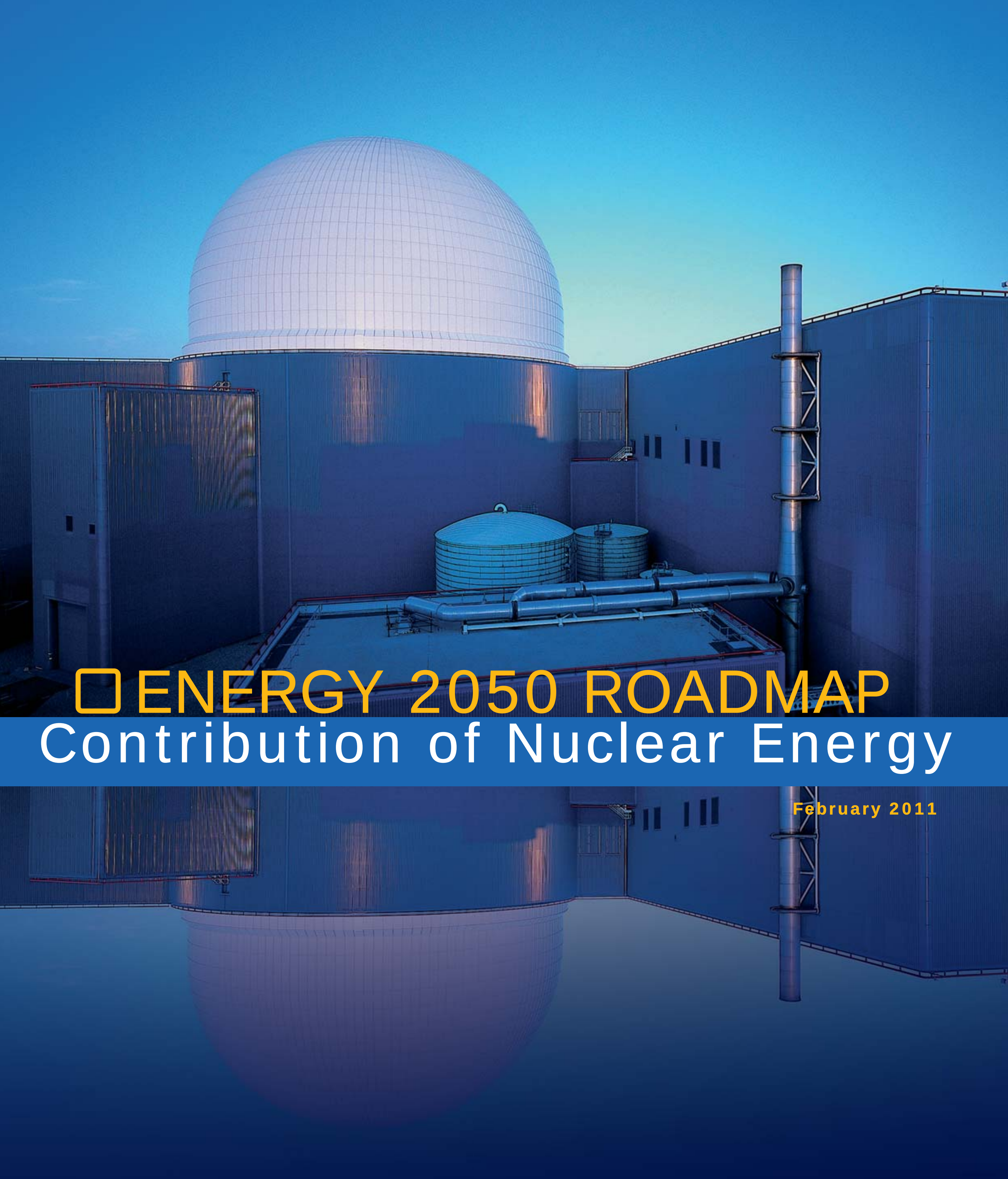

ENERGY 2050 ROADMAP

Contribution of Nuclear Energy

February 2011

FORATOM
for nuclear energy in europe

FORATOM
for nuclear energy in europe

The European Atomic Forum (FORATOM) is the Brussels-based trade association for the nuclear energy industry in Europe. Its main purpose is to promote the use of nuclear energy in Europe by representing the interests of this important and multi-faceted industrial sector.

The membership of FORATOM is made up of 16 national nuclear associations active across Europe and the nearly 800 firms that they represent.

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Cover picture : courtesy of EDF Energy & NIA

Foreword

by the Chairman of the European Parliament's Industry, Research & Energy Committee, Mr. Herbert Reul, MEP

Herbert Reul

Ensuring a competitive, sustainable and secure energy supply for European citizens, SMEs and industries is not only the goal of the EU's energy policy but it is also its core challenge! With the vast investment needs in energy generation and infrastructure over the next decades, the obligations to cut greenhouse gas emissions and make our energy sector sustainable, and with the need to keep our industries competitive and at the forefront of technological development, an ambitious and robust policy framework is urgently needed. In order to be in a position to sustain the achievement of these goals until 2050, crucial decisions have to be taken today. The European Parliament with its new powers enshrined in the Lisbon Treaty has a significant role to play in making our energy vision a reality. The answer to meeting the challenges we face lies in securing a balanced low-carbon energy mix. We therefore must include nuclear energy alongside renewables, CCS and other new and clean technologies such as fusion power in our long-term energy portfolio.

Many well-respected energy organisations, including IEA, WEC, NEA, IPCC, have underlined the importance of maintaining the share of nuclear electricity in the energy mix. It currently stands just below 30% in the EU. However, this cannot be done without political support. Therefore, we as decision-makers must ensure that the EU's Energy Roadmap 2050, inclusive of all low-carbon energy sources, underlines the key role nuclear power can play in ensuring European security of supply, competitiveness and sustainability. Completion of the EU legal framework for nuclear safety and radioactive waste management will help guarantee that the highest safety standards are applied by the nuclear industry. Furthermore, the industry itself has major tasks ahead in making sure that its costs remain competitive and that the sector remains at the forefront of the global technology and business development.

In 2011 we will make important decisions with regard to the Multiannual Financial Framework for the European Union and the 8th Framework Programme for Research. We have to ensure that the long-term financing of the development of innovative, low-carbon energy technologies is secured. By innovating and promoting clean and efficient technologies we can move towards the decarbonisation of the energy sector. Implementation of the European Strategic Energy Technology Plan (SET-Plan) and the Industrial Initiatives will be of great significance. The European Parliament will have a central role in these discussions and in forming an all-inclusive low-carbon-energy strategy for Europe until 2050.

I welcome the contribution of FORATOM to this important debate.

Foreword

by the FORATOM President and Vice-President

Ralf Güldner

Per-Olof Waessman

The European Commission’s Energy 2020 Strategy, published in November 2010, includes a commitment to establish a vision of the structural and technological changes required to move to a secure, competitive and low carbon energy system by 2050. With the aim of presenting such a vision, the Commission has embarked upon an exercise to analyse a set of energy scenarios up to 2050 and to draw up policy instruments which will ensure the achievement of these goals.

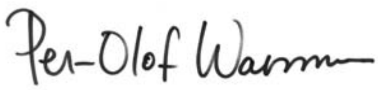
In order to contribute to the European Commission’s Energy Roadmap 2050, FORATOM engaged the Paul Scherrer Institute to scientifically review selected leading scenario studies in order to provide insights relating to the realisation of future levels of nuclear deployment in the scenarios. FORATOM also gathered the nuclear energy industry’s views on the conditions that need to be met in order to achieve the nuclear deployment reflected in the scenarios.

The scenario review showed that different pathways to achieve a low-carbon and cost-competitive energy landscape by 2050 include nuclear energy. Moreover, the scenarios with strong climate policy presented higher nuclear shares than business-as-usual cases. The review also highlighted the importance of the level of political support for nuclear energy in shaping future deployment.

