rely on and will be driven by new designs of nuclear power plants. (McLellan, 2008) The new designs can be subsumed as Gen III, Gen III+ and Gen IV reactors. According to the international plans gathered in figure 59, a trend towards new reactors can only be observed after 2015. Up to the year 2017 the central drivers for the expansion are Gen II nuclear power plants. From 2017 on, the majority of new nuclear power plants are NPPs of Gen III or Gen III+.



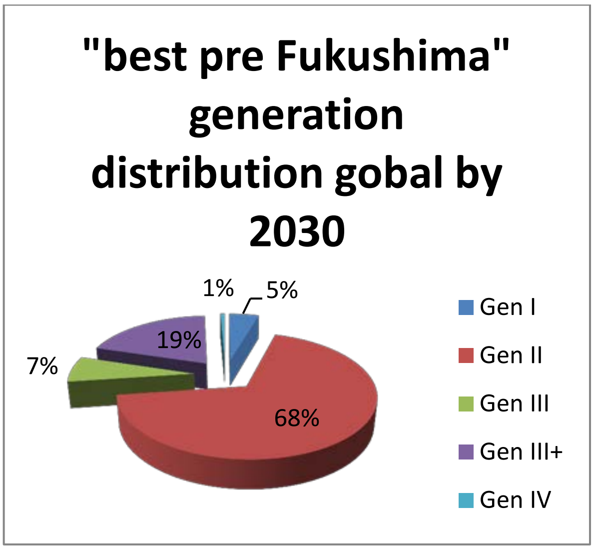


FIGURE 60: NUCLEAR POWER PLANTS DISTRIBUTION BY GENERATION IN 2020 AND 2030 "BEST POSSIBLE PRE FUKUSHIMA SCENARIO"

By 2020 only 22% of the global nuclear power reactor fleet will consist of NPPs from the so called new generation. The major part will consist of Gen II reactors with 74%. 5% of the operational reactors are projected to be Gen I reactors, almost the same amount as Gen III reactor. (see figure 60). By 2030 the picture does change only slightly compared to 2020. The share of Gen II reactors decreases to 68%, while the share of advanced reactors increases to 26%. Gen I reactors remain at a stable level of 5%. Gen IV reactors will play only a marginal role.

3.5. ISR 2 SCENARIO

One of the four scenarios is the ISR 2 Scenario. The main approach is described in section 2.4 and the principle limitations are highlighted in section 2.5.

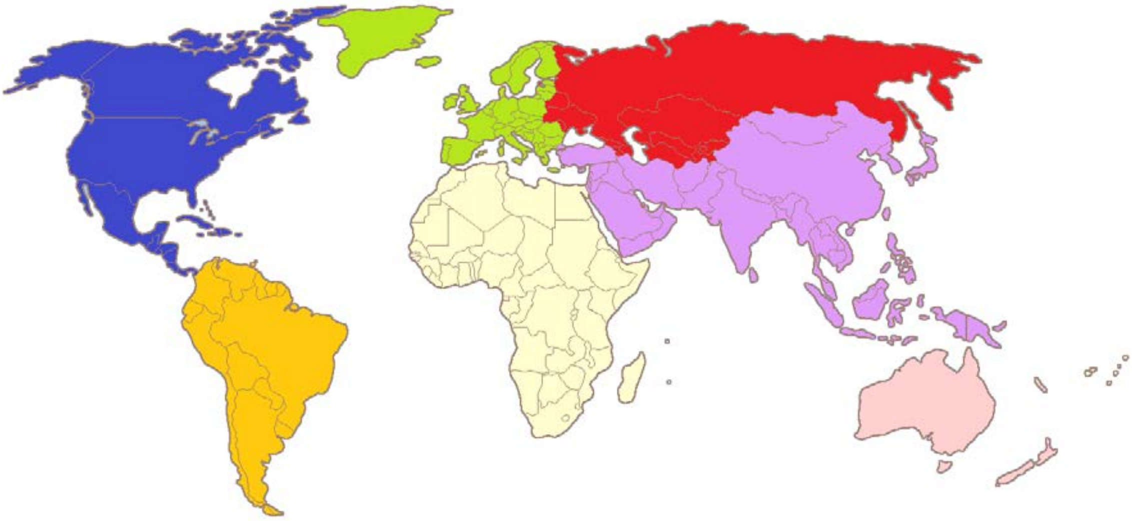


FIGURE 61: COLOURS PER REGIONS

The scenario is based on data extrapolation. All relevant available data regarding national nuclear development strategies are taken into account. The data, on which the scenario is based on, were taken from the published information by the WNA, the IAEA, and by country reports. The main assumptions and the framework for the best possible pre Fukushima Scenario are:

- Fukushima had implications for the global nuclear development
- The national development plans were reviewed and taken into account
- Several delays in the planning and construction phase
- Life time extension and long term operation for all reactors on a country by country base
- No shortages by fuel and heavy component supply

Based on the assumptions summarized in the following infobox the ISR 2 Scenario was created and discussed and described on a global level.

Info Box: Background and assumption of ISR 2 scenario
The basic assumption of the ISR Scenario 2 is that the accident at the Fukushima Daiichi NPP occurred, and that the accident influences the global nuclear market in a moderate way. The influence is very different from region to region, but the global trend towards new nuclear power plants is alive, although weaker than in the best post Fukushima Scenario. Europe: Germany will phase out as decided in 2011. Belgium and Switzerland will follow their strategy to phase out and not to replace existing capacities. New constructions and planned units will have a significant delay before starting commercial operation. The existing nuclear power plants built before 1980 will get the permission to operate for 40 years. The units built in 1980 or later will have a lifetime extension up to 50 years. Asia: Deferred reactor plans in China inland will start construction in 2015-16, with up to 2 units built at the same time at the same site. 6 years is the assumed construction time for a reactor in China, if detailed information is not available. New reactors in Korea it will take 6 years and 7 years in India. The Korean design in the UAE will be in commercial operation later than scheduled. Japan will build no new NPPs. Fukushima Daiichi, Fukushima Daiini, and other NPPs damaged by the earthquake will be decommissioned. All other units restart operation starting by 2014 over a period of 4 years. The lifetime of the Japanese reactors will be limited to 50 years if built after 1990, and to 40 years if built before 1990. (IEA 2012 p.190) CIS: The Russian nuclear program will be carried out as planned in 2010, with construction and planning behind schedule. Russian NPP of the second generation will have a lifetime of 50 years; the reactors from the first generation will have a lifetime as planned in 2013. The same assumptions are taken for the other CIS countries. North America: Reactors in North America will have a general lifetime of 60 years, but some reactors will have a shorter lifetime than stated in 2010. The plans for new added capacity are behind the schedule intended in 2010, and not all planned units will be constructed. South America: All reactors in South America will have a lifetime of 40 years. The plans for new added capacity are behind the schedule intended in 2010. Africa: All reactors in Africa will have a lifetime of 40 years. The plans for new added capacity are behind the schedule intended in 2010.

3.5.1. GLOBAL

The ISR 2 scenario shows an increase of installed nuclear capacity between 2011 and 2020. As described in section 2.4 and 2.5 the quality of the available data is sufficient for projections until 2020, while decreasing towards 2030.

