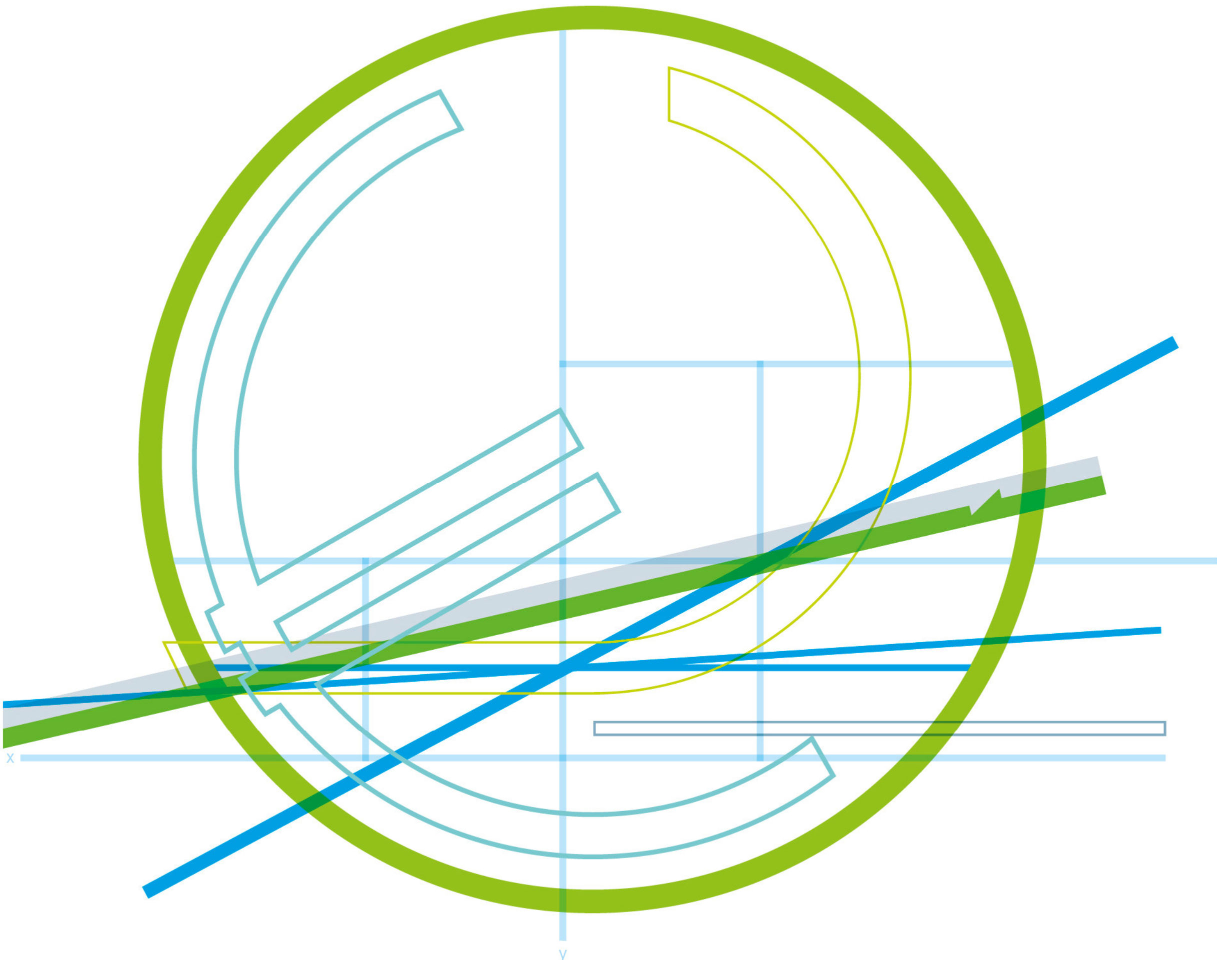
Blue Globe Foresight

Studie #15/2013

EHNUR

Evaluation of a hypothetical nuclear renaissance



Wolfgang Kromp et al.

VORWORT

Die Publikationsreihe BLUE GLOBE REPORT macht die Kompetenz und Vielfalt, mit der die österreichische Industrie und Forschung für die Lösung der zentralen Zukunftsaufgaben arbeiten, sichtbar. Strategie des Klima- und Energiefonds ist, mit langfristig ausgerichteten Förderprogrammen gezielt Impulse zu setzen. Impulse, die heimischen Unternehmen und Institutionen im internationalen Wettbewerb eine ausgezeichnete Ausgangsposition verschaffen.

Jährlich stehen dem Klima- und Energiefonds bis zu 150 Mio. Euro für die Förderung von nachhaltigen Energie- und Verkehrsprojekten im Sinne des Klimaschutzes zur Verfügung. Mit diesem Geld unterstützt der Klima- und Energiefonds Ideen, Konzepte und Projekte in den Bereichen Forschung, Mobilität und Marktdurchdringung.

Mit dem BLUE GLOBE REPORT informiert der Klima- und Energiefonds über Projektergebnisse und unterstützt so die Anwendungen von Innovation in der Praxis. Neben technologischen Innovationen im Energie- und Verkehrsbereich werden gesellschaftliche Fragestellung und wissenschaftliche Grundlagen für politische Planungsprozesse präsentiert. Der BLUE GLOBE REPORT wird der interessierten Öffentlichkeit über die Homepage www.klimafonds.gv.at zugänglich gemacht und lädt zur kritischen Diskussion ein.

Der vorliegende Bericht dokumentiert die Ergebnisse eines Projekts aus dem Forschungs- und Technologieprogramm „Neue Energien 2020". Mit diesem Programm verfolgt der Klima- und Energiefonds das Ziel, durch Innovationen und technischen Fortschritt den Übergang zu einem nachhaltigen Energiesystem voranzutreiben.

Wer die nachhaltige Zukunft mitgestalten will, ist bei uns richtig: Der Klima- und Energiefonds fördert innovative Lösungen für die Zukunft!

Ingmar Höbarth
Geschäftsführer, Klima- und Energiefonds

Theresia Vogel
Geschäftsführerin, Klima- und Energiefonds

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ProjektnehmerIn (Institution)	Institut für Sicherheits- und Risikowissenschaften, Universität für Bodenkultur Wien
AnsprechpartnerIn	Ao. Prof. Dr. Wolfgang Kromp
Postadresse	Borkowskigasse 4, 1190 Wien
Telefon	+43 1 47654 7700
Fax	+43 1 47654 7709
E-mail	risk@boku.ac.at
Website	www.risk.boku.ac.at

EHNUR

Evaluation of a hypothetical nuclear renaissance

Project team:

Karl Arlamovsky
Nikolaus Arnold
Daniel Baumgarten
Reinhold Christian
Michael Cerveny
Herbert Formayer
Martin Giersch
Klaus Gufler
Gueorgui Kastchiev
Wolfgang Kromp
Helga Kromp-Kolb
Wolfgang Liebert
Nikolaus Müllner
Wolfgang Rehm
Wolfgang Renneberg
Irene Schicker
Emmerich Seidelberger
Steven Sholly
Stephen Thomas
Geert Weimann
Werner Zittel

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2 Introduction

2.1 Background

Increased awareness of the global climate change problem, as well as oscillations in the crude oil prices plus the stopped transfer of Russian natural gas to European Union in the beginning of 2009 have given new and increased attention to nuclear energy technology. Even after Fukushima many countries in the world build their energy strategy on the further expansion of nuclear energy. Several member states of the European Union have started an initiative for European subsidies for new reactors as an instrument to limit the production of greenhouse gases.

2.2 Objective

The EHNUR project has the aim to analyze the usability and feasibility of a nuclear approach as an instrument to solve the climate problem. In a first step it defines the requirements nuclear energy would have to comply with in order to be able to contribute to the limitation of greenhouse gas emission in a relevant scope. In a second step those requirements are compared with potential applications of nuclear energy and hypothetical, historical and realistic nuclear energy expansion scenarios. The technical, administrative, economical boundary conditions as well as the perspectives on usable fuel resources are investigated. The associated risk potential of the operation of nuclear power is assessed under the assumptions of the development of the reactor fleet including new reactors with advanced safety features. In a last step a hypothetical scenario analyses what it would practically mean to Austria to restart a nuclear strategy as part of a new Austrian energy policy. The technical, administrative and economical boundary conditions and measures that would have to be implemented are analyzed. This could be of relevance for other nuclear free countries as well[1].

2.3 Structure of the project and the report

The project was structured into ten work packages, nine of which (2 to 10) were technical. Work package 2 dealt with the role of nuclear energy for greenhouse gas emission reduction. Work package 3 was devoted to short and mid-term development of the nuclear power reactor fleet on a global level. Work package 4 dealt with advanced generation reactors. Work package 5 was devoted to bottlenecks for the actual and future nuclear power development. Work package 6 dealt with fuel for nuclear power reactors. Work package 7 was devoted to

[1] A previous study (Kromp-Kolb and Molin, 2007) gave a broad overview on questions regarding the use of nuclear power, including climate change related issues that were a starting point for the EHNUR in-depth analyzes of nuclear energy scenarios and their climate change mitigation potential based on current data.

non-electrical use of nuclear power. Work package 8 dealt with the economics of nuclear power. Work package 9 was devoted to the risks for society from nuclear power. Work package 10 dealt with hypothetical considerations regarding the introduction of nuclear power in Austria. Work package 1 was administration, publicity and distribution of results.