FORATOM drew significant conclusions from this exercise and identified a number of recommendations to the EU and national decision-makers as well as to the nuclear industry. FORATOM is well aware of the challenges the industry faces. With this contribution FORATOM wishes to confirm the industry’s determination to be an important stakeholder in building a low-carbon, competitive and secure energy future.

Ralf Güldner
President

Per-Olof Waessman
Vice-President

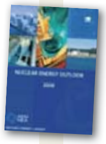


Contents

Executive Summary

FORATOM is the trade association for the European nuclear industry. “Energy 2050 Roadmap – Contribution of Nuclear Energy” is FORATOM’s contribution to the debate on the EU Energy Roadmap 2050. Part I of this report presents a review of scenarios prepared for FORATOM by the Paul Scherrer Institute (PSI), whereas Part II was elaborated by the FORATOM Ad hoc 2050 Roadmap Task Force gathering industry experts.

Part I includes a review of five well-known scenario studies. For each study, two scenarios are selected: (i) a baseline/reference/business-as-usual scenario; and (ii) a scenario which is consistent with a 50% reduction in global greenhouse gas emissions by 2050, and which realises a share of nuclear generation in Europe of roughly 30% in 2050.

Study	 Power Choices	 Energy Technology Perspectives 2010	 Energy Policy Scenarios to 2050	 Nuclear Energy Outlook 2008	 NEEDS
Author/sponsor	Eurelectric (2010)	IEA (2010)	WEC (2007)	NEA (2008)	EU Commission (2009)
Selected scenarios **Emission reduction**	1. Baseline 2. Power Choices 50% global reduction	1. ETP Baseline 2. ETP BLUE Map 50% global reduction	1. WEC Leopard 2. WEC Lion Very high global concern on climate	1. NEO Low 2. NEO High High concern on climate	1. NEEDS BAU 2. NEEDS 450 ppm +2 degree target

These scenarios present a range of possibilities for the future of nuclear energy in Europe in 2050. Nuclear plays a substantial role in Europe across the scenarios, with the nuclear deployment ranging from 117 to 424 GW in 2050, compared to the current 134 GW in the European Union (EU). For most studies with a strong climate change mitigation target, a nuclear share of roughly 30% is realised. The future role of nuclear electricity generation in the scenarios depends on two sets of driving forces and conditions: (1) the size of the future electricity market; and (2) the relative competitiveness and availability (and acceptability) of nuclear energy vis-à-vis other electricity generation options. The detailed analysis of the scenarios showed that there are four main factors that influence the role of nuclear energy:

- A major factor is represented by political limitations on deployment of nuclear which constrain its development in all studies. Nuclear phase-out policies, restrictions on users and sites as well as arbitrary caps greatly influence the final share of nuclear in 2050.

- The extent of electrification is very important for the size of the market for nuclear. The success of electric mobility and large-scale electrification of industry and buildings seem to influence whether electrification levels are of the order of 30% or above 40%.

- Competitive generation costs are assumed in all scenarios supporting the higher share of nuclear in the overall energy mix.

- All scenarios realising roughly a 30% nuclear electricity share are characterised by a strong climate policy or high concern for climate issues.

Overall, looking across the scenarios, if we account for a ‘central’ level of political support for nuclear, a moderately optimistic increase in electrification, an ambitious climate policy, and the realisation of relatively cheap generation costs, a level of nuclear deployment in EU27 or OECD Europe of 160-170 GW in 2050 could be achieved. Importantly, the review led to the observation that substantially higher levels of nuclear deployment could be realised under the condition that political support for nuclear is significantly enhanced in some Member States.

In parallel to the scenarios review, FORATOM Members, gathered in the Ad hoc 2050 Roadmap Task Force, concluded that the main drivers behind the contribution of nuclear energy to the 2050 low-carbon energy system in the EU will be: security of supply, transition to low-carbon fuels, competitiveness, strong global growth of nuclear energy capacities and new applications of nuclear energy.

The European Commission (EC) is estimating that “over the next ten years, energy investments in the order of € 1 trillion are needed, both to diversify existing resources, replace equipment and to cater for challenging and changing energy requirements”. Ensuring a secure energy supply for the coming decades is one of the main priorities of the EU’s energy policy. Furthermore, the EU has decided that in order to achieve the decarbonisation of the electricity and transport sectors by 2050, it must make a shift to low-carbon energy technologies. Substitution of fossil fuels, increased use of electricity and energy efficiency improvements in the power plants, will be driving this transition in the energy sector. Moreover, the competitiveness of European industry in the world and the competitiveness of nuclear energy in the European market must be driven by innovation for nuclear technologies. Additionally, strong global growth of nuclear capacity will create opportunities for utilities and for the nuclear supply chain.

In order to meet the requirements for maintaining nuclear energy’s share in the EU at about 30% in 2050, a number of conditions were identified. Part II of the report lists these conditions and some key recommendations to the EU decision-makers, national (as well as regional and local) authorities and to the nuclear industry itself.

Recommendations to the EU decision-makers

The EU decision-makers should ensure that:

- the EU's 2050 energy strategy, inclusive of all low-carbon energy sources, underlines the key role that nuclear power can play in ensuring European security of supply, competitiveness and environmental sustainability, and that clear and sustained political support is granted to nuclear energy at the EU level,
- a legal EU framework for nuclear safety and radioactive waste management is in place and properly implemented,
- the EP, which will have an important role in the forming an energy strategy for Europe until 2050, includes nuclear energy in its vision for a balanced low-CO_2 energy mix,
- an appropriate network of nuclear R&D infrastructures, covering all aspects of the safe long-term use of power plants and the development of new, safe, competitive and sustainable reactor technologies is in place,
- public financial support for the European Sustainable Nuclear Industrial Initiative (ESNII) launched under the SET-Plan will be available,
- sharing of best practices in terms of the decision-making process with regard to new nuclear projects is promoted and that open and transparent procedures with clear responsibilities and timelines continue to be supported,
- for nuclear new build financing, implementing multi-source financing schemes, possibly including EURATOM and/or EIB loans and specially developed loan guarantee instruments is considered by the EC,
- current market failures and bottlenecks for private investment in the EU are identified, that existing financing instruments are reinforced and new ones established, and that a level-playing field for all low-carbon energy technologies is achieved,
- long-term contracts between nuclear energy suppliers and users, co-investment and other risk-sharing models to facilitate new nuclear build investment are authorised,
- harmonised conditions for the safe long-term operation of nuclear power plants are developed throughout the EU,
- the EC and national decision-makers support the harmonisation of licensing procedures as well as an EU-level reactor design clearance,
- technical leadership, skills and industrial capacities in the nuclear new build supply chain are maintained and developed,
- EU's energy and trade agendas are linked in order to sustain the leading role of European industrial players globally,
- the key contribution of nuclear to the EU low-carbon energy mix is highlighted towards the general public,
- the EC plays a key role in supporting the local communities' networking efforts on nuclear related issues,
- in nuclear transport, harmonisation of package design licensing procedures is supported such that a container licensed by the Competent Authority of one Member State should be able to be used throughout the EU without having to obtain additional licences.

Recommendations to the national decision-makers

The national decision-makers should ensure that:

- the national radioactive waste programmes, including final disposal are developed and implemented, in order to assure safety in the long-term. This should be done in accordance with the proposed EU Directive on the management of spent fuel and radioactive waste,
- political decisions are taken without undue delay to ensure that geological disposal is implemented. These decisions should be taken in an open and transparent way with appropriate public participation,
- the activities of local committees, partnerships or similar structures active in local discussions on nuclear energy issues are supported,
- information about nuclear energy is made available and disseminated to the public in order to encourage the widest possible knowledge about nuclear energy, including in non-nuclear Member States,
- stable and efficient regulatory regimes exist,
- the harmonisation of national licensing procedures as well as an EU-level reactor design clearance are supported,
- diversified uranium imports, recycling of spent fuel, recycling of enrichment tailings and the development of fast breeder (GEN IV) reactors is encouraged,
- every effort is made to attract young generations in schools and colleges to scientific studies, and that the importance of nuclear energy and the opportunities created by the sector are promoted towards the public, and especially towards youth,
- in accordance with the principles set out in the Aarhus convention, national authorities justify decisions made and give feedback on the actual consideration of stakeholders' views in the final decisions regarding construction or dismantling of a nuclear installation,
- more effective information and education directed towards nuclear materials carrier personnel is applied in order for them to fully understand the real risks and precautions.