According to the scenario the global installed nuclear capacity in 2020 will be at 409 GWe net. This is an increase of around 40 GWe to 2010. Figure 62 shows this increase. Further figure 64 clearly identifies the main drivers for this development. The "old traditional markets" Europe and North America see only a slight increase of installed nuclear capacity, the CIS region and Asia experience a stronger increase. The growth is triggered mainly by Asia and the CIS region.

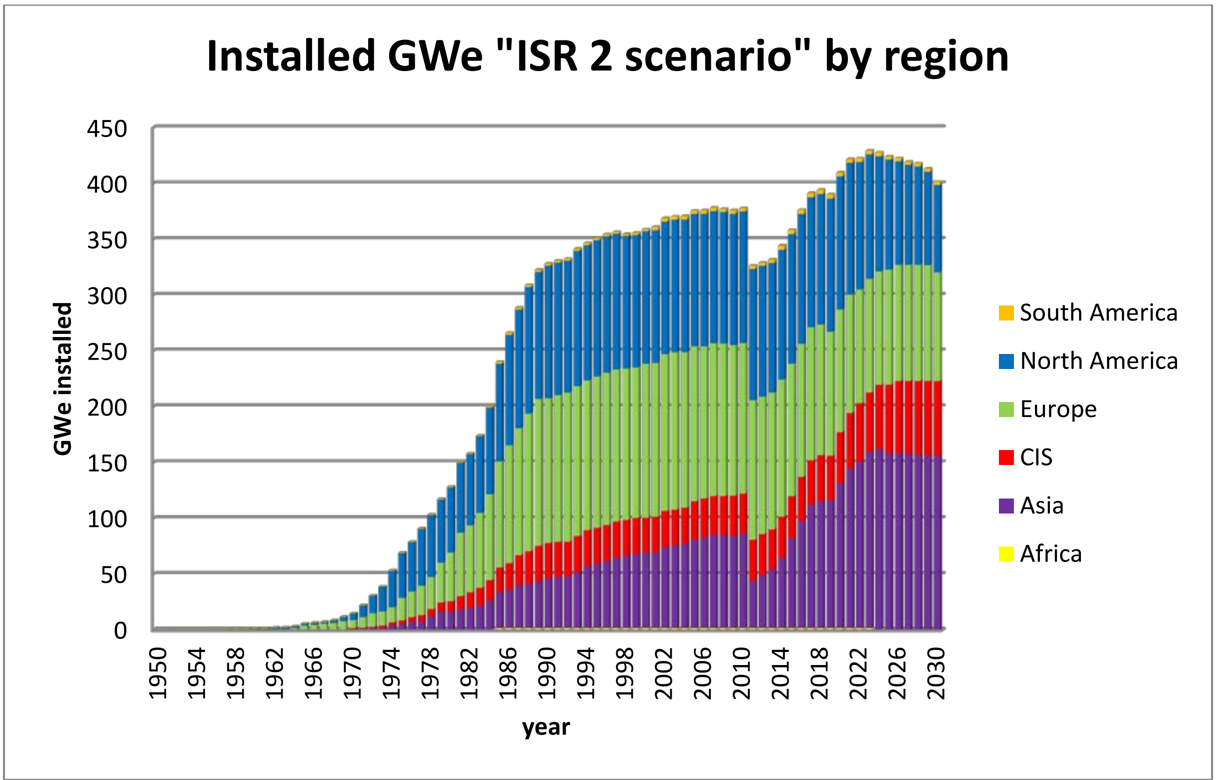


FIGURE 62: DEVELOPMENT INSTALLED NUCLEAR CAPACITY GLOBAL "ISR 2 SCENARIO"

The scenario assumes the peak of installed nuclear capacity to be reached in 2022. Due to the phase out of several reactors according to the scenario assumption the installed capacity will decrease until 2030 to 401 GWe. The growth of installed nuclear capacity in the CIS region and in Asia can not only be observed in figure 62 but also in figure 63.

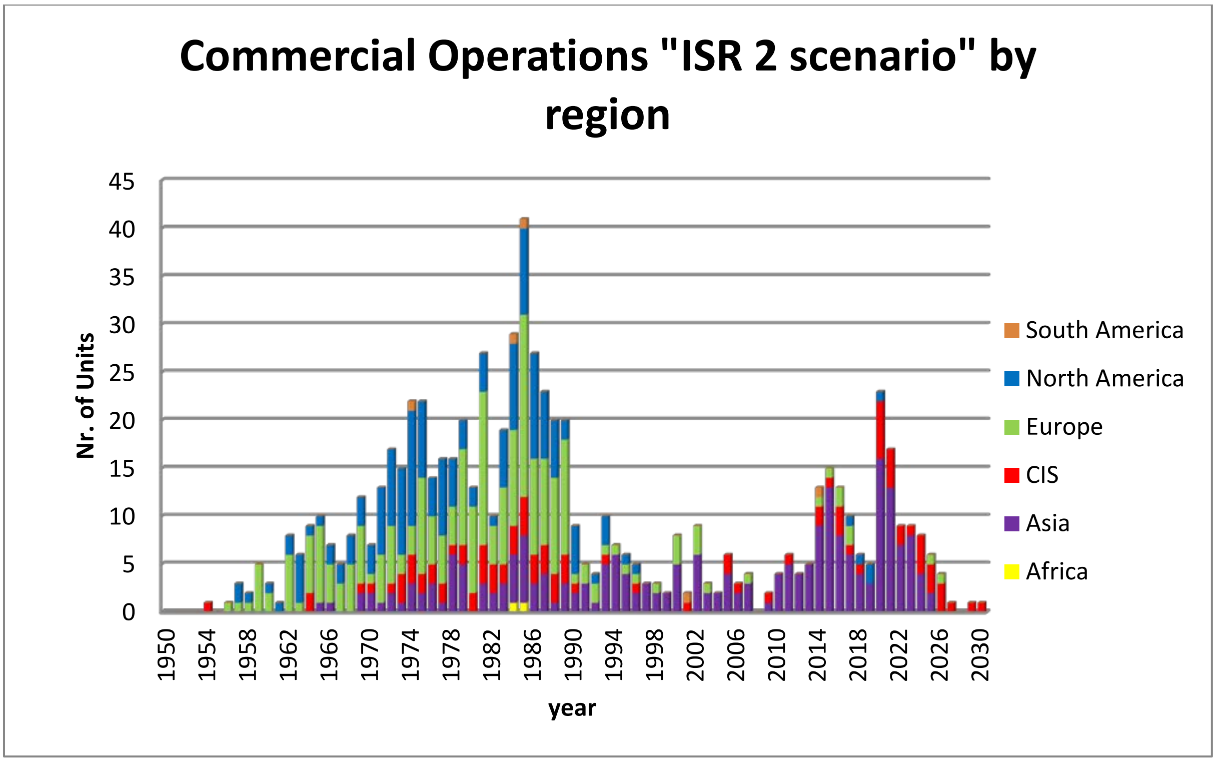


FIGURE 63: GRID CONNECTIONS GLOBAL "ISR 2 SCENARIO"

Figure 63 shows the grid connections over an 80 year period. The figure clearly indicates the nuclear markets of the future. New reactors will be grid connected and will go operational prevailingly in Asia and the CIS region.