In this Final Report, the methodological aspects of work packages 2 to 10 are described in Chapter 2.4. Chapter 3 is the synthesis report of the project. In Chapter 4 the results and the conclusions of the project are reported. Chapter 5 contains recommendations and an outlook. The main part is followed by nine annexes. The nine annexes contain the final reports of each work package.

Annex 1: Requirements from climate protection and security of supply, and degree to which those can be fulfilled by nuclear energy

Annex 2: Short and mid-term trends

Annex 3: Advanced generation reactors

Annex 4: Bottlenecks

Annex 5: Nuclear fuel availability

Annex 6: Non electrical use of nuclear power

Annex 7: Economics of nuclear power

Annex 8: Risks of Nuclear Power to Environment and Society

Annex 9: Hypothetical use of nuclear power in Austria

2.4 Methods

General

The methodological approach of EHNUR is based on literature research. This comprises materials and publications of the International Atomic Energy Agency (IAEA), the World Nuclear Association (WNA), the Organization of Economic Cooperation and Development (OECD) and its Nuclear Energy Agency (NEA), the International Energy Agency (IEA), the Global Energy Assessment (GEA), the EURATOM, as well as the U.S. Department of Energy (DOE), reports of nuclear power plant operators and nuclear regulatory authorities, national reports in the framework of the Convention of Nuclear Safety (CNS), specialized journals, conference papers and documentations of special meetings - when it comes to the potential development of the nuclear sector and the analysis of the potential range of nuclear energy conversion in the future. These documents are analyzed in a critical review by the experts in the EHNUR team – some of them have collected years of experience working in the nuclear industry or in leading a nuclear regular authority.

WP 1 Project communication, management and dissemination

For the communication and the management purpose WP 1 used different communication (common servers, Skype, etc…) and project management tools (MS Project) do coordinate the project team. Additionally the Kick Off meeting and the mid- term meeting was used to coordinate the work. Each work package carried out 8-15 specific field meetings. Furthermore there were a lot of coordination meetings of experts from different working groups in order to share the results. The dissemination activities were coordinated by work package 1. The invitations to the final events and the press conference were spread via e-mail and official announcements on the webpage of the project partners.

WP 2 Nuclear energy and greenhouse gas emissions

The present study estimates the current and possible future contributions of nuclear power to green house gas (GHG) mitigation by looking at different scenarios. The energy demand in the next decades was based on scenarios and projections by the IEA, more specifically, on the so-called "current policy scenario" of the World Energy Outlook 2012. In this scenario it is assumed that the policies implemented worldwide by 2012 will be maintained unchanged until the year 2035. The potential contribution of nuclear energy to avoid greenhouse gas emissions was evaluated based on different considerations for nuclear power plant build rates. First, build rates as predicted by scenarios from IAEA (IAEA, 2012) were considered. In a second step extreme build rates, which would substitute all coal-fired and gas-fired power plants, were evaluated. Finally, the results were compared with the completely different, normative scenario by GEA 2012 (that answers the question how to reach a desirable future, instead of trying to predict a plausible development).

WP 3 Short and mid- term trends of the development of nuclear energy

Within WP 3 a data base has been developed that contains past, present 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 WP3 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.

WP 4 Advanced generation reactors

Design documentation on advanced nuclear power plant designs and design concept were identified in publicly available literature. Extensive use was made of presentations by reactor vendors at meetings sponsored by the International Atomic Energy Agency (IAEA). A wide variety of published literature and so-called "grey literature" has been used in this chapter to get a comprehensive view on the status and the prospects of the existing concepts of new reactors.

WP 5 Bottlenecks

The study of WP 5 is based on a literature research. The main documents that have been used are reports from nuclear utilities and regulators, materials from international nuclear organizations (IAEA, IAE, WNA), reports to scientific conferences, articles in specialized magazines (Nucleonics Week, Nuclear Engineering International, Nuclear Fuel), reports of the European Commission, European Nuclear Energy Forum, nuclear operators, regulators, TSOs, independent experts, NGOs, as well as studies of different authors. The collected data were also used to draw conclusions for the study on a hypothetical nuclear power scenario for Austria.

WP 6 Nuclear fuel availability

To carry out a comprehensive assessment of the world's uranium resources and resulting availabilities, it is necessary to understand the current market situation and its interconnections. An extended research on available literature was performed to identify stakeholders, major producers (countries or companies) as well as historical trends and expectations for the uranium market. A large database was established containing information on countries and mines and related resources, historical production trends and issues, expected expansions and other relevant data. Primary (reports by mining companies, country reports etc…) and secondary data (data published by the IAEA, OECD/NEA, WNA, etc.) were used.

WP 7 Non-electrical use of nuclear power

All information used in the WP7 report was collected from open literature sources. The investigation concentrated on publications by the IAEA and the IEA. Older publications by international agencies (IEA, IAEA, and OECD/NEA) were evaluated in order to extrapolate technological development trends, to proof changes in scenarios and methods applied to develop scenarios and to evaluate their quality and reason for deviations. In all cases where the very substance of the information had to be collected from a large number of documents, these documents were collected in a Thesaurus like documentation.

WP 8 Economics of nuclear power

WP8 is based on literature research and on own calculations, a two-step approach. First the main variables (pre-construction phase, construction phase, operation phase, post-operation phase) were elaborated and individually described. The basic information was taken out of the literature. The second step consists of scenarios of nuclear power costs. For this purpose a model was created and used. The prior identified variables were taken into account and the calculations were based on the identified four phases.

WP 9 Risk for society

The risk of nuclear power for environment and society was analyzed in several important categories such as technical failure and severe accident, security and proliferation, ecological and environmental, health and social, economics` and liability risks. The available relevant literature was reviewed. To some extent risk categories were analyzed in historical retrospect to get an idea about evolution of risk knowledge and consciousness. Significant stakeholder views were cited and commented. Severity of risk categories was indicated in specific risk clusters. The influence of a hypothetical nuclear renaissance on risk categories was discussed. In contrary to only an analytical assessment of nuclear risks - generally used in the nuclear community - a descriptive one was applied.

WP 10 Hypothetical use of nuclear power in Austria

The IAEA requirements for newcomer states were adopted and complemented for a hypothetical Austrian nuclear power program. For the nuclear safety infrastructure for Austria the IAEA guidance for establishment of a nuclear safety infrastructure (IAEA, 2011) was used. IAEA requirement documents (e.g. IAEA 2003, IAEA, 2006, IAEA 2011a, IAEA 2012b) are used to define additional measures needed in the operation, decommissioning, and radioactive waste repository closure periods. The nuclear safety infrastructure based on (IAEA, 2011) is conditioned on relevant Austrian conditions (e.g. a nuclear skeptical population and Parliament, Austrian grid conditions, and Austrian siting limitations for nuclear facilities), Austrian international treaty and convention obligations, and European Council requirements. The cost of the hypothetical small Austrian nuclear power program is coarsely estimated considering government costs (including regulatory oversight), capital cost and interest on construction loans for four nuclear units, operations and maintenance (O&M) costs – including nuclear fuel – for four nuclear units, and the costs associated with decommissioning four nuclear units and emplacing radioactive waste and spent fuel in a geological repository. Utility profits are not included in the cost estimate, nor are cost increases over time due to inflation. A more pessimistic case (involving higher unit construction costs, lower plant availability, and higher O&M costs) is also considered. The objective of the cost estimate is not precision, but rather an order-of-magnitude estimate.

In a workshop including leading Austrian stakeholders the chances and obstacles to a hypothetical Austrian nuclear power program were discussed.

3 Description

With increased awareness of the problem of climate change and because of volatile crude oil price development and the insecurity of gas supplies nuclear technology has received new attention. Within the EU Austria is increasingly confronted with positions that attribute nuclear energy an important role in green house gas mitigation and reduction of energy import dependence.

The EHNUR project analyzed critically the usefulness of a new nuclear attempt ("nuclear renaissance"). A realistic assessment of the potential of nuclear power was compared to the demands of the energy system and climate protection as a contribution to an objectification of the discussion on the national and European level. The study focuses on the main technical and economical potentials, bottlenecks and risks of nuclear power to create a complete basis for the assessment of the perspective of nuclear power, including its limits, its potential for development and its use.

To clarify the implications of implementation of the nuclear option measures needed for a hypothetical nuclear renaissance in Austria are analyzed. The results are of relevance for any medium sized country considering phasing in nuclear energy.

1.) Climate researchers agree that anthropogenic greenhouse gas (GHG) emissions have an adverse effect on global climate, as the concentration of GHG in the atmosphere influences the radiation balance and therefore the average global temperature (Müllner et al., 2013). Concentrations of more than 450 ppm CO2 eq. are likely to cause an increase of the average global temperature of more than two degree Celsius, a limit that has been established as critical for the capacity of many ecosystems to adapt. It is also a temperature above which stabilization of the climate might not be possible. It is therefore the declared political goal not to exceed the 2°C target. By projecting current emission trends it becomes apparent that after 10-15 years at most emissions have to be reduced drastically to find a pathway compatible with the 2°C target. Therefore the period up to 2050 is of main interest in climate policy (UNEP, 2010), (UNEP, 2010a) and (UNEP, 2012).