Recommendations to the nuclear energy industry

The nuclear industry should ensure that:

- the safe operation of all nuclear installations is continued,
- the efforts in harmonising safety requirements and thus supporting the European Community framework for nuclear safety are pursued,
- safety standards for the design and operation of new nuclear reactors are developed by the industry in conjunction with WENRA, ENSREG and the European Institutions,
- the efforts to increase the availability factors of NPPs are continued, and hence the sector is continuously driven towards improving its performance record,
- the cost of new nuclear reactors remains competitive,
- EU researchers and companies increase their efforts to remain at the forefront of the growing international nuclear market,
- an industry support (from the nuclear sector but also from the electro-intensive industries) is available to launch a large-scale demonstration for coupling of a nuclear reactor with industrial process heat applications,
- financial provisions are available for the implementation of waste management programmes and that safety remains the priority,
- nuclear facilities continue to be as open as possible and allow visits by the general public in order to increase its level of knowledge on nuclear matters,
- standardisation of nuclear reactor designs is promoted by the nuclear energy industry with the support of ENSREG and the European Institutions,
- both mine operators and utilities invest in uranium mines and that geological exploration is sustained to convert “prognosticated” and “speculative” resources into “identified” resources,
- research and investment is enhanced to develop new uranium mine projects in a timely manner and to facilitate the deployment of new technologies,
- partnerships with universities, technical colleges and engineering schools are supported, and that the creation of master degrees in the appropriate disciplines is encouraged,
- the transparency and openness of nuclear activities in the entire fuel cycle is further ensured,
- wider dissemination of information relating to the safety of nuclear transport is promoted and that the general public is encouraged to visit transport facilities,
- proliferation-resistant reactor designs are given special attention and are promoted, that IAEA safeguards requirements are considered and safeguards approaches discussed with the inspectorates as early as possible when a facility is being designed,
- nuclear equipment, material and technology is always under IAEA safeguards,
- the initiative to use low-enriched uranium in research reactors around the world continues to be supported by the nuclear community.

Contributors

"Energy 2050 Roadmap – Contribution of Nuclear Energy" was developed by the FORATOM Ad hoc Task Force on the 2050 Roadmap. FORATOM would like to thank all those who have contributed to the report:

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Scenario review:

To support development of "Energy 2050 Roadmap – Contribution of Nuclear Energy", FORATOM engaged the Laboratory for Energy Systems Analysis (LEA) at the Paul Scherrer Institute (PSI) to undertake a review of selected energy scenarios and provide scientific comments on the Roadmap.

PSI is the largest research centre for natural and engineering sciences in Switzerland, and LEA is an interdepartmental laboratory uniting specific analytical research concerning all energy systems, including nuclear, fossil and renewables. The project team at PSI comprised:

- Hal Turton, Head of the Energy Economics Group, LEA, The Energy Departments, PSI
- Stefan Hirschberg, Head of LEA, The Energy Departments, PSI

The views expressed in the "Energy 2050 Roadmap – Contribution of Nuclear Energy" do not necessarily reflect the views of PSI or the project team.

Introduction

FORATOM's vision is "to support the development of nuclear energy in Europe in order to ensure that a long-term EU-wide low-carbon energy strategy includes the continued deployment of nuclear technologies to maintain, and ultimately increase, nuclear energy's one third share of the EU electricity generation market".

In the context of the EU-wide debate on the Energy Roadmap 2050, FORATOM engaged the Paul Scherrer Institute (PSI) to carry out a review and analysis of five reputed studies in order to provide insights relating to the realisation of future levels of nuclear deployment. The selected studies were: EURELECTRIC Power Choices (2010), OECD/IEA Energy Technology Perspectives (2010), WEC Energy Policy Scenarios to 2050 (2007), OECD/NEA Nuclear Energy Outlook (2008) and the European Commission NEEDS (2009).

The first part of this report comprises the review of scenarios. It includes an analysis of storylines and selected assumptions for the scenarios and identifies a number of key outputs (and the factors determining these outputs) from each scenario for Europe. These factors comprise the role of low-carbon electricity sources, the relationship between nuclear generation and other low-carbon options (renewables, CCS), and investments in the electricity grid. The review analyses how nuclear generation in Europe may change in the future and how it could respond to increasing electricity demand and other driving forces. In addition, the review assesses the potential contribution of nuclear generation to GHG abatement in 2050 in Europe.

The second part of this report was developed by the FORATOM Ad hoc 2050 Roadmap Task Force, gathering industry experts. Building on the key outputs determined in Part I, Part II discusses the main drivers for the development of the nuclear energy industry until 2050. Furthermore, it determines the conditions that need to be met in order to at least maintain the nuclear electricity share in the EU at about 30% in 2050. This part includes recommendations to the EU and national decision-makers as well as to the nuclear energy industry in support of FORATOM's long-term vision.

Part I:
SCENARIOS REVIEW

1 Approach

Scenarios of the European energy system present possible futures for nuclear energy and other energy sources. They illustrate how the level of nuclear generation may change, and provide a consistent storyline and quantification of the driving forces and conditions affecting deployment of nuclear and alternatives. Such scenarios can be used to “explore possible developments in the future and…test…strategies against those potential developments…”[1] and are thus a useful tool for supporting the formulation of the FORATOM report entitled *”Energy 2050 Roadmap – Contribution of Nuclear Energy”.*

The objective of this review of selected scenario studies is to provide insights into the conditions supporting the realisation of future levels of nuclear deployment in the scenarios. The review also aims to ascertain whether the scenarios provide a plausible view of the future of nuclear energy in Europe. Five scenario studies are analysed in this review, shown in Figure 1.1. For each study, two scenarios are selected: (i) a baseline/reference/business-as-usual scenario; and (ii) a scenario which is consistent with a 50% reduction in global greenhouse gas emissions by 2050 (see Figure 1.1), and which realises a share of nuclear generation in Europe of roughly 30% in 2050.

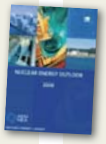
Study	 Power Choices	 Energy Technology Perspectives 2010	 Energy Policy Scenarios to 2050	 Nuclear Energy Outlook 2008	 NEEDS[2]
Author/sponsor	Eurelectric (2010)	IEA (2010)	WEC (2007)	NEA (2008)	EU Commission (2009)
Selected scenarios Emission reduction	**1. Baseline** **2. Power Choices** 50% global reduction	**1. ETP Baseline** **2. ETP BLUE Map** 50% global reduction	**1. WEC Leopard** **2. WEC Lion** Very high global concern on climate	**1. NEO Low** **2. NEO High** High concern on climate	**1. NEEDS BAU** **2. NEEDS 450 ppm** +2 degree target

Figure 1.1 Selected scenarios for review, including emission reductions

These scenarios exhibit a range of outcomes for the future of nuclear energy in Europe in 2050, as shown in Figure 1.2 (note, the definition of Europe varies across the studies as indicated). Nuclear deployment ranges from 117 to 424 GW in 2050 across the scenarios, although for most studies with a strong climate change mitigation target, a nuclear share of roughly 30% is realised.