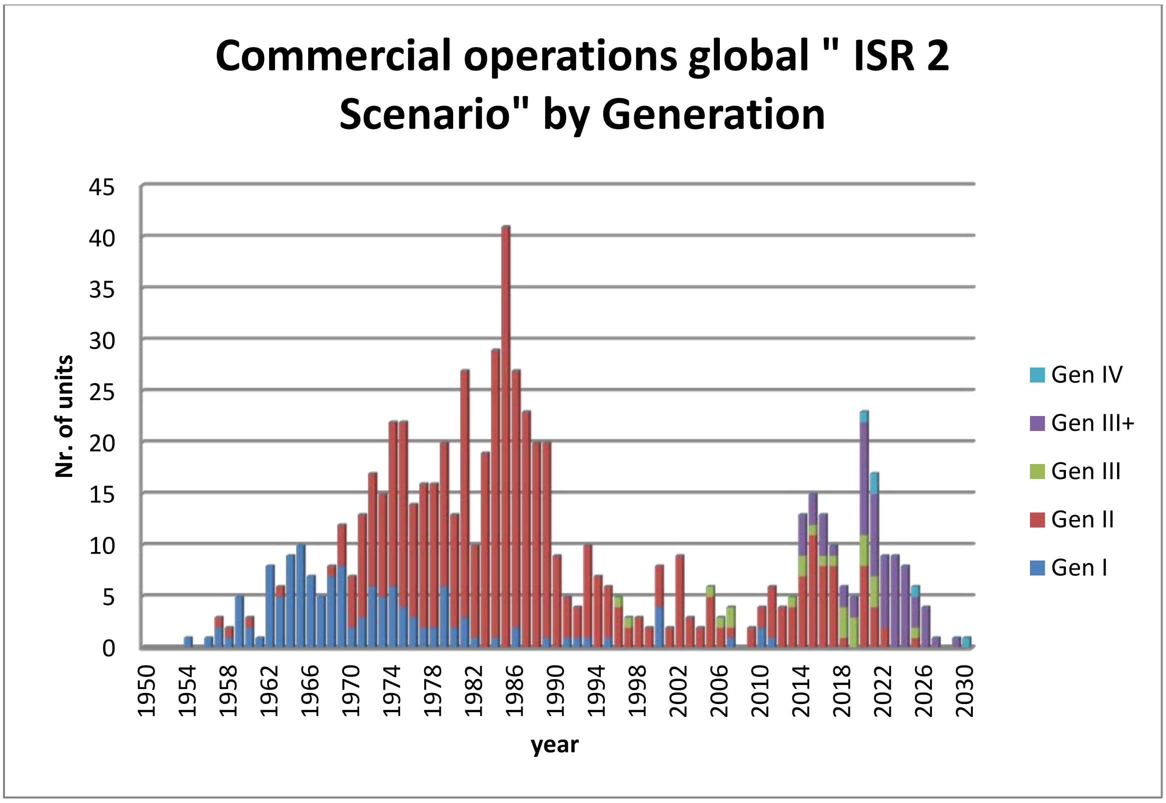
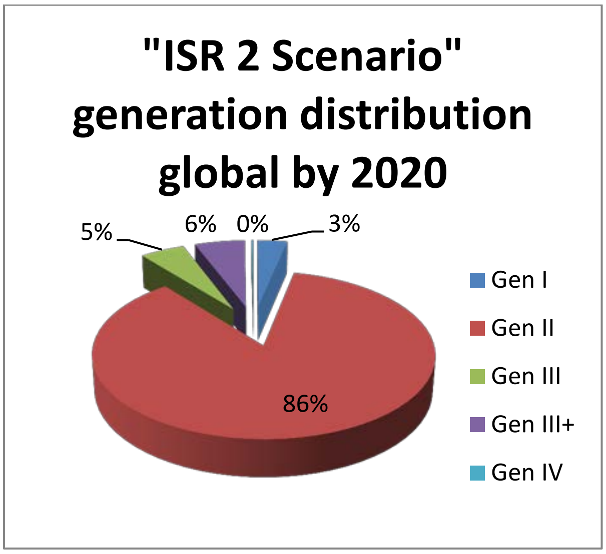


FIGURE 64: GRID CONNECTIONS GLOBAL “ISR 2 SCENARIO” BY GENERATION

Figure 64 indicates that from 2017 on, the majority of new operaitonal reactors are going to be nuclear power plants from advanced generations. The number of new grid connections will not reach the numbers of the 1970s and 1980s.



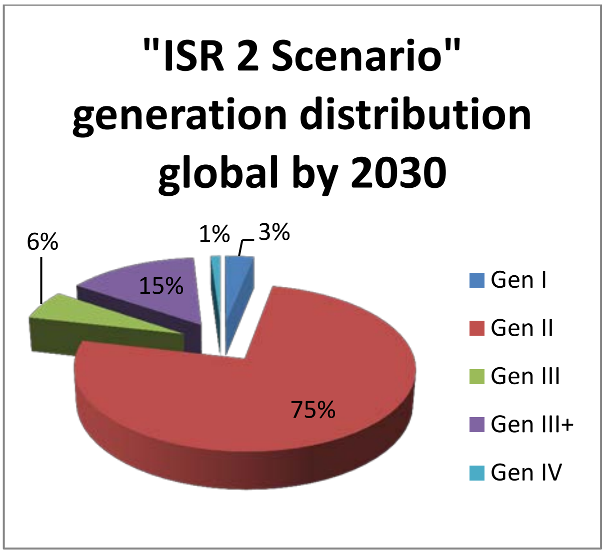


FIGURE 65: NUCLEAR POWERPLANTS DISTRIBUTION BY GENERATION IN 2020 AND 2030 “ISR 2 SCENARIO”

The distriubution by generation will not change significantly. The changes that can be observed are driven by the shutdown of older units and the new grid connections after 2017. By 2020 only 11% of the global nuclear power reactor fleet will consist of NPPs from the so called new generation. The major part will consist of Gen II reactors - 86%. 3% of the operation reactors are going to be Gen I reactors.

By 2030 the picture changes slightly. The major part of operational reactors are going to be reactors of the second generation (75%). Advanced generation reactors will contribute 21% to the global share. Gen IV reactors will contribute 1%, which is less than Gen I reactors (3%).

4. RESULTS

The four scenarios created within the project show a large spectrum on how the future development of installed nuclear capacity could be at a global level. The identified six crucial factors (change of national nuclear development strategies, constructions delays, planning delays, national strategy for LTO and lifetime extension, national strategy for phase out) for future nuclear development and its different specifications in each scenario created a broad approach towards the projections of the future installed nuclear capacity. Table 17 summarizes the different assumptions for the scenarios.