CO2 neutral, renewable and low carbon sources of energy have to substitute the currently prevailing fossil fuels. Although nuclear power is not emission free, its GHG emissions are significantly lower than emissions from fossil sources (Van Leeuwen et al., 2005), (Sovacool, 2008) and (Beerten, 2009).

Table 1: Nuclear prevented CO2 eq. emissions in the IAEA "low" and "high" scenario in 2035

	IAEA low	IAEA high
Total generated electricity (TWh)	43300	49500
Nuclear generated electricity (TWh)	4100	6900
Nuclear share of electricity production	9.8 %	13.8 %
CO2 intensity of electricity generation (g CO2 eq. / kWh)	530	530
Nuclear CO2 prevention potential for the year 2035 (Gt CO2 eq.)	2.17	3.66
Extrapolated total emissions in the year 2035 (Gt CO2 eq.)	71.5	71.5
Nuclear share of "prevented" emissions	3.0 %	5.1 %

However, the global problem of climate change cannot be solved by nuclear energy. In 2010 the current operating fleet worldwide prevented emissions of roughly 3 % of the total global anthropogenic GHG emissions (Müllner et al., 2013). Projections for development of nuclear power published annually by IAEA (IAEA, 2012a) aim to provide a plausible range for build rates of nuclear power plants. Following the so called "low –scenario" the contribution to climate change mitigation from nuclear stays at 3 %, while the "high – scenario" predicts a rise to 5 %, see (Müllner et al., 2013) and Table 1. Extrapolating emissions further to 2050, using the figures provided by (IAEA, 2012a) for nuclear electricity generation confirm again a nuclear climate change mitigation potential of 5 %.

These numbers show that the expected contribution of nuclear energy to climate change mitigation is low. In addition, in the past projections from institutions like IAEA, OECD, WNA have consistently overestimated nuclear energy build rates (Gufler, 2013). Figure 2 shows estimates (projections) on the total installed nuclear capacity in the year 2000 that were published in the 1970ties and 1980ties. All of them estimated higher capacities than were actually built (Gufler, 2012). Closest to the actual number was the IAEA "low" scenario from the year 1986 (Char/Csik 1987) that was written under the impression of the Chernobyl accident. But it still projects an overall installed capacity of 500 GWe (which is 35 % more than the present capacity of 371 GWe). The most optimistic scenarios predicted more than 5000 GWe installed capacity (more than 10 times above the actual builds).

Considering the constant bias of previous predictions, the EHNUR project developed scenarios for comparison (Gufler, 2013). Based on currently announced programmes to build nuclear power plants, to extend life times and to shut units down the future installed capacity was evaluated. In general at least ten years pass from the announcement of a plan to build a nuclear power plant to the time when the plant is actually connected to the grid. Projects which did not start yet, and are not yet announced, may have an influence after 2020-2025 – up to this date projections based on currently known projects can be expected to be precise.

Both IAEA and ISR are projecting for the near term future based on currently known planning, and in fact, the projected installed capacity (ISR 1) agrees well with the one of the IAEA "low" scenario up to 2020 (refer to Figure 1).

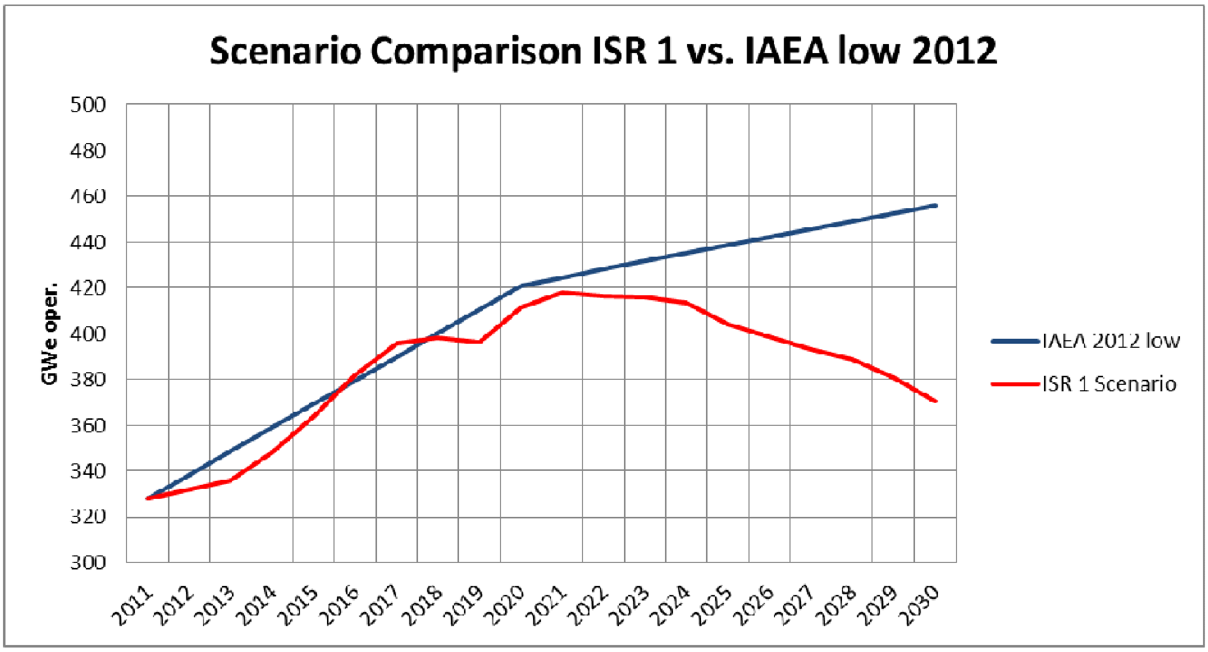

Figure 1: IAEA low scenario compared to ISR1 Scenario[2]

To project beyond 2020-2025 additional assumptions are needed for boundary conditions such as economic growth or policy measures, which add to the uncertainty. For this period ISR projections, since they are purely based on currently known planning, differ significantly from the IAEA trend (Gufler, 2013).

The climate change mitigation potential of nuclear energy in (IAEA, 2012a) and other current projections is marginal, and based on past experience it is doubtful whether the "low" and "high" predictions even envelope the most likely future (Gufler, 2012a).

But assuming that policy makers and the nuclear industry would foster nuclear power as low carbon technology, and assuming that the related expansion of nuclear energy would economically, technically and politically be feasible[3], what, theoretically, could be its possible contribution in the critical time frame up to 2050? One could consider as thought experiment a "business as usual" scenario, i.e. all current trends and policies continue as enacted (as in the "current policies" scenario of (IEA, 2012)), but all fossil fuelled power plants will be replaced by new nuclear power plants by 2035.

[2] The IAEA 2012 "low" scenario includes the installed capacity of the Japanese nuclear fleet. To be comparable to the ISR Scenario (which assumes a stepwise restart of the Japanese reactors) the values of the IAEA scenario have been adjusted in the Figure.

[3] This is not the case, please refer to the following analysis of "bottlenecks" under 3.)