1 For example, Royal Dutch Shell, http://www.shell.com/home/content/aboutshell/our_strategy/shell_global_scenarios/what_are_scenarios/
2 New Energy Externalities for Sustainable Development, http://www.needs-project.org/2009/ [8]

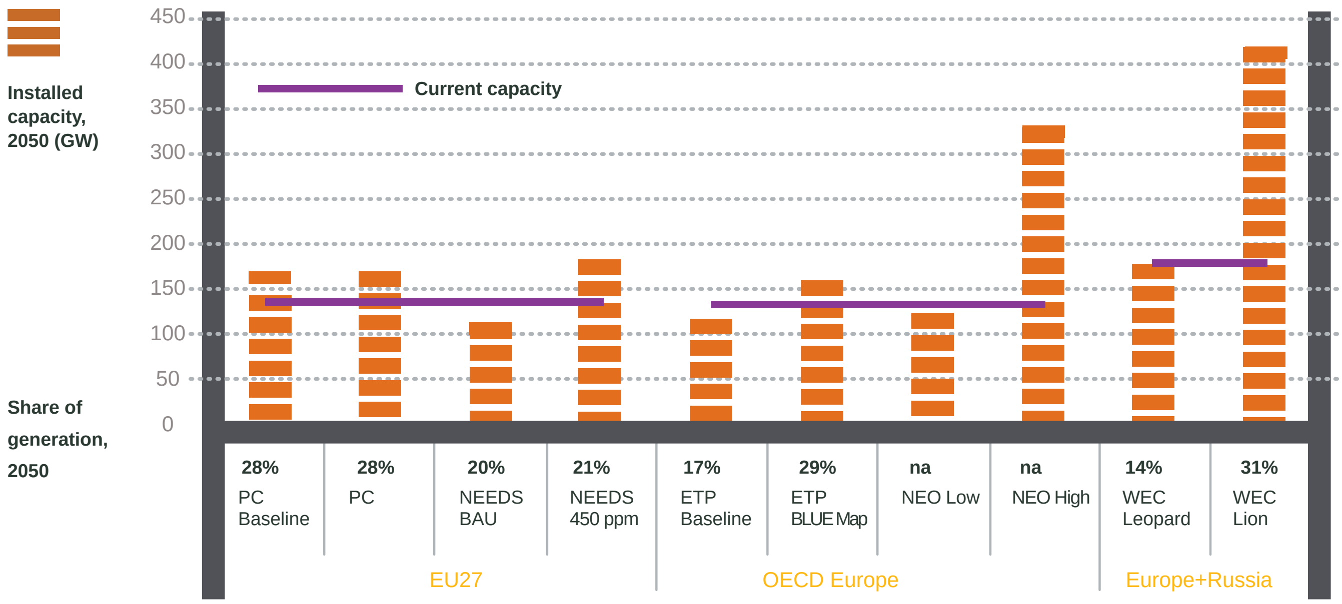


Figure 1.2 Scenario estimates of European nuclear deployment, 2050

These outcomes for the future of nuclear electricity generation in the scenarios depend on two sets of driving forces and conditions: (1) the size of the future electricity market; and (2) the relative competitiveness and availability (and acceptability) of nuclear energy vis-à-vis other electricity generation options. The size of future electricity market depends on the level of electrification and the overall demand for energy, which in turn depends on the level of energy intensity (and efficiency) and economic development. The relative competitiveness of nuclear is influenced by assumptions on the cost and availability (and acceptability) of nuclear and other technologies, fuel costs and policy, especially climate change policy. The review will thus investigate how these driving forces are represented in each of the scenarios and their influence on the future of nuclear in Europe. The review will also examine the role of nuclear in greenhouse gas abatement, and global developments of nuclear energy consistent with the scenarios for Europe.

In Section 2 we examine each scenario study in detail, looking at: the key assumptions and driving forces; the size of the electricity market; the role of nuclear and other technologies (particularly low-carbon technologies); the factors affecting the deployment of nuclear specific to each study; the contribution to GHG abatement; and the global context. A synthesis of key findings is presented in Section 3.

2.1 Scenarios
Power Choices

The EURELECTRIC Power Choices study [1] presents two main scenarios, a Baseline scenario and the Power Choices (PC) scenario.

ASSUMPTIONS AND DRIVING FORCES

- Economic: Annual GDP growth in the EU27 averages 1.8% over the period 2010–2050 in both scenarios, equating approximately to a doubling of GDP between 2010 and 2050.[3] The tertiary sector and non-energy-intensive industry grow the fastest.

- Policy: In the Power Choices scenario, the EU is assumed to reduce domestic greenhouse gas emissions by 75% from the 1990 level by 2050, consistent with a global target of 450 ppm (presumably CO_2-e) and a 50% reduction in global CO_2 emissions (relative to 2005). This translates to a 73% reduction in energy CO_2 emissions in the EU27 from 2005. The Baseline scenario assumes a continuation of policies in place as of Spring 2009, including the ETS (with the cap decreasing 1.7% per year) and national and community policies for efficiency and renewables.

- Real prices of imported energy increase moderately over 2010–2050 (oil by ~75%, gas ~116% and coal ~53%).

One important set of assumptions for determining the choice of technology is technology cost, illustrated in Figure 2.1. Other relevant technology-specific assumptions include:

- Nuclear is available in all EU27 countries, except 10 countries without historical experience and no plans for nuclear.[4] Germany and Belgium are assumed to phase-out nuclear, while Italy and Poland develop nuclear. No new nuclear designs are assumed.
  - Costs for nuclear vary across countries, and depend on whether investment is for a new site or replacement/extension of an existing plant (i.e., costs vary from the values in Figure 2.1). Costs also "increase non-linearly as the development of new nuclear sites [comes] close to full nuclear potential, which is assumed specifically for each country". No additional details are provided in the report, except the statement that "…capacity expansion is rather limited…because the potential for developing new nuclear sites is considered to be rather limited…".

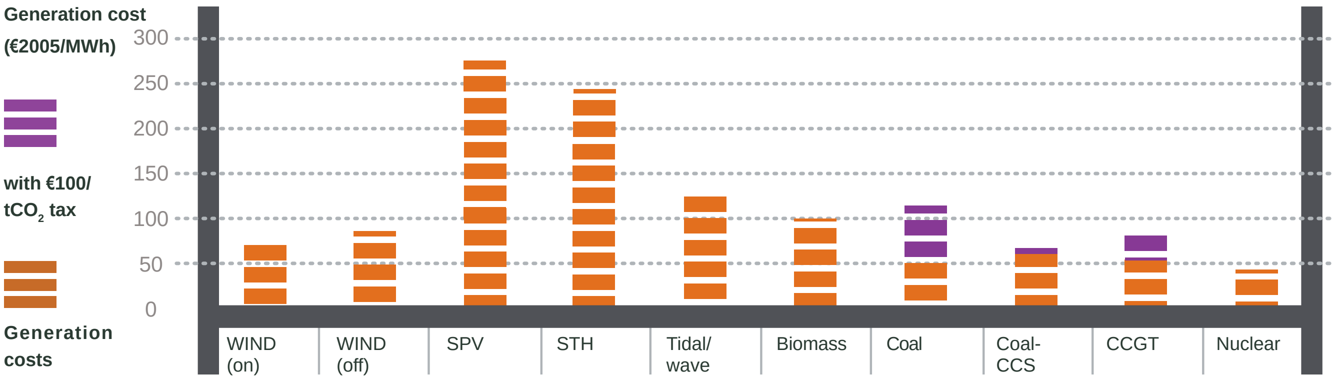


Figure 2.1 Generation costs in Power Choices scenarios, 2050 (Figures 11 and 13 in [1])
Note: Fuel prices from "today". Note also, costs for nuclear vary by country, site and capacity.
Levelised costs for renewables based on 9% discount rate; discount rate for other technologies is not reported.

- CCS is commercially available from 2025; no binding targets for renewables post-2020, with support policies phased out 2020-2030 (Power Choices).

- Strong electrification of transportation, with moderately optimistic assumptions of battery cost development (Power Choices).