TABLE 17: COMPARISON INDICATORS EHNUR SCENARIOS

	Best pre	Best post	ISR Scenario 2	ISR Scenario 1
Change of national nuclear development strategies	None	Weak	Moderate	Moderate
Construction delays	None	Weak	Moderate	Strong
Planning delays	None	Weak	Moderate	Strong
National strategy for LTO and life time extension	None	Weak	Moderate	Strong
National strategy for Phase out	None	Weak	Moderate	Strong
Construction and planning stops	None	Weak	Moderate	Strong

The impacts of the different assumptions on the installed global nuclear capacity are shown in figure 66. The different starting points in the year 2011 are due to the accident at the Fukushima Daiichi nuclear power station in 2011. As the best pre Fukushima scenario is based on the assumption that the accident at Fukushima did not occur the starting point in 2011 is much higher than in the other scenarios.

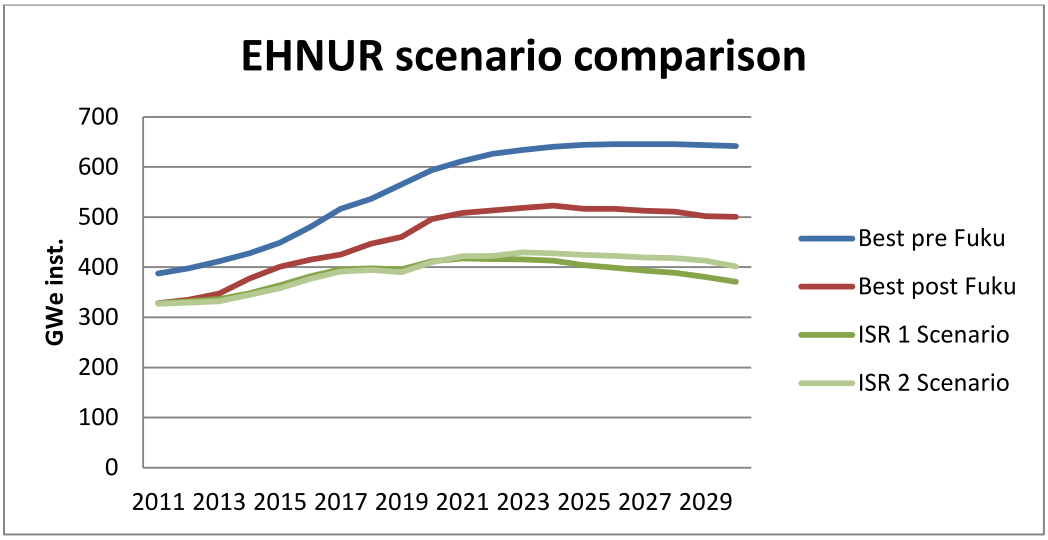


FIGURE 66: EHNUR SCENARIO COMAPRIOSN

The best pre Fukushima scenario indicates a strong growth of installed nuclear capacity between 2010 and 2020 from 378 GWe to 593 GWe an increase of 56.9%. The best post Fukushima scenario indicates a development from 378 GWe in 2010 to 496 GWe in 2020, which is an increase by 31.2%. The ISR scenarios also indicate a growth of installed nuclear capacity between 2010 and 2020. The ISR 1 scenario projects an increase of installed capacity by 8.8% reaching 411 GWe in 2020. ISR 2 scenario indicates an increase by 8.3% up to 409 GWe in 2020. The graph in figure 66 includes the restarts of the temporary shutdown reactors in Japan, and therefore the incline of installed capacity looks deceptively strong. The ISR scenarios project an increase of installed capacity by 41-43 GWe compared to the year 2020.

All scenarios indicate an increase of installed nuclear capacity until 2020. The grade of increase is fluctuating severely depending on the scenario assumptions. The strongest increase between 2010 and 2020 in the after Fukushima scenarios is about 120 GWe in the best post Fukushima scenario. The weakest increase can be observed in the ISR 2 scenario with 41 GWe.

TABLE 18: COMPARISION PROJECTED INSTALLED NUCLEAR CAPACITY EHNUR SCENARIOS

	Best pre	Best post	ISR Scenario 2	ISR Scenario 1
2020	593	496	409	411
2025	644	516	424	403
2030	641	500	401	370

The comparison of the development of installed nuclear capacity until 2025 indicates an increase of installed nuclear capacity in three of the four scenarios. The best pre Fukushima scenario shows an 8.5% increase between 2020 and 2025, the best post Fukushima scenario an increase of 4.1% and the ISR 2 Scenario an increase of 3.5% of the installed nuclear capacity. The ISR 1 scenario indicates a decrease of 1.8% of the installed capacity.

For the year 2030 all post Fukushima scenarios demonstrate a decrease of installed nuclear capacity between 2020 and 2030. The ISR 1 Scenario indicates a decrease below the level in 2010. The best post Fukushima and the ISR 2 scenario are significantly respectively slightly above the level in 2010. Only the best pre Fukushima scenario foresees an increase between 2020 and 2030, although suffering a slight decrease between 2025 and 2030. The decrease was partially expected due to selected method for the scenario development (see section 2.4).

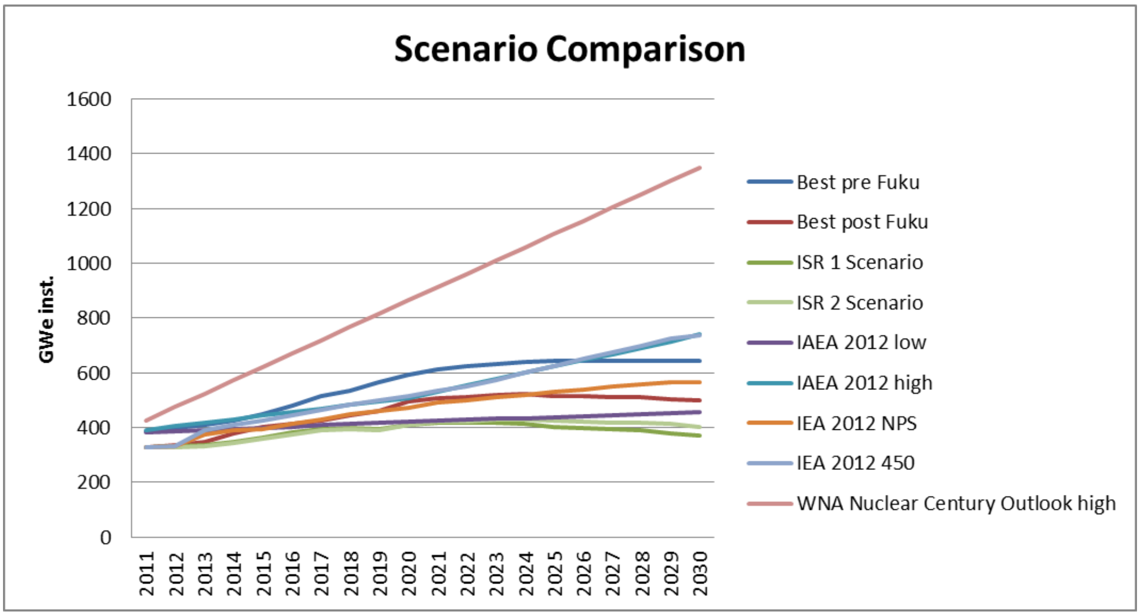


FIGURE 67: EHNUR SCENARIO COMPARISON WITH INTERNATIONAL PROJECTIONS 1

Figure 67 illustrates the comparison of the scenarios created in the EHNUR project with international projections and scenarios. The selected scenarios for the comparison are scenarios from the IAEA and the IEA created in the second half of the year 2011 and taking into account the accident at the Fukushima Daiichi nuclear power station. The WNA outlook was published in 2008. The WNA Nuclear Century Outlook High is a very optimistic scenario which is far above all other projections. It reflects the nuclear potential on a global level, at a time when the discussion on a nuclear Renaissance was at its peak. The graphs of the IAEA, IEA and WNA projections shown in the figures were extracted from the literature and extrapolated linearly. As the WNA projection is far above all other projections, for an easier handling figure 68 shows the comparison of the EHNUR scenarios with the IAEA scenarios.