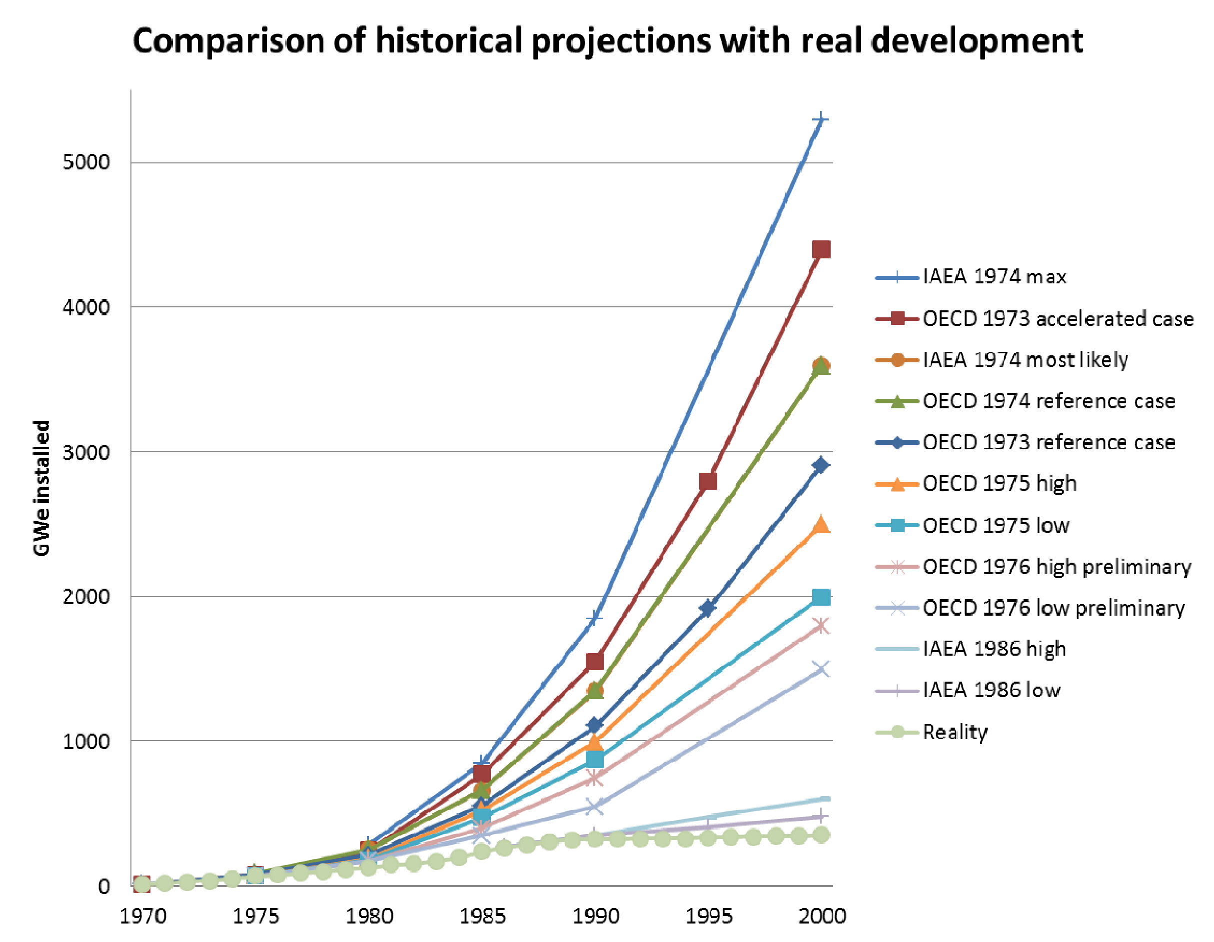

Figure 2: Past scenarios of OECD and IAEA on installed nuclear capacity, all projecting higher installed capacities for the year 2000 than was actually the case.

Table 2: Nuclear prevented CO2 eq. emissions in a massive expansion scenario (4000 GWe installed capacity) in 2035

Fossil fuels substituted by nuclear in 2035 (TWh)	26800
CO2 intensity of electricity generation (g CO2 eq. / kWh)	750
Nuclear CO2 prevention potential for the year 2035 (Gt CO2 eq.)	20.1
Extrapolated total emissions in the year 2035 (Gt CO2 eq.)	71.5
Nuclear share of "prevented" emissions	28.1 %

In this hypothetical case roughly 4000 GWe nuclear power would be needed[4] (more than ten times the installed capacity of today) and in consequence roughly 25-30% of the GHG emissions to be expected in 2035 could be avoided[5] (see Table 2).

[4] 30700 TWh per year would have to be generated by nuclear power. Assuming a load factor of 80% this amounts to 4000 GWe installed capacity.

This would require 3000 – 4000 new units (depending on the rated power of the units), while even optimistic projections of international institutions like IAEA, such as the IAEA "high" scenario, predict no more than 400-500 new units up to 2035.

Despite the fact that this theoretical expansion scenario could substantially contribute to the necessary reductions of GHG, even that massive expansion would not be sufficient to lead the economy to a 2°C pathway. The world would still face the problem that GHG emissions from other sectors would lead to above critical concentrations of CO2 in the atmosphere (Müllner et al., 2013) causing dramatic climate change.

2.) The hypothetical contribution of nuclear energy to climate change mitigation could be larger, if nuclear energy were used for non-electrical applications as well (Weimann, 2013)[6]. Non-electrical applications which are typically included in medium and long-term scenarios are

- water desalination
- district heating
- hydrogen (H2) production
- process heat
- hydrocarbon (CH) production

Several nuclear combined cycle district-heating systems are in operation, as well as small modular reactor plants providing heat-only supplies in a pilot stage. Nuclear desalination plants are built at demonstration level and could, in principle, be introduced commercially between 2020 and 2030. High temperature systems for nuclear hydrogen or CH-synthesis seem to be possible at least in principle, but are far from being a mature technology.

If electricity, H2 or CH based vehicles would substitute fossil fuel based vehicles, nuclear energy could play a significant role in the energy- and emission-intensive transport sector as well.

The estimates on R&D still needed to prove hydrogen / hydrocarbon production for large scale commercial applications are high and it takes at least until 2035 to lead nuclear applications from demonstration level to commercial deployment. Moreover the technological infrastructure for a hydrogen economy on a national or world wide scale will not be built before the feasibility of hydrogen production has been technically and economically proven.

[5] Refer to (Müllner et al., 2013) for details on boundary conditions

[6] Again, such contributions are only hypothetical since "bottlenecks" that make high expansive growth of nuclear energy impossible are not reflected, see Kastchiev (2013).

Regardless of all other technical and economical bottlenecks for nuclear expansion strategies it seems definitely unlikely that these technologies will be available long enough before 2050 to play a relevant role in avoiding greenhouse gas emissions to stop climate change.

About 50 million metric tons of hydrogen are currently produced for industrial purposes. Most of this hydrogen comes from steam reforming natural gas, oil, and coal. This process, while about 80% efficient, is a source of greenhouse gas emissions. GHG-emission free thermochemical water splitting technologies with high efficiency (efficiency requirements exclude electrolysis) are currently researched, e.g. iodine sulfur cycle, but large scale applications based on nuclear-generated heat are not expected to be available in the near- to midterm future. Hydrocarbon generation is based on the availability of hydrogen, which means that the technological steps which are still to be taken are in principle the same.

District heating needs expensive infrastructure, can be deployed only within a small radius from the power station and, if operated as combined cycle, reduces efficiency for electricity production. For safety reasons nuclear power plants are constructed in sparsely populated areas, which poses an intrinsic limitation to the use of nuclear district heating.

3.) Assuming the technical and economical barriers for massive nuclear energy programmes could be overcome and nuclear power could be expanded such that it could contribute significantly to climate change mitigation, then a new problem would arise: the question of the availability of uranium as fuel. Current operating reactors utilize the thermal neutron spectrum, which means that they use the isotope uranium 235 as fuel. Natural uranium contains only 0.7 % of uranium 235, and the uranium ore concentrations in rock mined today range from a record high of about 20 % (mass percent) in Mc-Arthur River in Canada to very low values of 0.01% at Trekkopje in Namibia, with 0.02 – 0.34 % being a representative value for most mines (except Canada).

The increase in nuclear power installed capacity must be matched by the increase in mining capacity to ensure continuous supply of uranium for nuclear power plants. The total uranium accessible at reasonable costs determines for how long nuclear power plants can be operated (Arnold et. al., 2011). Based on OECD/NEA/IAEA estimates of the available uranium resources (OECD-NEA/IAEA, 2012) IAEA concluded that “total identified resources are sufficient for over 100 years of supply based on current requirements” (IAEA, 2012). “Current requirements” means that there is no increase in nuclear power generation. For the scenarios in (OECD-NEA/IAEA, 2012) which assume an increase in nuclear generating capacity very much in line with (IAEA, 2012a), IAEA concludes that “the currently defined uranium resource base is more than adequate to meet “high-case” requirements through 2035 and well into the foreseeable future” (IAEA, 2012). “Foreseeable future” indicates a time frame of roughly 50 years, as becomes clear in (OECD-NEA/IAEA, 2012), were it is estimated that about 90% of the reactors planned for the high demand scenario could be supplied with uranium over their lifetime, based on the resources identified in 2011.