3 The rate declines from around 2.4% for 2010-2015, to 2.1% for 2015-2020, 2% for 2020-2025, 1.7% for 2025-2030, and 1.55% beyond 2030 [1]. The slowdown is described as a result of population ageing, slowing productivity growth and competition from emerging economies.
4 Austria, Cyprus, Denmark, Estonia, Greece, Ireland, Latvia, Luxembourg, Malta and Portugal

- Efficiency: Sectoral energy efficiency policies are incorporated in the scenarios (stronger in Power Choices than in Baseline). The exact impact of these policies on energy demand is not reported, but some indication is provided in the results for final energy demand, which is 20.4% lower in the Baseline scenario compared to a 'No Policy Case'. However, some of this reduction is likely caused by price-induced efficiency resulting from supply-side policies in the Baseline (like the ETS). Final energy demand is 45.4% lower in PC compared to the same 'No Policy Case', but here price-induced efficiency measures (and the electrification of transportation) are important developments.

SCENARIO RESULTS

Energy demand and electrification

Between 2010 and 2050, final energy demand declines in the Power Choices scenario (by more than 25%) and is roughly unchanged in Baseline scenario. Since GDP doubles over the same period (see above), this implies a rapid decrease in energy intensity, well above historical rates in both scenarios. This appears to be quite optimistic, and is explained in the scenario as being a result of accelerated efficiency in the buildings sector (residential and tertiary) from sectoral efficiency policies and from the carbon price (see above). A significant part of the overall improvement in intensity also comes from the adoption of electric drivetrains (including plug-in hybrids) in the transportation sector (PC scenario only). This development drives a large increase in overall electrification (from 20% in 2005 to 45% in 2050 in PC), complementing some additional electrification in stationary sectors (in which electricity demand increases approximately 10%).

As a consequence, electricity demand increases roughly 60% in PC between 2005 and 2050 to around 5200 TWh (and around 4700 TWh in the Baseline). By 2050, transportation consumes around 1600 TWh in the PC scenario (equivalent to half of total generation in 2005), with most of the passenger transport market supplied by electric and plug-in hybrid vehicles.

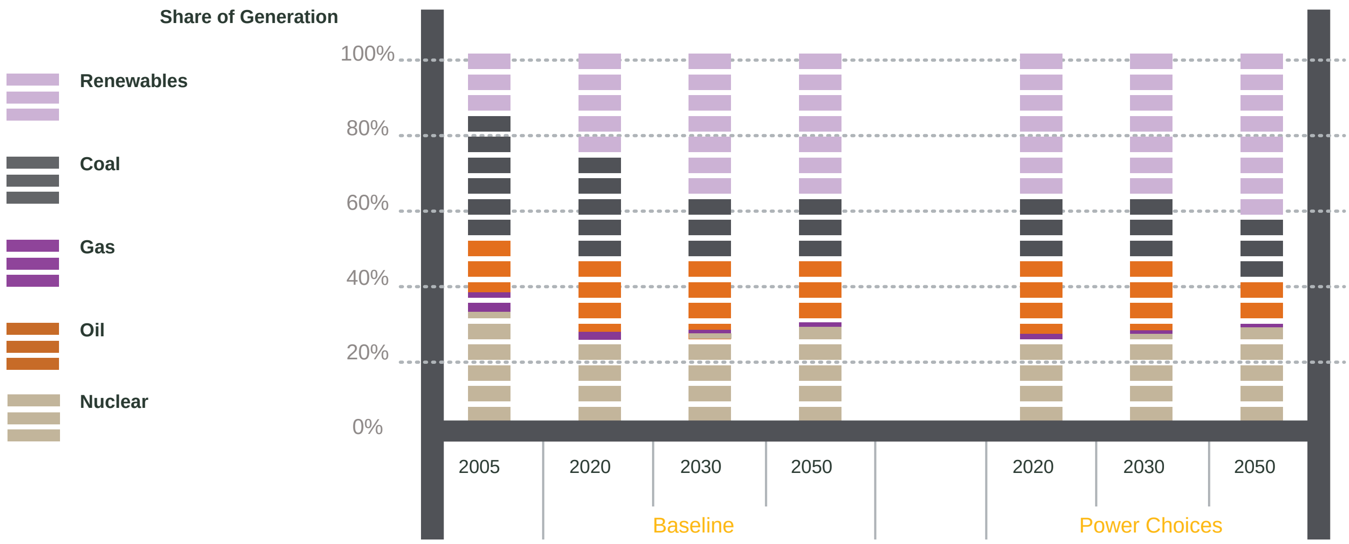


Figure 2.2 Share of electricity generation, Baseline and PC scenarios
Note, an identical generation share is reported for 2000 and 2005 ([1], Table 8 and Figure 22). Thus, it is not clear from the report which values correspond to which year.

Electricity generation and the role of nuclear

The share of nuclear generation declines from 2005 to 2020, then increases gradually to a share of around 28 % in both the Baseline and PC scenarios. In absolute terms, installed capacity increases from 134 GW in 2005 to 175 GW in 2050 (PC). In comparison, generation from renewables increases from 14 to 40% (34% in Baseline), and installed capacity increases from 163 GW to 728 GW. The total contribution of fossil fuels decreases, particularly coal. The contribution from CHP increases to almost 20% by 2030 in the PC scenario, but declines thereafter since CHP is not assumed to be amenable to carbon capture. Total investment in new capacity over the period 2011-2050 amounts to 197 GW nuclear, 191 GW fossil-CCS, and 821 GW renewables (>60% wind).[5] Of the nuclear installations, 81 GW is installed in the decade 2025–2035 (much of which replaces decommissioned plants). This amount seems ambitious given historical developments.[6] The Power Choices scenario also requires investment in grid infrastructure and smart grids, with the average grid tariff increasing 50% in 2020 and 100% by 2050, compared to 2005. In the Baseline, the corresponding increases are 35% and 70%, since renewable deployment is also high in this scenario.

Summary of factors driving nuclear energy deployment in the Power Choices scenario

Given the assumptions and results above, we can begin to understand the drivers behind the deployment of nuclear in the PC and Baseline scenarios. These include drivers affecting the size of the potential market for nuclear and assumptions affecting the competitiveness and availability of nuclear in this market. Turning first to the latter, nuclear is relatively cheap in these scenarios (see Figure 2.1) although assumptions about the limited availability and high development costs of new nuclear sites, together with the phase-out and restrictions in 12 EU countries, limit overall deployment.[7] The availability of other low-carbon technologies, notably wind and CCS, also has some influence on nuclear deployment, but it appears to be a secondary effect.[8] Alternatives such as CHP cannot produce zero- or very-low carbon electricity, so only offer limited competition with stringent mitigation policy. In terms of the size of the market for nuclear generation, this is driven partly by the level of electrification, which is high in the PC scenario due primarily to assumptions about the strong electrification of transportation.[9] The size of the market is also affected by the robust level of economic growth in this scenario, offset by aggressive energy efficiency. Finally, the role of climate policy is only partly illustrated—for example, a strong deployment of nuclear is observed in both the PC and Baseline scenarios, despite the somewhat weaker climate policy in the Baseline (in which nuclear deployment appears to be driven also by increasing coal prices).

Contributions to emissions abatement

The PC scenario leads to a 73% reduction in energy-related CO_2 emissions compared to 2005 (with carbon prices reaching $€_{08}$ 103/t CO_2 in 2050), while emissions are reduced approximately 31% in the PC Baseline. The report presents a breakdown of avoided emissions, compared to a hypothetical level that would prevail if the technology mix, efficiency and structure of the energy system were fixed from 2005 to 2050. This estimate attributes around 300 Mt CO_2 of abatement to

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5 Among the technologies experiencing large increases in deployment rates in the PC scenario: installation of wind (on- and off-shore) capacity reaches up to 18 GW per year (compared to 5 GW per year in 2000-2005); solar capacity deployment peaks at around 8 GW per year (vs. 0.4 GW for 2000-05); and nuclear capacity at 9 GW per year (vs. ~1 GW per year in 2000-2005). Total investment in the power sector is estimated in the study to be: €755 bn (2010-20); €720 bn (2020-30); €946 bn (2030-40); €799 bn (2040-50). Energy costs as a percentage of GDP increase from around 10.5% in 2000 to 13% in 2025, then decline to around 10% in 2050.