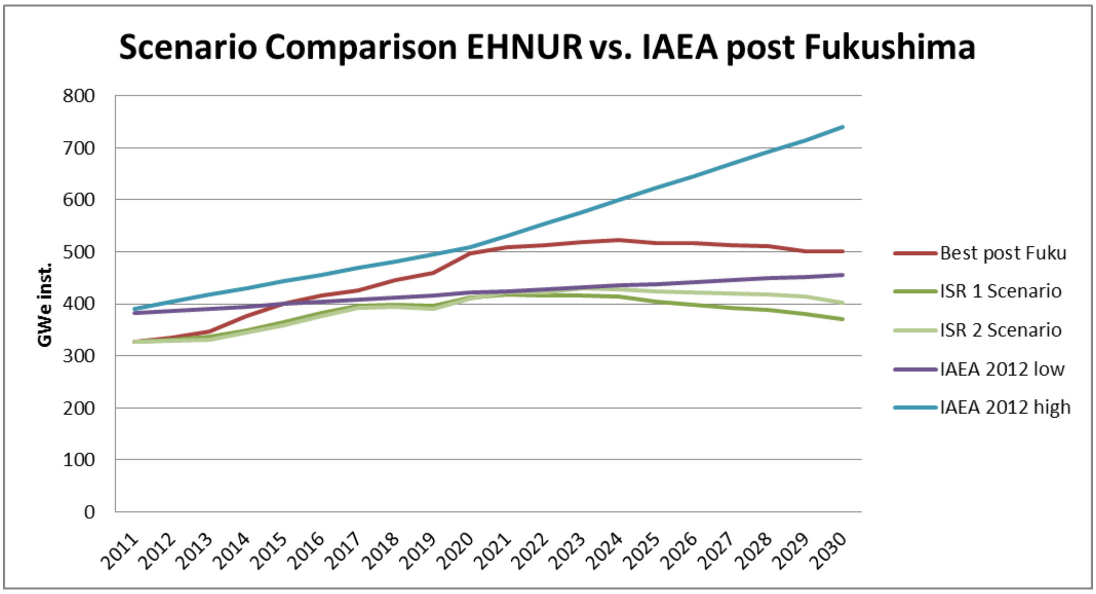


FIGURE 68: EHNUR SCENARIO COMPARISON WITH INTERNATIONAL PROJECTIONS 2

The comparison shows similarities between the IAEA 2012 low scenario and the ISR scenarios until 2020. The IAEA high scenario and the best Fukushima are similar regarding the development growth towards the year 2020. The gap opening between 2020 and 2030 can be explained by the methodology and the different assumption on shutdowns of reactors. The development path of the IAEA low scenarios is similar to the ISR scenarios, which is an indicator that the database is valid and the results are reliable and significant.

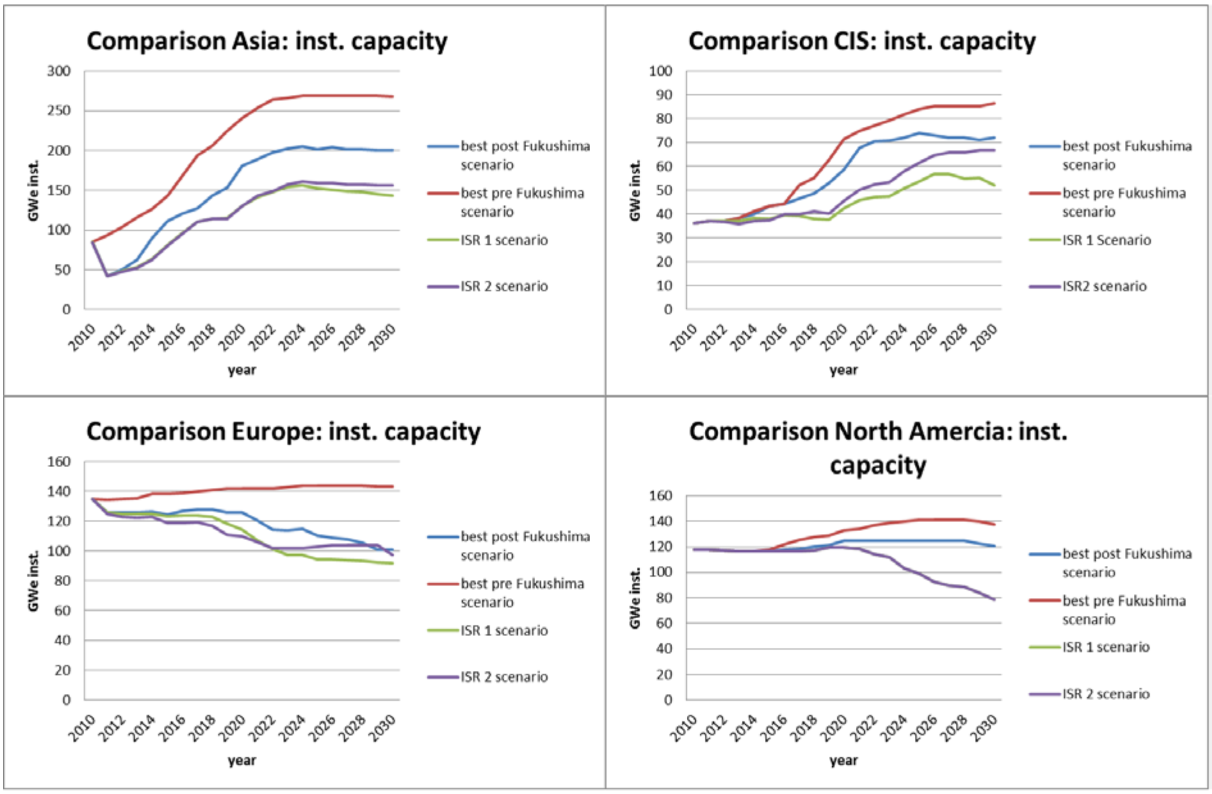


FIGURE 69: EHNUR SCENARIO COMPARISON ON A REGIONAL LEVEL

Figure 69 shows the different scenarios for the different regions of the world. Africa and South America are excluded due to the low installed nuclear capacities and due to the fact that no significant changes in the capacity are expected for 2020 and 2030.