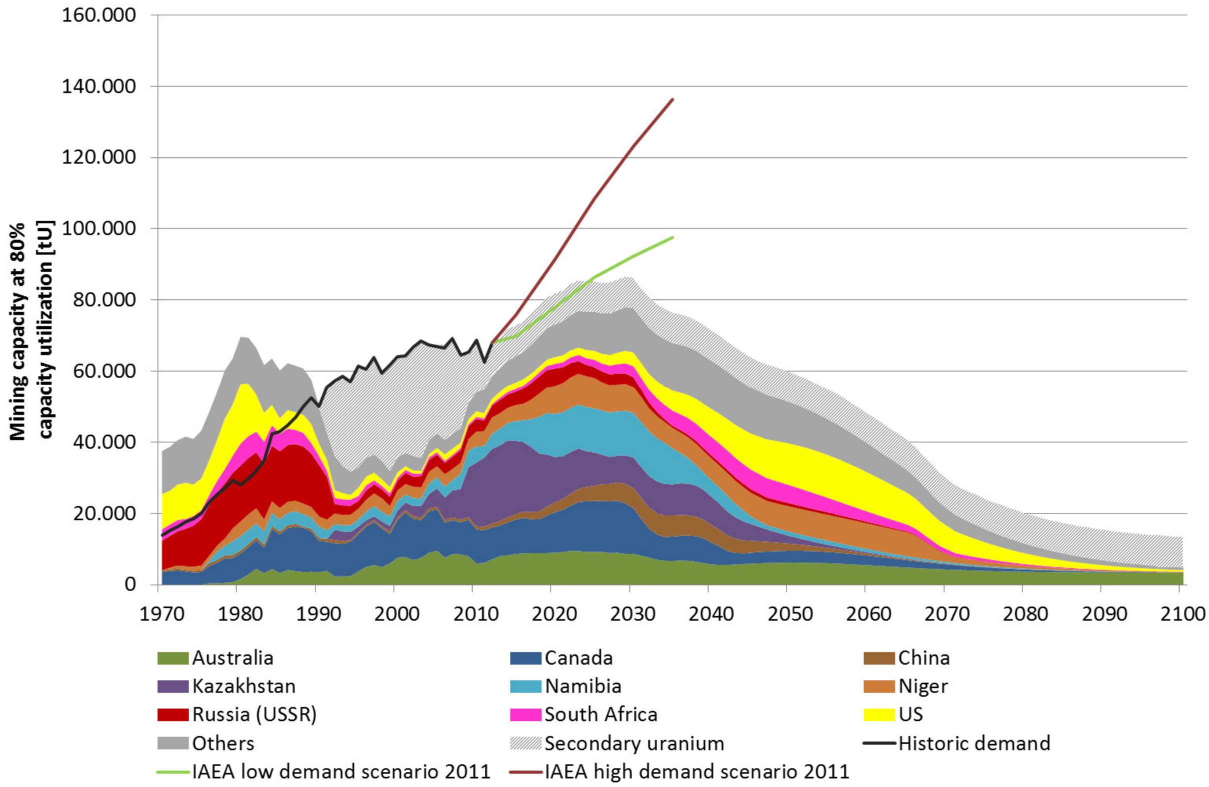

Figure 3: Historic (before 2012) and projected (after 2012) global annual mining amounts (in tonnes uranium) as evaluated in Zittel et al. (2013) and uranium demand for IAEA "high" and "low" nuclear power build rate scenarios from 2011. Countries which are important uranium producers today or (possibly) in future are highlighted in different colours In addition uranium supply from sources other than mining is shown. The future production scenario is based on Reasonably Assured Resources[7] and current mining plans, assuming all of these resources can be mined at 80% capacity utilization at production centres. The figure represents an optimistic picture for global mining, especially in the short and medium-term, as delays in new mining projects and production downtimes can be expected and the average capacity utilization at uranium mines only amounted to 76% in the past decades. Note that the production scenarios become quite uncertain after 2030 and contain production from currently operated and planned uranium mines until the local resources are expected to be depleted. Production from RAR not assigned to production centres is approximated via bell-shaped curves.

It is already questionable whether the increase in mining capacity can meet the requirements of the "high case" up to 2035 (Zittel et al., 2013). As shown in Figure 3 there is legitimate doubt that uranium can be mined fast enough[8] to fuel the nuclear power plants in the IAEA

[7] The estimates on uranium resources are based on worldwide exploration work. They differ in reliability of the estimates of their content and are subdivided into classes of recovery costs. Reasonably Assured Resources (RAR) have a relatively high assurance of existence. Identified Resources comprise RAR plus some Inferred Resources, which have less certainty of existence.

[8] The timeframe from delineation of a uranium deposit until the start up of a mine can be 15 years or more. (Hall and Coleman 2013 Critical analysis of world uranium resources: U.S. Scientific Investigations Report 2012–5239) Due to the relatively low uranium prices there is not much interest in developing new uranium deposits.

"high" scenario (OECD-NEA, 2011). Even more, as the figure represents an optimistic scenario, it is questionable whether uranium supply within the next two decades could meet the uranium demand in the IAEA "low" scenario. Since the future production depends on the success of the currently planned mining projects, it appears quite possible that an unfavorable development can result in supply shortages or significant price increases already around 2020. A reason for this is that the timeframe from delineation of a uranium deposit until the start-up of a mine can be 15 years or more. (Hall and Coleman, 2013) and there is not much interest in developing new uranium deposits at the moment, due to the relatively low uranium prices. The short-term economic view of the companies operating uranium production facilities is in contrast to the long-term aspects of nuclear energy. Furthermore it can be assumed, that uranium ore with higher grades and lower production costs has already been extracted in the past, so production efficiency and economic competiveness can be expected to decline in the future.

Even higher nuclear energy build rates that are necessary to substitute fossil fired power plants and expand nuclear for non-electric applications, are not compatible with currently projected mining activities. While there may be margin to build up mining capacity[9], it is impossible increase the mining capacity such that the uranium demand for all nuclear power plants of a massive nuclear expansion scenario (with ten times higher build rates than projected by (IAEA, 2012) today) can be satisfied. And a second problem would arise: uranium resources that can be accessed in an economically feasible manner are limited, and would be depleted within the lifetime of the constructed nuclear power plants.

The IAEA estimated that about 90% of the reactors planned for the high demand scenario could be supplied with uranium over their lifetime, based on the resources identified in 2011 (OECD-NEA/IAEA, 2012). Should governments decide to step up their nuclear programmes, the time frame with enough uranium available will be much shorter. If it was possible to extract uranium resources fast enough to ensure supply for extreme scenarios (i.e. replacing all fossil fuelled power plants with nuclear power plants and provide energy for heat and transport as well) the currently identified resources would be depleted in less than ten years.

Therefore the contribution of thermal nuclear power plants to climate change mitigation is limited to the above mentioned 3-5 % of GHG emissions avoided by year, not only, but also, due to the limited resources of uranium. An expansion programme like the one mentioned above would have to rely on another source of fuel.

[9] Mining capacity in Kazakhstan was expanded at a tremendous rate to fill the gap between demanded and produced resources, which exists since 1990. This expansion in Kazakhstan was state driven. It can be doubted that such an increase in mining output can be repeated in any other country due to political, environmental, socio-economic and/or resource related frame conditions hampering such a development – or in other words, due to the safety- and environmental standards, which, in most countries, are stricter than in Kazakhstan (Arnold & Gufler, 2012).

4.) Nuclear technologies that could overcome the problem of the limited availability of the isotope uranium 235 are fast reactors and breeder reactors. Natural uranium consists to 99.3% of the isotope uranium 238 and to 0.7% of the isotope uranium 235. Only the isotope uranium 235 is fissile and can be used as fuel for nuclear reactors. But there is the possibility for uranium 238, by neutron capture and beta decay, to transmute to the isotope plutonium 239, which is again fissile and can be used as reactor fuel too. However, since plutonium based reactors use neutrons of higher energy – so called fast reactors – the geometry of the reactor core is different. Breeder reactors are reactors which breed plutonium from uranium 238. This technology, in principle, permits to extend the existing uranium resources. Even better, previously used reactor fuel, which currently poses a threat due to its high radioactivity, could become a resource for fast reactors and breeder reactors.

Up to now fewer than ten fast reactors have been deployed in a scale suitable for commercial operation. But fast reactors have had a very poor record with one single exception – the BN-600 fast breeder reactor at Beloyarsk in Russia has a lifetime load factor of 74.1% as of June 2013. The other fast reactors had lifetime load factors significantly below that (Sholly, 2013):

- BN-350 (Aktau; Kazakhstan), 44.48%.
- Fermi Unit 1 (United States), 3.41% in 1971, the only year of data available in IAEA's PRIS database, and during the time it operated it was under trial operation.
- Monju (Japan) was connected to the grid on 29 August 1995 and has been closed since 8 December 1995, except for a brief period of operation in 2010.
- Phénix (France), 41.34%.
- Prototype Fast Reactor (Dounreay, United Kingdom), 23.87%.
- Superphénix (France), lifetime value not estimated in PRIS, but its best year was only 32.18%.
- The 25 MWe Chinese Experimental Fast Reactor was first connected to the grid on 21 July 2011; IAEA PRIS reports no load data for this unit, which operated for only 26 hours online in 2011.
- India operated the Fast Breeder Test Reactor (13.2 MWe design) from 1985, and has operated through 2013. The FBTR was shut down from 1987-1989, and operated at only 1 MW from 1989-1992, and then at 10.5 MWe from 1993. The operating life was extended for another 20 years, but with the reactor operating at 50% capacity.

This means that most of the fast reactors deployed so far have still the character of experimental or demonstration reactors. The most promising designs so far for fast reactors are based on sodium as primary coolant – which leads to currently unresolved safety issues. Being liquid, metal sodium gets highly activated during its passage through the reactor core. This means the primary coolant of a sodium cooled fast reactor is highly radioactive. In addition, sodium reacts with air and water – which means that a sodium leak, either to the atmosphere or to the water loop, bears the risk of a catastrophic accident.

A different problem is the so called "breeding ratio", i.e. the ratio new plutonium produced from uranium 238 to plutonium burned to during operation of the reactor. To operate a large fleet of fast reactors plutonium is needed. The plutonium currently available from spent fuel of the light water reactors could fuel at most 50 reactors. To generate plutonium on a large scale these reactors would need breeding ratios considerably larger than one, while current reactors demonstrate at best ratios close to one.

Generation IV reactor concepts, as proposed in 2002 by the Generation IV International Forum to be researched and developed within the upcoming decades, include fast reactors (GFR, LFR, SCWR and MSR). But only the Molten Salt Reactor (MSR) is designed to be a fast breeder reactor. The other three fast reactor concepts in Generation IV are fast burner reactors (consuming excess plutonium and highly enriched uranium; with breeding ratios less than 1). Commercial scale Generation IV fast reactors are not expected to become operational until the 2040-2050 time frame. Only small technology demonstrator reactors are expected to be available before 2040 (for more details refer to (Sholly 2013), as well as (De Santi, 2009), (IAE/NEA, 2010), (Lee, 2010) and (Riou, 2009)). It turns out, that fast reactors and breeders or burners, will not be available in time to contribute to climate change mitigation.