6 As discussed below, this study reports a global scenario consistent with the PC scenario which includes a rapid global expansion of nuclear, which is likely to compete for financial, material and human resources.

7 The potential impact on the deployment of changes to these assumptions is illustrated in a sensitivity analysis on the nuclear phase-out in Germany and Belgium. If the phase-out is stopped, and new investment allowed in these countries, an additional 33 GW of nuclear capacity is in operation in 2050 (up from 175 GW).

8 Sensitivity analyses which delay the availability of CCS or reduce the scale of off-shore wind deployment result in a small (1.4–1.6%) increase in nuclear production in 2050. In both cases, the impact on other technologies is larger, implying that the other deployment constraints on nuclear are restricting the ability of nuclear to expand substantially beyond the level in the Power Choices scenario.

9 The role of electrification of transport is illustrated by one of the sensitivity scenarios in the PC report—the so-called ‘No efficiency’ sensitivity scenario which considers the case with lower support for energy efficiency and no electrification of transportation. In this scenario, nuclear output is cut by 26.8% in 2050 relative to the main PC scenario (total electricity demand also drops 24.5%, so the share of nuclear decreases slightly).

nuclear in 2050, representing only 7% of total abatement. This smaller contribution can be partly attributed to the high share of nuclear in generation (31.7%) in 2005 (or 2000),[10] and thus the deployment of nuclear is already high in the hypothetical 'fixed' case.[11] An alternative way to estimate the contribution of nuclear to abatement is to determine the level of emissions that would prevail without this technology. Unfortunately this cannot be determined without access to the scenario model, but we can make a very preliminary estimate if we simply assume a complete phase-out of nuclear by 2050, with the generation replaced by coal, gas and renewables. The impact on emissions ranges from 50 Mt CO_2 (if we assume nuclear is replaced by the same proportion of coal, gas (both with CCS) and renewables as in the rest of the mix in the PC scenario) to 700 Mt CO_2 (if we assume renewables and CCS cannot expand, but coal and gas are added in proportion to the 2050 mix),[12] compared to total energy CO_2 emissions of 1,063 Mt in 2050 in PC. Clearly, with such a change one would expect impacts on energy prices (given that nuclear is a cheap source of generation) and hence demand, which would change total electricity generation. Further impacts would be expected if the same 75% emission reduction target were to still be reached. Nonetheless, this provides some guidance.

Global developments

The Power Choices scenario was developed with the aim of defining an emissions scenario for the EU27 consistent with a global target of stabilising atmospheric concentrations at 450 ppmv CO_2-equivalent. The documentation reports some findings for the consistent development of the global energy system. Globally, the share of nuclear generation increases from 16 to 28% (from 2005 to 2050) as "third and fourth generation designs mature". The assumptions about 4th generation designs appear to be inconsistent with assumptions for the EU analysis which exclude designs which are not "commercially developed today". Simultaneously, total global generation increases very strongly, from around 18 to 83 PWh, such that global nuclear generation increases approximately 8-fold, with installed capacity increasing by almost 3000 GW (compared to a net increase of 40 GW in the EU27). One implication of such a large global deployment is that industry developments are likely to be driven by global, rather than EU needs (if global energy system development follows a pathway similar to that in the PC scenario).

10 Table 8 in [1] presents an identical generation share for the year 2000 as that shown in Figure 22 [1] for the year 2005. Thus, it is not clear from the report which values correspond to which year.

11 The scenario report also presents a breakdown of the contribution of different technology options, including nuclear, to reductions in the emissions intensity of electricity from 2010 to 2050 (Figure 21 in [1]). However, it is unclear how to interpret this breakdown since the share of nuclear is roughly identical in 2010 and 2050 in the PC scenario, and thus would not be expected to make a significant contribution to changes in average emissions intensity. Some other elements of Figure 21 [1] are also unclear. For instance, the impact of improved thermal efficiency of power plants does not appear in the figure as a factor reducing emissions intensity, even though efficiency is reported to change (Figure 12 in [1]). In addition, the direction of fuel switching appears to go from gases to solids between 2010 and 2050 (Table 8 and Figure 22 in [1]), so the estimated contribution of fuel switching "from solids to gas" in Figure 21 [1] is difficult to interpret. Without additional analysis and discussion with the authors to clarify these points, we have chosen not to use the information in Figure 21 in [1] to estimate the contribution of nuclear energy to abatement.

12 The emission factors for generation from coal technologies and CCGT can be determined from the documentation. We make the conservative assumption that all the installed coal and gas generation is with CCS (i.e. assuming that most of the gas-CCS and coal-CCS capacity reported is installed towards the end of the time horizon). The report provides no information about the emission factor for gas-CCS, so we assume the same ratio as for coal:coal-CCS.

2.2 Scenarios
Energy Technology Perspectives

From the IEA's Energy Technology Perspectives [2] report, the Baseline and the BLUE Map scenarios were selected for review.

ASSUMPTIONS AND DRIVING FORCES

- Economic: In both scenarios, GDP in OECD Europe grows by 63% between 2007 and 2050, growing an average of 1.5% from 2007–2030 and 0.7% from 2030–2050. The factors behind this economic development pathway are not discussed, although part of the slowdown appears to result from a slowdown in population growth (from 0.25% in 2007–2030 to zero). The scenarios assume a roughly constant material output of the energy-intensive industry from 2007 to 2050, implying most of the growth in value-added occurs in the tertiary and non-energy-intensive industry sectors. Mobility demand (freight and passenger) does not increase significantly.
- Policy: In the BLUE Map scenario, global energy-related CO_2 emissions are reduced by 50% in 2050 relative to 2007 levels. For OECD Europe, this translates to a reduction of 74% in energy-related CO_2 emissions.[13] The Baseline assumes no new energy or climate policies during the scenario period from 2007-2050, however the ETS remains in place with permit prices increasing to $43/t CO_2 in 2020 and $83/t CO_2 in 2050. The report does not explicitly discuss how other existing measures are represented in the scenario.
- Prices for imported energy carriers grow slowly in the Baseline (oil prices increase around 24% in real terms between 2008 and 2050, gas by 43% and coal prices decline by around 5%), and decline strongly in the BLUE Map scenario (oil by 28%, gas by 17% and coal by 52%), presumably due to climate policy.

One important set of assumptions for determining the choice of technology is technology cost. Investment costs are reported in Figure 2.3, along with an estimate of generation costs (which are not reported). Other relevant technology-specific assumptions include:

- Nuclear: The phase-out of nuclear in several countries is incorporated in the scenario, although it is not clear which country-level assumptions apply.[14] The scenario