The regional development in Asia and Europe between 2010 and 2011 demonstrate the impact of the accident at the Fukushima Daiichi nuclear power plant. The difference between the best pre Fukushima and the other scenarios is significant. The future development of the two regions is different. While the trend for Asia shows a strong increase of installed nuclear capacity, the trend in Europe is diverse.

The figure indicates that Asia and the CIS region will have an increase of installed nuclear capacity, Europe will have a decrease and North America will remain on the level of 2010 or have a decrease, but no increase is shown.

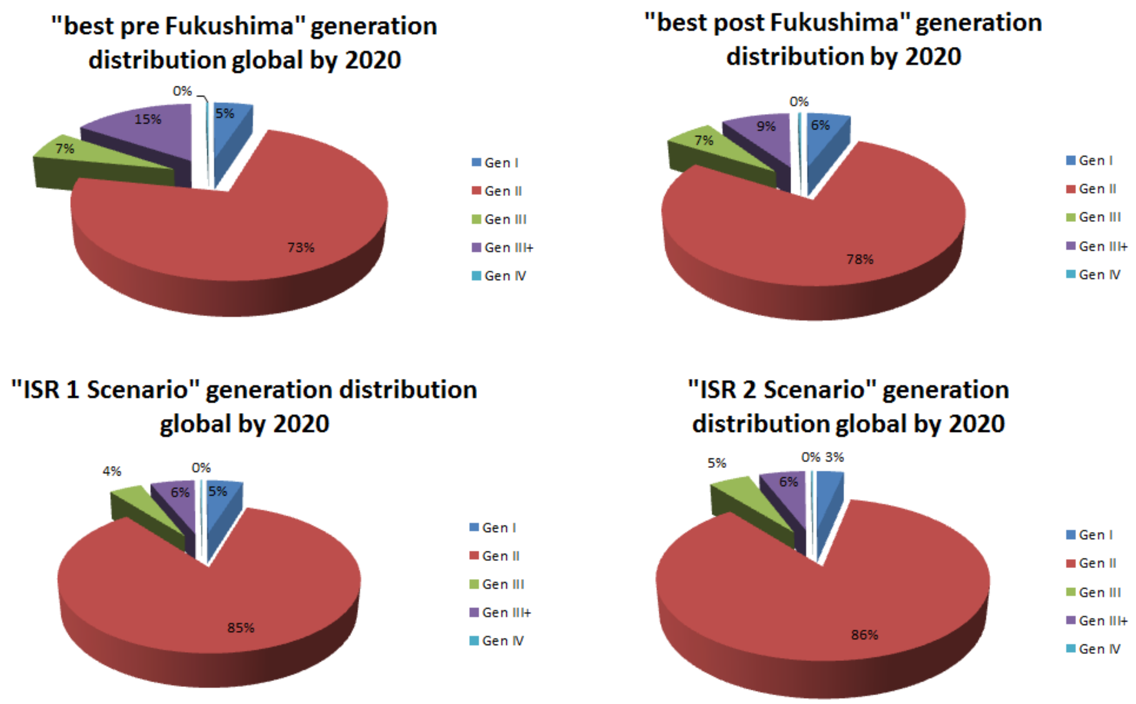


FIGURE 70: EHNUR GENERATION DISTRIBUTION COMPARISON BY 2020

The global power reactors fleet in 2020 will be dominated by Gen II reactors. The differences between the different scenarios are visible, but not significant. The scenarios project that the share of Gen II reactors in 2020 will be between 73% and 86%. Reactors of the first generation will be between 3 and 6%. Advanced reactor designs (Gen III and Gen III+) will have a share between 10 and 22% depending on the scenario. Gen IV reactors will not play any role in 2020.

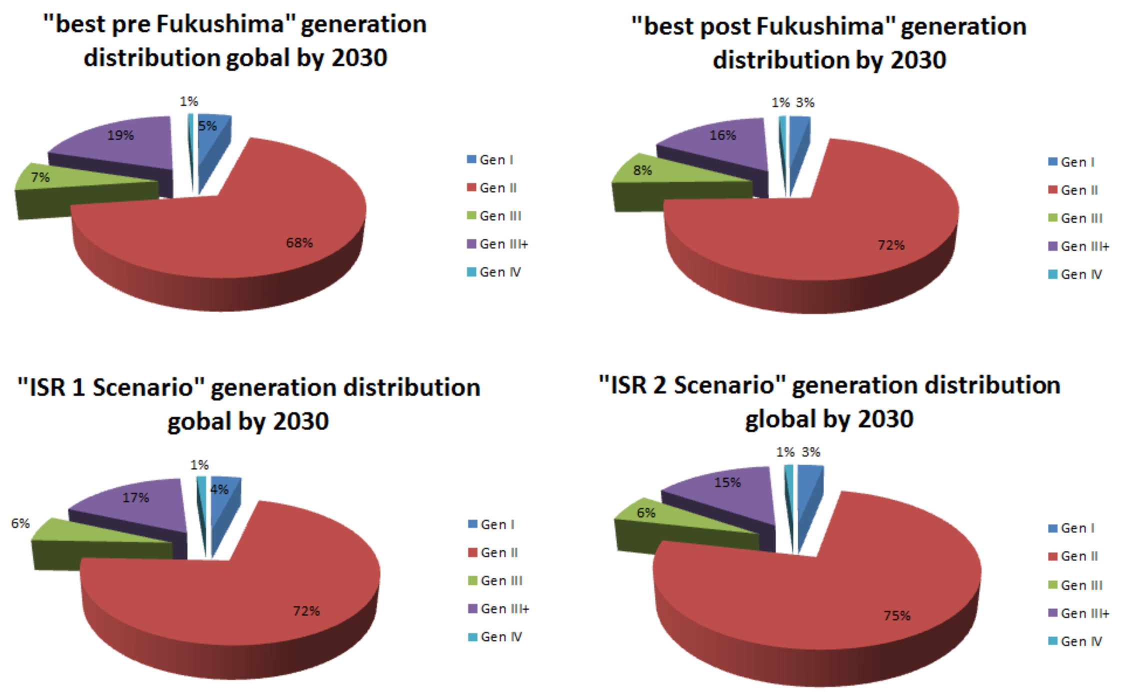


FIGURE 71: EHNUR GENERATION DISTRIBUTION COMPARISON BY 2030

Changes in the shares of reactor generations between 2020 and 2030 can be observed, but in all scenarios the power reactors fleet will heavily depend on Gen II reactors. The share of second generation reactors is between 68% and 75%. Gen III and Gen III+ reactors´ share will be between 21% and 26% of the nuclear power reactors fleet. Gen I reactors will add between 3 and 5% to the nuclear reactor fleet. Gen IV reactors play only a marginal role in 2030.