5.) Beside the problem of resources, the investments needed for nuclear expansion programs constitute a serious bottleneck (Thomas, 2013). The nuclear option depends on government guarantees and subsidies. In countries with liberalized electricity markets investors fear the financial risks of new builds, especially overruns in construction time of nuclear power plants, and underestimation of capital costs because of the risk that these extra costs will not be recoverable from the market.

Until now existing nuclear power programs depend on state financed support in different forms. It is not credible that the investment needed for a massive nuclear expansion programs of about 4000 GWe capacity by 2035 can be procured (5 billion Euro is a conservative estimate for the overnight cost of a single 1000 MWe nuclear power unit). As consequence nuclear energy cannot expand to meet the capacities foreseen in the high growth scenarios. A limited expansion will happen but only in non-liberalized markets or in markets where the state provides comprehensive support, especially for price- and loan-guarantees.

In addition to the need for large investments, a number of other bottlenecks will curb the expansion of the nuclear program:

To achieve a total of 3500 new reactors by 2035 (assuming the average single unit capacity is 1200 MWe), 1000 or more sites would be needed, the majority of them new. From 2015 to 2035 the average number of reactors commissioned would need to be more than 175 per year (from current 3.3 per year during last 10 years and the historical maximum of 23 per year from 1980–1990).

The construction workforce needed to construct 175 new reactors each year would be more than 50 million man-years (each year more than 2.5 million managers, engineers, boilermakers, iron workers, welders, electricians, Instrumentation & Control workers, pipe fitters, insulators, carpenters, painters, craft supervisors, quality control and licensing inspectors, etc. working on nuclear power plant construction) (KHNP, 2012). To design, manufacture, construct and operate 3500 new power reactors the world nuclear industry would require about 2 million people (from current 250 000), of which about 350 000 or more would be operating personnel (NW, 2007). Even with current build rates the nuclear industry faces problems to employ trained personnel in sufficient numbers (Simonovska, 2012). Large numbers of graduates from related fields would have to be hired (e.g. mechanical engineers instead of nuclear engineers) and trained on the job. Quality of construction work would be questionable.

Capacity to manufacture sets of heavy components for power reactors would have to be increased from 34 sets per year (currently available and planned till 2020, (WNA, 2013) to more than 175 per year in the following years. Considering the time needed to construct and commission factories for heavy components considerable delays can be expected. The temptation to lower standards to help delayed build programs could compromise the quality of components.

Initial costs to construct 3500 new reactors would be about 21 Trillion EUR (optimistic scenario), based on €6000/kWe (Cooper, 2012). However the costs could be easily doubled or even tripled (pessimistic scenario), taking into account construction delays and cost overruns due to the lack of capital, the large number of projects, shortage of qualified construction workforce and operational personnel, costs of new transmission lines, costs to upgrade electrical grids and for replacing capacities, costs for decommissioning and management of radioactive waste and spent fuel.

Operation of 3500 new reactors (ten times more than in operation today) would create additional problems and difficulties in the management of huge quantities of radioactive waste and spent fuel, especially regarding final storage of spent fuel. In addition the risk of severe accidents will remain considerable and possibly grow, not only because it is proportional to the number of constructed reactors, but also taking into account problems with the quality and lack of qualified construction and operational personnel (see below). These factors will create additional public concern – even now most Europeans believe that risks related to nuclear energy are underestimated, and they identify lack of security against terrorist attacks on power plants and the disposal and management of radioactive waste as the major dangers (EC, 2010).

Due to the discussed bottlenecks – huge initial costs, lack of capital, financial risks, capacity to manufacture sets of components, lack of construction and operating personnel, questionable quality of manufacturing, construction and operation under such conditions, risks of new severe accidents and public reaction – the construction of 4000 GWe nuclear capacity by 2035 can be excluded.

6.) The nuclear risk of severe accidents and large releases has special characteristics (Seidelberger, 2013). On one hand technical safety features of the new generation of nuclear power plants are more advanced than those of older reactor types. On the other hand, due to the complexity of the system, unforeseeable human failures, immanent organizational weakness of nuclear institutions, accumulation of large amounts of highly radioactive materials and the high power levels of nuclear reactors, severe accidents with catastrophic consequences cannot be excluded, see e.g. (Perrow, 1984), (Andreev et al., 2012), (Kan, 2012) and (NAIIC, 2012). There is always a residual risk which remains[10]. History showed that severe accidents can happen, even though safety systems of nuclear power plants are continuously improved. Improved safety and reduced calculated overall frequency of severe accidents is one of the main differences between the so called “Generation II” reactors, i.e. reactors that were developed in the 60ties and 70ties, and “Generation III/III+” reactors, the reactors that are build today (mostly)[11]. Generation III/III+ reactors are already designed with the intention to cope with core melt in case of severe accidents e. g. using core catchers and passive safety systems (see Figure 4). However, experimental evidence for the functionality of these measures on sufficiently large scale is at best difficult to achieve, but might even be prohibitive due to the risk involved. But most of the currently operating reactors are “Generation II” reactors.

For economic reasons a worldwide trend to extend the life time of Generation II reactors can be observed. The lifetime of Fukushima Daiichi Unit I, a Generation II NPP, was e.g. extended by ten years just about one month prior to the Fukushima accident. Generation II reactors as e.g. Mochovce Nuclear Power Plant at 150 km distance from Vienna are still in construction (Kastchiev et al., 2012).

Considering the current trend to life time extension it can be assumed that the last plants of Generation II NPPs will not be shut down before 60 years from now. Considering the frequency of nuclear catastrophes in the past, it seems likely that another nuclear catastrophe will happen in the next decades.

Even if the probability of severe accidents could be lowered by one order of magnitude from Generation II to Generation III, for a massive nuclear expansion scenario of 3000-4000 new units up to 2035, i.e. an increase of current capacity by a factor of ten, the overall risk of a nuclear catastrophe would at least remain at the current level. As shown above a massive expansion scenario would require a different type of fuel (plutonium) and different types of reactors (fast burner and breeder reactors). More reprocessing plants, concentrating large

[10] For a discussion of severe accidents in GenII/III/III+ reactors see (Sehgal et. al., 2012)

[11] For a discussion of differences between the Gen II and Gen III/III+ safety concepts see (WENRA RHGW, 2009)

amounts of radioactive material in one place, would be required, posing new and additional risks. Fresh reactor fuel would be highly radioactive, which would increase the risk during transport, as well as occupational doses of plant workers.

The use of digital instrumentation and control system leads to increased risks concerning cyber-attacks (Arnold, 2012a), as was recently emphasized at the International Disaster and Risk Conference IDRC Davos 2012. Companies of all kinds were urged to install teams of defense specialists ("Computer Emergency Response Teams, CERT", or "Computer Security Incident Response Teams CSIRT") for self protection because potential attackers are a minimum of two years (technologically) ahead of defence specialists (De Landgraaf, 2012).

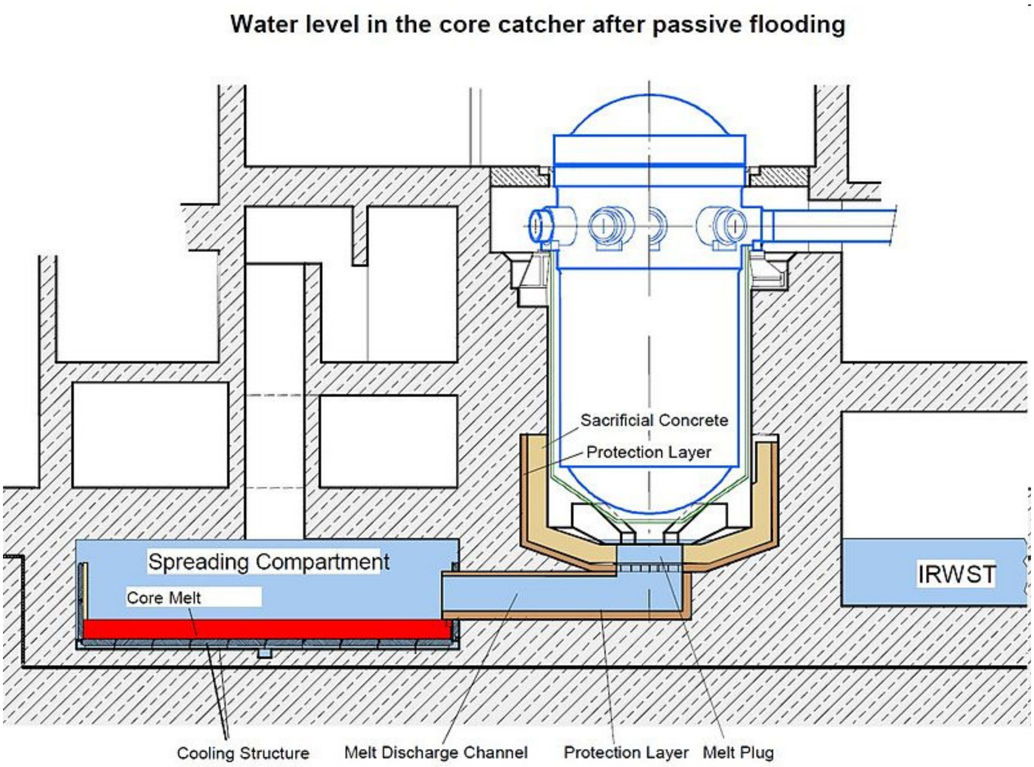

Figure 4: Generation III SA management design for EPR, core melt spreading and cooling for ex-vessel melt retention (Wikipedia, 2013, Areva, 2009). However, analytical and experimental programmes that could confirm that concepts like the above core catcher actually work are still ongoing, and face potentially unresolvable methodological problems.