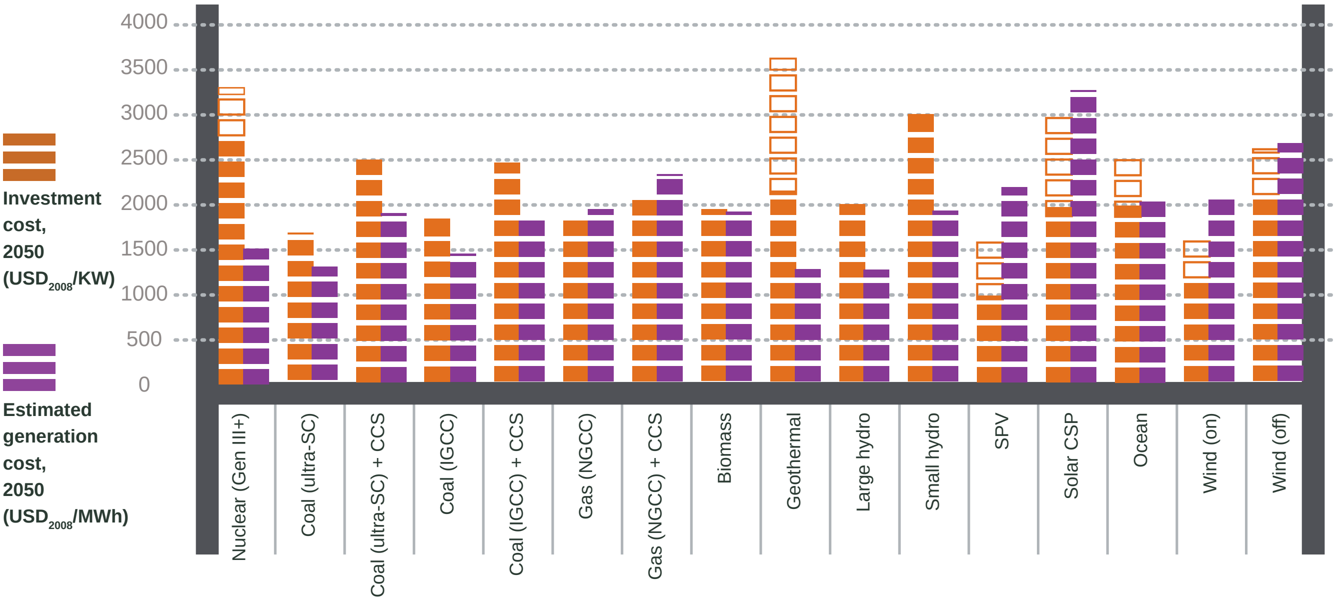

Figure 2.3 Investment and estimate generation costs in BLUE Map scenario, 2050 (Tables 3.2, 3.3, 3.4 and 3.5 in [2])
Note, these are costs for the USA, and region-specific cost multipliers are applied (but not reported). The costs represent the minimum of the range reported. Generation costs are not reported, but are estimated based on expert judgment of plant lifetimes and capacity factors, and fuel costs, using a discount rate of 8% (8-14% is reported). Carbon costs are excluded.

13 Note that it is not clear that there is an explicit policy assumption for Europe, but rather this reduction of 74% may be the result of a least-cost allocation of the global abatement requirement.

14 From the results, nuclear generation is reported for France, the UK, Italy and Poland, with no nuclear generation is seen in Germany, the Netherlands, Sweden and Spain. Other countries are not reported.

includes some new nuclear designs[15]. Critically, the scenarios assume a maximum global nuclear capacity of 1200 GW; how this translates to assumptions for Europe is not discussed.

- The study uses nuclear cost data from the IEA/NEA.[16] Region-specific multipliers are applied to the costs but the implication is that the same costs are used throughout Europe.

- CCS is available and already deployed on a large scale by 2030 (estimated 30 GW in OECD Europe in BLUE Map).

- Moderate electrification of transportation and buildings, with high diversity among country-level strategies for transport in Europe.

- Efficiency: In the Baseline, historical rates of decoupling between economic growth and energy demand are assumed to continue. This is accelerated in the BLUE Map scenario, driven largely by the emissions target.

SCENARIO RESULTS

Energy demand and electrification

Between 2007 and 2050, overall final energy demand declines by 13% in the BLUE Map scenario, although in the industry, buildings and transport sectors the total reduction is 25% (and a slight increase (8%) in the Baseline scenario).[17] Taking into account the 63% increase in GDP, the improvement in energy intensity in the Baseline is well within the recent historical range of 1.3% per year. The more rapid decrease in energy intensity in the BLUE Map scenario coincides with an increase in electrification from 19% in 2007 to 27% in 2050, mainly in the buildings and transportation sectors[18] and thus appears to be reasonable within the framework of an ambitious CO_2 abatement target. Overall, electricity demand increases by 19%, while electricity consumption increases around 27% in BLUE Map between 2007 and 2050 to around 4300 TWh (and around 53% in the Baseline).[19] Transportation consumes around 360 TWh of electricity in 2050 in the BLUE Map scenario, which is around 10% of total transportation energy demand. Demand in stationary sectors increases by roughly 10%.

Electricity generation and the role of nuclear

The share of nuclear generation increases from 25.9 % in 2007 to 29.3% in 2050 under the BLUE Map scenario, but declines to a share of around 16.7% in the Baseline (see Figure 2.4). In absolute terms, installed capacity increases gradually from 130 GW in 2007 to 162 GW in BLUE Map (2050) but declines to 117 GW in the Baseline. In comparison, generation from renewables increases from 20 to 55 % (40 % in Baseline), and installed capacity increases from 269 GW to 854 GW. The total contribution of fossil fuels declines from 53% to 15.5%, mainly from CCS-equipped plants (mainly coal). The contribution of CHP increases to nearly 20% in the BLUE Map scenario, with a significant contribution from biomass-CHP. Total investment in nuclear in Europe to 2050 is estimated at USD_{2008} 586 billion; the scenario documentation suggests that financing nuclear energy in Europe may be easier than in other regions due to the higher number of large utilities (with a market capitalisation of more than USD 25 billion).[20] The description of the BLUE Map scenario in Europe also notes the important future role of smart grids, but does not

15 “a few advanced systems such as sodium fast reactors and high-temperature gas reactors are likely to be built and operated before 2050” [2]

16 IEA/NEA (International Energy Agency/Nuclear Energy Agency) (2010), Projected Costs of Generating Electricity: 2010 Edition, IEA/NEA, Paris.

17 The origin of this discrepancy is unclear. It seems very unlikely that the difference is attributable to the only sector not mentioned (agriculture), given its minor contribution to demand.

18 Note, however, the electrification rate can be calculated to be 30% in buildings, industry and transportation in 2050 (in Tables 8.4, 8.6, 8.8 and Figures 8.16, 8.19 [2]). Given that these sectors dominate final energy demand, it is unclear why the electrification rate is reported to be 27%.

19 Note, net electricity demand in all sectors is approximately 3640 TWh in 2050 in the BLUE Map scenario (Table 8.4 [2]). The difference between electricity ‘demand’ and ‘consumption’ (4300 TWh, Table 8.2 [2]) increases from 2007 to 2050 in the scenario, and appears to be because of increasing use of electricity in ‘Transformation’ (which is not defined, but may refer to own use, hydrogen production and/or pumped storage) (Figure 4.1 [2]). Elsewhere, the scenario documentation reports a 30% increase in demand (Table 4.1 [2]) to 4071 TWh.

20 There is relatively little discussion of financing renewables in Europe, while financing of CCS is discussed primarily in terms of bridging the “commercial gap”, including grants, feed-in tariffs and price guarantees. Note, however, such support mechanisms do not appear to be represented in the scenarios, but are instead presented as measures likely to support the realisation of the scenarios.