5. CONCLUSION

Starting from the late 1950´s nuclear energy production entered the electricity markets. Until the mid-1980´s more and more nuclear power stations went online around the globe. The nuclear industry at that time was focused mainly on Europe and North America. In 1979 the accident at Three Mile Island (TMI) nuclear power station raised the awareness of the public that nuclear power plants can suffer accidents, which could affect the surrounding areas. TMI had an impact on the nuclear industry (Char and Csik, 1987) by increasing the concerns of the public regarding the nuclear safety issues. The public acceptance decreased. Simultaneously, the capital costs necessary to build a new nuclear power plant increased (partly due to increased requirements of the licensing and partly due to increased construction times), so that the interest of the utilities to invest in new reactors decreased. The Chernobyl accident in 1986 had severe implications on the global nuclear landscape and the global nuclear market. After Chernobyl the number of new nuclear power plants ordered decreased strongly. Between 1990 and 2005 only a few new nuclear power stations were completed and went operational.

In the early years of the new century the discussion on a nuclear renaissance started. (McLellan, 2008). The discussion on a nuclear renaissance was triggered by the discussion on global warming and greenhouse gas emissions (Wang and Hansen, 2007). The nuclear industry was seeking to create a new – more positive – image and role for nuclear power. McLellan (2008) summarizes the indicators for a nuclear Renaissance with improved performance and reduced construction costs and construction time for new nuclear power plant designs. He focuses on the situation on the US and in Canada around the year 2005. At that time the discussion on the nuclear Renaissance swapped from North America to Europe.

The indicators for a nuclear renaissance identified by McLellan (2008) are:

- Improved performance (load factor),
- New nuclear power plant designs (Gen III, Gen III+ and Gen IV),
- Reductions in construction costs and construction timespans for realizing new nuclear power plant designs.

The operational load factors increased all over the world since the 1980 until 2013, so that the annual nuclear electricity production could increase despite of stagnation in installed capacity. New nuclear power plant designs were proposed around the globe in that time, but by in 2013 only 1% of the global nuclear power reactor fleet can be considered as advanced generation reactors (Gen III, Gen III+ and Gen IV). Today, still 90% of the global power reactor fleet consists of second generation reactors and 9% of the reactors are first generation designs.

The WP 3 report focusses on the development of nuclear power reactors fleet in a short- and mid-term perspective and analyses whether new nuclear power plant designs (Gen III, Gen III+ and Gen IV) are going to be the drivers for a nuclear Renaissance.

The analysis of past development demonstrated that the first wave of nuclear built-up was triggered by activities in Europe and North America. In the (former) Soviet Union and its East-Europe allies (CIS region) there was a significant trend towards nuclear energy usage, but the number of realized reactor units was low compared to the markets in Europe and North America. When looking at the historical data on the installed nuclear capacity it is a striking observation that all over the last decades the projections on expected future nuclear expansion published within these years dramatically overestimated the actual build up within the projection periods. Based on that experience one has to be very careful regarding todays projections into the future.

Taking into account the development in recent years and the scenarios for future nuclear development around the world a shift from “traditional” nuclear markets towards “emerging” nuclear markets can be observed. The current increase in installed capacity is driven by Asia (and partly by the CIS region) and it can be expected that this will also be the case till 2020 and 2030.

A differentiation between regional developments is crucial to understand the future trends in nuclear energy production on a global level. It is not possible to summarize the overall trend by one generalized term, like “nuclear renaissance”. . However, all created scenarios identified similar, more differentiated trends.

The installed nuclear capacity in Europe will drop slightly up to 2020 and suffer a significant drop until 2030. North America experiences a stagnation of its level of installed nuclear capacity until 2020. After 2020 a decrease of installed nuclear capacity will be seen. The CIS region will have an increase of installed nuclear capacity to 2020 and 2030. Asia will experience a strong expansion of installed nuclear capacity until 2020 and 2030. Asia is going to be the largest nuclear market of the future, mainly driven by China.

This shift of the global nuclear landscape towards Asia brings several future challenges for the nuclear industry. One crucial factor might be the nuclear fuel cycle facilities, which by 2013 are located in North America, Europe and the CIS region. As the center of the nuclear market is moving, also new nuclear fuel cycle facilities are likely to be built in the new focus region of the nuclear industry. Such a development might be critical in terms of proliferation concerns (in particular related to sensitive facilities like uranium enrichment) (see WP 9 report).

The construction time of new reactors - one promise of the nuclear renaissance to be reduced - must be considered on a regional level too. The construction time of new reactor designs in Europe and the US exceeds the scheduled time frame by several years. The average construction time of nuclear power reactors over the past two decades in the UK was about 6.1 years and in France 9.4 years. The construction time of reactors in Asia and the CIS region is far below the levels in Europe and North America (i.e. Japan 4.4 years, Korea 4.6 years, China 5.8 years) (Schneider, 2012).

The study revealed that a distinction between the construction time of old reactors designs (proven Gen II designs) and new advanced reactor designs is necessary in order to make a sensible comparison. The study revealed that the construction of old designs in China suffers some delays (up to 1 year). The construction of new advanced reactors in Asia and CIS are suffering bigger delays (1-2 years). In Europe the construction delays for Gen III+ are huge. The EPR at Olkiluoto was scheduled to be operational in 2009 (construction started in 2005). In February 2013 TVO announced that the operation will not start until 2016. (WNN, 2013)

If comparing the reactor generations under construction and in planning phase in Asia and the CIS region, a significant difference can be noted. In the CIS region mainly Gen III+ reactors are under construction or planned. In Asia there are several Gen II designs under construction. Gen III and Gen III+ designs will become operational mainly after 2018. Nevertheless there will be some Gen II designs being completed even after 2018.

The proclamation of a nuclear Renaissance in based on the promise to introduce an improved and advanced generation of nuclear power plants. The analysis performed here highlights that despite the share of advanced generation reactors - on a global level - will indeed increase towards 2020 and 2030; the large majority of nuclear power plants in operation will still consist of reactors from the second generation. Depending on the scenario the share of Gen II reactors in 2020 will be between 73 and 86 percent. In 2030 the share of second generation reactors will be between 68 and 75 percent. Advanced generation reactors (Gen III and Gen III+) will contribute between 10 and 22 percent to the nuclear power reactor fleet by 2020. The share will increase towards 2030 between 21 or 26 percent. Gen IV reactors´ contribution will be at around 1 percent or lower. The rest are going to be first generation reactors. Those results make clear, that by 2030 the nuclear power reactor fleet will consist mainly by second generation reactors. Chapter 9 of the EHNUR report presents the safety related questions and problems of second generation reactors.

If looking on the regional distribution the fact of second generation reactors becomes even clearer. In North America and Europe the second generation reactors in 2020 and 2030 will contribute with over 90 percent to the regional power reactor fleet. The situation in Asia and the CIS is a different. In Asia the share of second generation reactors in 2020 will be between over 60 percent and in 2030 around 52 percent. In the CIS region Gen II reactors in 2020 will contribute over 56 percent and in 2030 over 52 percent.

The nuclear renaissance is not happening on a global level. There are some indicators that we might see a regional renaissance of nuclear power, which is not driven by the assumed factors of a global nuclear Renaissance. If talking about renaissance the only markets were this term could be used is the CIS region, were after the Chernobyl accident and the crash of the Soviet Union several projects were halted. Asia will experience a strong growth of nuclear power production, but the starting level in Asia is very low. Asia will introduce nuclear power on a large scale, but it does not seem to be a nuclear renaissance because there was no peak in the past. From the data no trend towards a nuclear renaissance is visible for Europe and North America. It seems more likely that in the “traditional” nuclear markets the installed nuclear capacity will decrease until 2030.