Additional proliferation issues would arise due to increased demand for uranium enrichment and later on, probably, due to a large-scale plutonium economy implying dramatically increased access to weapon-grade plutonium. Governments might pursue "hidden agendas" regarding military aspects, see also Liebert (2011). So even if the safety of nuclear power plants increases, massive expansion scenarios necessarily increase the risk of nuclear catastrophes (Bell, 2011) and nuclear proliferation.

7.) Should Austria decide to introduce a nuclear power programme it would have to do much more than the construction of the units (Sholly, 2013a). Austria would have to:

- Pass a constitutional amendment rescinding the ban on nuclear power.
- Pass a nuclear law (enabling legislation), including guarantees for feed-in tariffs as privilege for nuclear power.
- Pass legislation establishing liability for nuclear accidents.
- Establish and staff an independent Nuclear Regulatory Authority (NRA) and its Technical Support Organization (TSO).
- Establish a nuclear constabulary or an equivalent means to provide external security for nuclear power plant sites and a geological repository, as well as fuel and radioactive waste shipments from power plant sites to the repository.
- Upgrade emergency planning and response capabilities for responding to nuclear accidents inside Austria and for providing assistance to neighboring transboundary countries in such an event.
- Build structures (storage facilities/ disposal sites / conditioning facility) to handle the different kinds of radioactive waste.

Assuming an immediate start of the programme, the first reactor could, at best, start operation around 2028, with three reactors to follow in 2030, 2032, 2034. Austria could not introduce more than four reactors, because there are not enough suitable sites, and because the grid in Austria could not accommodate more NPPs. The grand total estimate for a 4-unit nuclear power program is roughly €150[12] billion (optimistic) to €170 billion (pessimistic). Costs for nuclear generated electricity would range from 7-15 €Cent / kWh (not considering profits).

The potential costs and consequences of a severe accident involving large releases of radioactive materials are not considered in this report.

The possible contribution to reduce greenhouse gas emissions[13] from an Austrian nuclear power programme would be modest with at most[14] 12%, but expensive and connected to a spectrum of multiple risks.

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[12] This estimate is based on: (a) a per unit cost of €10 billion (as an all-in estimate, including overnight costs, owner's costs, connection of the plant to the grid, escalation, inflation, and interest on construction loans); (b) operations and maintenance (O&M) expenses – including fuel – of 3 Eurocents per kilowatt hour; (c) 93% plant availability, as predicted by the designers; (d) decommissioning costs of €1.5 billion per unit; (e) a single radioactive waste and spent fuel repository at a cost of €15 billion; and (f) lifetime governmental costs of €7 billion (over 110 years), see (Sholly, 2013a).

[13] Assuming four reactors of 1000 MWe, with load factor of 0.85, will be built instead of gas-power stations with a CO_2 intensity of 500 g CO_2 eq. / kWh and zero emissions for the nuclear kWh, the contribution to climate change mitigation would be roughly 15 million tons CO_2 eq. (total GHG emissions in Austria in 2011 (EC, 2013) amounted to 83 million tons of CO_2 eq., assuming growth rates for energy use and CO_2 emissions of 1.7% (AEC,2007) total Austrian CO_2 emissions in 2035 would amount to 123 million tons of CO_2 eq.).

A high level workshop with Austrian stakeholders[15] took place in November 2012 in Vienna in the frame of the project. The stakeholders were invited to discuss the implications of a hypothetical Austrian nuclear energy programme. The aim of the workshop was to bring together experts from different fields – science, politics and the regulatory body – to get a comprehensive view on potential bottlenecks.

The stakeholders identified several bottlenecks for an Austrian nuclear program:

- The Austrian constitution needed to be amended. This was expected to take at least 3-5 years. A legal framework including an independent regulatory authority needed to be established. The regulatory authority would need independent funding and an adequate legal framework.
- One of the major bottlenecks discussed by the stakeholders was financing. The lack of potential investors can be observed in other countries such as Great Britain. In order to get investors the state would need to give loan guarantees.
- Lack of human resources for construction, regulatory body, regulation, operation.

Additionally it was mentioned that for a small nuclear program with only four reactors an Austrian utility would need a strategic partner for the nuclear competence, since four reactors are not sufficient for a utility to cover all necessary fields which are needed for operation of nuclear power plants.

The spectrum from pro-nuclear to nuclear critical experts agreed that in view of the efforts needed in all the above listed areas, the nuclear option would not be viable in Austria. This result is of relevance for any medium sized country considering phasing in nuclear power.

4 Results and Conclusions

Anthropogenic climate change requires a rapid shift towards a CO2 neutral economy, if the global average temperature increase is to be kept below 2°C. Climate change mitigation measures are needed in the near term to medium term future. A change in the GHG emission trend is needed with emissions peaking around 2020. By 2050 the economy should be CO2 neutral. Such a shift would strongly influence the energy (and electricity) supply system,

[14] The assumption that nuclear power would substitute exclusively gas power is not realistic, since nuclear power load-follow capabilities are limited, especially when a high degree of renewable energy sources are connected to the grid. Such a nuclear power programme would necessarily also substitute renewable energy sources, and therefore the CO2 intensity would be lower (Renneberg, 2011).

15 H. Böck, Atominstitut; M. Ditto, Leitung Strahlenschutz; S. Hossain, ISR; W. Kempel, Leitung Abt. III.5 BmeiA; W. Kromp, ISR; H. Kromp-Kolb, Forum für Atomfragen; W. Liebert, ISR; A. Molin, Abt. V/6 Lebensministerium Nuklearkoordination; G. Oberreiter, BMeiA; H. Rauch, Atominstitut; W. Renneberg, Büro- für Atomsicherheit, Ex-Director General for Nuclear Safety, Germany; W. Sandtner, BMBF, später BMW, Germany; E. Seidelberger, ISR; G. Weimann, ISR

which is currently based to a larger part on fossil fuels. The EHNUR project answers the question whether nuclear power could significantly contribute, or even be the backbone of a new, sustainable and CO2 neutral energy system to cope with the 2°C target.

The most important result of the present study is that the role of nuclear power to mitigate GHG emissions is marginal. Nuclear power cannot contribute significantly more than 3% to the reduction of GHG emissions in the mentioned time frame until 2050. It will not be possible to expand nuclear power programmes significantly in the frame important for climate change mitigation, because of technical and economical bottlenecks. Already the limited uranium supply and the substantial investment costs inhibit massive expansion scenarios with the current nuclear technology, and new nuclear technologies, making use of the full spectrum of uranium isotopes, will not be commercially available in time.

According to the results of the EHNUR project nuclear power therefore cannot be the appropriate tool for climate change mitigation. This conclusion holds independent of any political or ideological debate about pros and cons of nuclear energy and is based on the thorough assessment of hurdles, bottlenecks and barriers which make a large or massive nuclear expansion unfeasible within the next decades (Gufler, 2013), (Zittel et. al. 2013), (Kastchiev, 2013) and (Thomas, 2013).

The political question is if nuclear power should be deployed as very modest backup for other GHG mitigation strategies and technologies. To help in answering this question the EHNUR project established minimum requirements or normative benchmarks (Müllner et al., 2013) for nuclear power as part of the overall climate change mitigation strategy. To be a valid option for climate change mitigation nuclear energy should:

- guarantee sustainable availability;
- be CO2 neutral (low carbon);
- not cause ambient pollution;
- not cause catastrophic accidents;
- be proliferation resistant;
- be technologically feasible;
- be economically feasible, and
- be diverse and complementary to the other sources of energy in the overall energy supply system.

Available nuclear energy technologies cannot fulfill most of those requirements:

Sustainable availability: Current reactors utilize uranium 235 as fuel, which is a rare resource in nature. It is estimated that with the present rate of consumption nuclear power will be available for 50 to 100 years. An larger or massive expansion of nuclear energy usage would run into troubles concerning uranium supply already in the short and mid-term future. Should the utilization of nuclear power increase with a longer term perspective new technologies have to be introduced – fast breeder reactors, or thorium breeder reactors whose other ramifications have to be considered carefully.