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7. GLOSSARY

BWR	Boiling Water Reactor
CIS	Commonwealth of Independent States
DoE	Department of Energy (US)
EdF	Electricite de France
ENEF	European Nuclear Energy Forum
ENEF	European Nuclear Energy Forum
FR	Fast Neutron Reactor
GCR	Gas Cooled Reactor
GEA	Global Energy Assessment
HEU	Highly Enriched Uranium
I & C	Instrumentation and Control
I & C	Instrumentation and Control (equipment)
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
INPRO	Innovative Nuclear Power Reactors & Fuel Cycle (IAEA)
IRSN	Institute for Radioprotection and Nuclear Safety (France)
KOPEC	Korea Power Engineering Company
LPG	Liquid Pressurized Gas
LTE	Life Time Extension
LTO	Long Term Operation
LWGR	Light Water Graphite Reactor
LWR	Light Water Reactor
MOX	Mixed (uranium and plutonium) OXides (nuclear fuel)
NEI	Nuclear Energy Institute (US)
NGO	Non-Governmental Organization
NPP	Nuclear Power Plants

NRC	Nuclear Regulatory Commission (US)
OECD/ NEA	Organization for Economic Co-operation and Development/ Nuclear Energy Agency
PHWR	Pressurized Heavy Water Reactor
PRIS	Power Reactor Information System (IAEA)
PWR	Pressurized Water Reactor
QC	Quality Control
RPV	Reactor Pressure Vessel
RW	Radioactive Waste
SF	Spent (nuclear) Fuel
SG	Steam Generator
SNPTC	State Nuclear Power Technology Company (China)
TMI	Three Mile Inland NPP
TSO	Technical Support Organization
TVO	Teollisuuden Voima Oyj (Power Company, Finland)
WNA	World Nuclear Association
WWER	Water Water Energy Reactor (Russia)

8. ANNEX 1

119 different nuclear power plants styles were identified to be in operation, in construction or in planning phase around the world. The identified nuclear power plants are grouped according to their generation and their design in the following tables (see tables 19-23). The description of the background for the grouping into generations can be found in chapter 5 of the work package 4 report.

Table 19: Generation I Reactors

Generation I Type	Reactor
PWR	Gidropress 6-loop VVER 440/179 Gidropress 6-loop VVER 440/210 Gidropress 6-loop VVER 440/230 Gidropress 6-loop VVER 440/270 Gidropress 6-loop VVER 440/365 Westinghouse 1 loop Westinghouse PWR Prototype PWR Babcock & Wilcox PWR DPRK-PWR
BWR	GE- BWR 1 GBWR-12 / EPG-6 AEG-GE BWR Superheater
LWGR	RBMK – 1000 (1. Generation) AMB-100 AMB-200 AM-1

PHWR	Indian PHWR -220 Class Siemens PHWR Prototype AECL CANDU 200 AECL CANDU Prototype AECL CANDU NPD-2 CVTR (Carolinas-Virginia Tube Reactor) OCM PHWR
GCR	MAGNOX HWGCR (Heavy Water Gas Cooled Reactor) HTGR Prototype
FR	BN-350 LM-FBR SGR Westinghouse PLWBR KNK
HWLWR	HW BLWR 250

Table 19 gives an overview on the generation I reactors included in the database. Generation I reactors can mainly be considered as prototype reactors.

TABLE 20: GENERATION II REACTORS

Generation II Type	Reactor
PWR	Babcock & Wilcox 205 Babcock & Wilcox Lowered Loop Chinese PWR 1000 Chinese PWR 300 Chinese PWR 600 Combustion Engineering

	Combustion Engineering CE80-2L Framatom 3 loop Framatome 3-loop CP0-Type Framatome 3-loop CP1-Type Framatome 3-loop CP2-Type Framatome 4-loop N4-Type Framatome 4-loop P4-Type Gidropress 4-loop VVER 1000/187 Gidropress 4-loop VVER 1000/302 Gidropress 4-loop VVER 1000/320 Gidropress 4-loop VVER 1000/338 Gidropress 4-loop VVER 1000/392 Gidropress 6-loop VVER 440/213 Gidropress 6-loop VVER 440/311 KWU 2-loop KWU 3-loop KWU 4-loop KWU 4-loop (Convoi) KWU 4-loop (Pre Convoi) Mitsubishi PWR 2 loop Mitsubishi PWR 3 loop Mitsubishi PWR 4 loop OPR - Optimized Power Reactor PWR Mitsubishi 2 loop PWR Mitsubishi/Westinghouse 3 loop
	Westinghouse 2-loop Westinghouse 3-loop Westinghouse 4-loop

	Westinghouse PWR
BWR	ABB-Atom BWR ABB-Atom BWR 75 General Electric - BWR General Electric BWR/2 Mark I General Electric BWR/3 Mark I General Electric BWR/4 Mark I General Electric BWR/4 Mark II General Electric BWR/5 Mark II General Electric BWR/6 Mark III Siemens BWR/69 Siemens BWR/72
LWGR	RBMK-1000 (2. Generation) RBMK-1500
PHWR	AECL CANDU 500 A AECL CANDU 500 B AECL CANDU 750 A AECL CANDU 750 B AECL CANDU 850 AECL CANDU-6 AECL CANDU 791 Indian PHWR 540 Class Indian PHWR 700 Class KWU PHWR

GCR	Advanced Gas Cooled Reactor
FR	BN - 600 BN – 800 China Experimental Fast Reactor (Sodium Cooled- Pool Type) Indian Sodium Cooled Fast Reactor Japanese Sodium Cooled Fast Reactor

As it can be seen in Table 20 , generation II reactors are numerous and designed by different companies around the world. Furthermore generation II reactors are the most spread of the world. Detailed information on the numbers can be found in section 3.1 and 4 of the report.

TABLE 21: GENERATION III REACTORS

Generation III Type	Reactor
PWR	CAP 1400 KEPCO APR 1400 2-loop Gidropress 4-loop VVER 1000/428 Gidropress 4-loop VVER 1000/446 Gidropress 4-loop VVER 1000/466
BWR	GE/Hitachi/Toshiba - Advanced Boiling

The design features of generation III and III+ designs can be found in chapter 5 of the work package 4 report.

TABLE 22: GENERATION III+ REACTORS

Generation III+ Type	Reactor
PWR	AREVA EPR AREVA-US EPR GE-Hitachi ESBWR Gidropress 4-loop VVER 1200 N Gidropress 4-loop VVER 1200/392 M Gidropress 4-loop VVER 1200/491 P Gidropress 4-loop VVER TOI Mitsubishi US-APWR Westinghouse AP1000
BWR	GE-Hitachi ESBWR

Only reactors under construction or in planning phase were included in the database. Therefore several designs proposed by the GEN IV council were not taken into account, because in the beginning of 2012 there were no detailed plans were to build them.

TABLE 23: GENERATION IV REACTORS

Generation IV Type	Reactor
FR	BREST BN-1200
GCR	Gas Turbine-Modular Helium Reactor HTR-PM