Low carbon: even though GHG emissions from nuclear power plants are usually lower than emissions from typical fossil fuelled power stations, they are not zero, and depend mainly on uranium ore grade, mining and enrichment techniques as well as emissions during the construction of the final repository. Currently nuclear power avoids roughly 3 % of total worldwide GHG emissions. Would nuclear power substitute all fossil electricity generation by 2035, it could avoid 25-30% of GHG emission in the year 2035. But such a massive nuclear expansion is unfeasible, more likely a nuclear contribution of about 3% is to be expected. And even though the contribution of a massive nuclear expansion to climate change mitigation would be considerable, there are still major additional actions needed to keep on a 2°C climate pathway.

Ambient air pollution: Though air pollution in normal operations is low, in case of accidents pollution can be devastating and is very long lived.

Catastrophic accidents: Nuclear reactors, no matter how safe they may be, always carry a residual risk for severe, catastrophic accidents (Sehgal et al., 2012) and large releases of radioactive materials (Seibert et. al., 2012). With every new generation of reactors the attempt to reduce the residual risk even further is made, but even with future technologies a nuclear catastrophe cannot be fully excluded. The main contribution to current nuclear electricity generation stems from Generation II reactors, which were designed in the 70ties and 80ties. The current generation of reactors (Generation III and Generation III+) promises that the risk for severe accidents is reduced by a factor of ten. But if the current number of reactors is increased dramatically, as necessary for climate change, the risk of a nuclear catastrophe stays at best constant.

Proliferation risk: Massive or even significant moderate expansion of nuclear energy would request a massive or significant expansion of uranium enrichment which has an intrinsic and serious link to increasing the probability of weapons proliferation. It is hard to believe that access to this most sensitive technology can be restricted to only a dozen of states as today. If in the future breeder reactors should partly replace light water reactors reprocessing of spent fuel is essential. Plutonium discharged from breeder blankets would be of highest weapon grade quality. Access to such plutonium would tremendously increased by breeder programmes of the future thus dramatically increasing proliferation dangers.

Technologically feasible: Only light water technology is ready for commercial utilization. New nuclear technologies, which are necessary if nuclear were to be used on large scale, are not yet commercially proven. This is especially true for fast and breeder reactors, thorium breeder reactors, and very high temperature reactors needed for hydrogen economy. New technologies might become available at earliest in 2040.

Economically feasible: When analyzing recent new builds it becomes questionable if current reactor technologies can be build without state aid, state loan guaranties or guaranteed electricity prices for the long amortization periods. There are no new builds in states with liberalized electricity markets, and there are even examples of operating reactors being shut down because of competition from electricity from gas fired power plants.

Complementary to other sources of energy: Nuclear is cost intensive in its initial phases – the time period during which renewables need resources to significantly increase in capacity. Nuclear is a base load power source, renewables have highly variable, weather dependant outputs. Nuclear cannot easily follow fluctuating demand and is not a well suited complementary energy source.

The Global Energy Assessment (IIASA, 2012) confirms the results of the EHNUR project. It adopts a normative approach for its single scenario. The scenario requires that by 2050 society is on a climate pathway to fulfilling the 2°C target while still providing access to modern energy services to all humans. Starting from the goal of a sustainable, CO2 neutral economy, GEA calculates back and investigates which energy pathways lead to such a future. One of the important results of the analysis shows that none of the evaluated pathways make it necessary to use nuclear power. No matter if a high-energy demand pathway, a high-energy efficiency pathway or a mixed pathway is assumed, or if technological breakthroughs in transport can be achieved so that electric and hydrogen powered vehicles are going to be introduced, nuclear energy is limited to satisfy only a small fraction of global energy demand, thus contributing only marginally to climate change mitigation. Furthermore, all pathways allow other energy sources to substitute nuclear energy.

As stated in IIASA (2012, p. 1237) – nuclear energy is a controversial supply option because of unresolved problems of long-term waste disposal, the risk of catastrophic accidents and the associated liabilities, economic considerations, other issues, like bottlenecks and doubts on the long term availability of fissile uranium resources and the possible proliferation of weapons-grade fissile material.

The substantial risks of nuclear technology should be held against its possible contribution to climate change mitigation, which is marginal.

5 Outlook and Recommendations

Implications of a nuclear growth scenario on the waste disposal strategies

The impacts of nuclear growth scenarios on the waste problem were not part of the study. A complementary study on the implication on waste and waste disposal strategies including transmutation techniques could be useful for a comprehensive view on worldwide nuclear perspectives.

Implications of a nuclear growth scenario on the nuclear fuel cycle

When talking about nuclear growth, this growth will to a great deal affect “newcomer” countries and “emerging” nuclear countries. Until now the nuclear fuel cycle facilities are mainly located in the “traditional” nuclear markets. By this the access to nuclear weapon material and technologies to produce them is internationally limited. The shift from traditional nuclear markets to new actors in the nuclear industry will have severe implications on the nuclear fuel cycle. With more and more countries developing nuclear capacities and independent nuclear fuel production capacities the role of the IAEA safeguards will become even more crucial. Additionally the spread of nuclear fuel cycle know how imposes severe risk concerning proliferation. An in depth analyses should be performed and should elaborate mitigation strategies to contain such risks.

Link between the FlexRISK and the EHNUR project

The KLIEN Fonds funded project FlexRISK (Seibert P. et al., 2012, see also flexrisk.boku.ac.at) studies the geographical distribution of the risk due to severe accidents in nuclear facilities, especially nuclear power plants (NPP) in Europe. Maps and diagrams indicate, e.g., where in Europe the risk to be affected by a severe accident is especially high, or which contribution is incurred by the NPPs of a specific country (flexrisk.boku.ac.at). The FlexRISK project focused only on Europe. The EHNUR database can be used to expand the focus region towards a global picture. When combining the two projects a comprehensive global risk map could be created (adopting simplified methods to handle the large amount of data). With such an instrument the radiological spread of nuclear power plant accidents could be shown for every NPP in the world. Such an instrument does not exist yet. Austria could play a pioneer role in this field.

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7 Appendix

7.1 List of Abbreviations

CERT	Computer Emergency Response Team
CSIRT	Computer Security Incident Response Team
EHNUR	Evaluation of a Hypothetical Nuclear Renaissance
EC	European Commission
EPR	European Pressurized Water Reactor
FBTR	Fast Breeder Test Reactor
GEA	Global Energy Assessment
GFR	Gas cooled Fast Reactor
GHG	Greenhouse Gas
GWe	Gigawatt electrical
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
IDRC	International Disaster and Risk Conference
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
ISR	Institute for Safety- and Risk Research
KHNP	Korean Hydro and Nuclear Power
kWe	Kilowatt electrical
kWh	Kilowatt hour
LFR	Liquid metal Fast Reactor
MSR	Molten Salt Reactor
MWe	Megawatt electrical
NEA	Nuclear Energy Agency
NPP	Nuclear Power Plant
NRA	Nuclear Regulatory Authority
NW	Nucleonic Week

OECD	Organization for Economical Co-operation and Development
PRIS	Power Reactor Information System
QC	Quality Control
SA	Severe Accident
SCWR	Supercritical Water Reactor
TSO	Technical Support Organisation
UNEP	United Nations Environment Programme
UNDP	United Nations Development Programme
WANO	World Association of Nuclear Operators
WENRA	Western European Nuclear Regulators Association
WNA	World Nuclear Association

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Annex 9: Hypothetical use of nuclear power in Austria

8 Contact details

Projektmanager	*Ao.Univ.Prof. Dr. Wolfgang Kromp*
Institute	*University of Natural Resources and Life Sciences Vienna, Institute of Safety and Risk Sciences*
Contact address	*Borkowskigasse 4, 1190 Wien* *Tel.: +43-1-47654 DW 7700 FAX DW 7709* *email: risiko@risk.boku.ac.at,* *http://www.risk.boku.ac.at/EHNUR*
Partners of the consortium	*PSIRU, University of Greenwich* *IANUS, TU Darmstadt* *Umweltmanagement Austria* *ÖGUT, Österreichische Gesellschaft für Umwelt und Technik*

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Author
University of Natural Resources and Life Sciences Vienna, Institute of Safety and Risk Sciences
Wolfgang Kromp
Borkowskigasse 4, 1190 Wien
Tel.: +43-1-47654 DW 7700 FAX DW 7709
email: risiko@risk.boku.ac.at,
web: http://www.risk.boku.ac.at/EHNUR

Partners of the consortium

- PSIRU, University of Greenwich
- IANUS, TU Darmstadt
- Umweltmanagement Austria
- ÖGUT, Österreichische Gesellschaft für Umwelt und Technik

Project team

- Karl Arlamovsky
- Nikolaus Arnold
- Daniel Baumgarten
- Reinhold Christian
- Michael Cerveny
- Herbert Formayer
- Martin Giersch
- Klaus Gufler
- Gueorgui Kastchiev
- Wolfgang Kromp
- Helga Kromp-Kolb
- Wolfgang Liebert
- Nikolaus Müllner
- Wolfgang Rehm
- Wolfgang Renneberg
- Irene Schicker
- Emmerich Seidelberger
- Steven Sholly
- Stephen Thomas
- Geert Weimann
- Werner Zittel

Owner, publisherand media owner
Climate and Energy Fund
Gumpendorfer Straße 5/22, 1060 Wien
E-Mail: office@klimafonds.gv.at
Web: www.klimafonds.gv.at

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