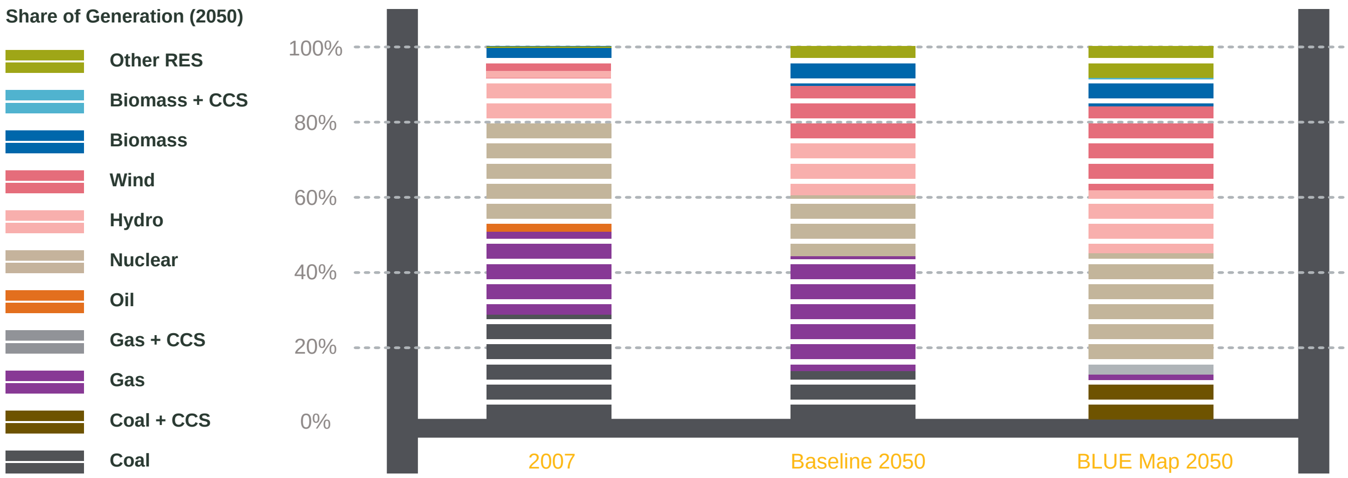

Figure 2.4 Share of electricity generation, Baseline and BLUE Map scenarios

discuss in quantitative terms the impact of these scenarios on the grid.[21]

Summary of factors driving nuclear energy deployment in the ETP BLUE Map and Baseline scenarios

From the available assumptions and results above, we can begin to understand the drivers behind the deployment of nuclear in the ETP scenarios. One important factor is the relatively cheap cost of nuclear generation (see Figure 2.3), which appears to make this technology particularly attractive in the presence of a climate policy. This can be seen by comparing the BLUE Map scenario (which includes a strong abatement target throughout Europe) with the Baseline (which incorporates only existing measures, including the ETS for the EU members of OECD Europe). Nuclear deployment in the Baseline is still substantial, but around 28% lower than in the BLUE Map scenario, with conventional fossil generation playing a much larger role partly because coal prices do not increase significantly. Non-cost barriers are also an important factor driving nuclear deployment: the scenarios appear to assume restrictions on deployment in a number of European countries (such that there is no nuclear capacity in 2050 in Germany, the Netherlands, Spain and Sweden, and possibly others). Moreover, a global limit is applied for the deployment of nuclear (1200 GW) which has the effect to further restrict nuclear in Europe since this global cap is binding in the BLUE Map scenario.[22] As a consequence, the availability of other low-carbon technologies has a limited effect on nuclear deployment. This is particularly the case for CCS, and for renewables up to a high level of deployment.[23] Turning to the factors affecting the size of the market for nuclear, the level of electrification is moderate in this scenario, with a 10% contribution of electricity to transportation. Other assumptions on the overall growth of the European economy, and energy efficiency are also relatively moderate, thus the overall size of the electricity market in these scenarios is among the smallest across the reviewed scenarios.

21 Note, however, that further information is provided for global grid development, with an estimated USD 12.3 trillion of grid investment to 2050 in the BLUE Map scenario (USD8.3 tn in Baseline). The additional cost in BLUE Map is driven by electrification of transportation, integration of renewables, and deployment of smart grids. In comparison, total energy system investment costs for the BLUE Map scenario are USD316 tn (270 tn Baseline).

22 The ETP study presents a sensitivity scenario with a higher global limit of 2000 GW for nuclear (“BLUE hi NUC”). Results are only presented globally, where this more optimistic assumption increases generation in almost the same proportion (65%) and the global share of nuclear from 25 to 39% (displacing fossil fuels and renewables 3:2). Thus, this assumption is clearly critical for the upper deployment of nuclear. One could surmise a similar impact in OECD Europe.

23 This is illustrated in another global sensitivity analysis that considers no deployment of CCS (“BLUE no CCS”). This has no impact on nuclear deployment, since nuclear is already deployed up to the assumed capacity limit of 1200 GW. A second sensitivity scenario which assumes a 75% share of renewables is also presented (“BLUE hi REN), in which nuclear output is more than halved compared to the BLUE Map scenario in 2050. This occurs because more flexible generation (namely natural gas) is needed to manage the high share of intermittent renewables deployed in this scenario. The implication is that very high levels of renewable deployment may make less flexible generation options such as nuclear less attractive; but any assumptions on renewables which are less optimistic than in BLUE Map are unlikely to affect deployment given that nuclear is already deployed up to the 1200 GW limit.

Contributions to emissions abatement

The BLUE Map scenario leads to a 74% reduction in energy-related CO_2 emissions compared to 2007 levels in OECD Europe (with carbon prices reaching US$$_{08}$ 175/t CO_2 2050). Compared to the Baseline in 2050, emissions are 73% lower. The study attributes 7% of the total abatement (relative to the Baseline) to the higher deployment of nuclear, or around 200 Mt CO_2 in 2050 out of 2.9 Gt of total abatement. Recall that nuclear deployment is around 45 GW higher in the BLUE Map scenario. The electricity sector as a whole contributes 34% to abatement, split between nuclear, CCS (12%), renewables (12%), and increased efficiency and fuel switching in fossil plants (3%). Of interest again is the emissions level in the absence of nuclear, but again this cannot be determined without additional information on the methodology used in the study. Simple extrapolation based on the emissions saving provided by the 45 GW of additional generation relative to the Baseline indicates that emissions would be around 700 Mt CO_2 higher in 2050. On the other hand, assuming that nuclear generation were replaced by the same proportion of coal, gas (both with CCS) and renewables in the rest of the electricity mix, emissions are estimated to increase by around 30 Mt CO_2 in 2050 (i.e., CCS and renewables expand their contribution in electricity sector abatement). Such a case is highly speculative and likely to induce changes in electricity prices and hence demands,[24] in addition to changing the total level of emissions.

Global developments

So far we have focused primarily on the results of the BLUE Map and Baseline for OECD Europe. However, these results come from a set of consistent global scenarios of energy system development with a target of reducing global energy-related CO_2 emissions by 50% from 2007 levels by 2050 (BLUE Map). Globally, the share of nuclear generation increases from 14 to 24% in the BLUE Map scenario, and declines to 10.5% in the Baseline (from 2007 to 2050). This corresponds to an increase from 2700 TWh to 9600 TWh (or 4800 TWh in the Baseline), and from 374 GW to 1200 GW (610 GW Baseline). The report estimates that this would require annual gross capacity additions of 30 GW, which appears to be quite plausible compared with the average of approximately 25 construction starts per year in the 1970's. OECD Europe's share of global installed capacity decreases from 35% to 14% (19% in the Baseline), indicating that global forces are likely to drive much of the future development in the nuclear industry (if global energy system development follows a pathway similar the BLUE Map scenario).

24 Some indication is provided by the global sensitivity with a higher level of nuclear generation ("BLUE hi NUC"), which shows that increased deployment of nuclear lowers electricity prices and increases demands, while reducing overall emissions. Of note, this 800 GW expansion of global nuclear capacity reduces net global emissions by only 900 Mt CO_2.

2.3 Scenarios

WEC Energy Policy Scenarios to 2050

The WEC energy scenarios study [3, 4 and 5] analyses four alternative scenarios. This review focuses on two of these—the Leopard and Lion scenarios—which exhibit the largest divergence in greenhouse gas emissions and nuclear energy deployment. Unlike other studies, the WEC study does not include a scenario that achieves a significant reduction in global emissions, with global emissions increasing in all scenarios. The definition of Europe in the WEC scenarios includes EU27, Russia and a number of other states.[25]

DRIVING ASSUMPTIONS

- Overall drivers and economic development:
  - The Leopard scenario is dominated by market mechanisms and private interests, with a focus on domestic energy security. International market forces and free trade are constrained by national barriers. These conditions restrict international cooperation, innovation, technology transfer, and ultimately economic growth. In this scenario, European GDP grows by 87% between 2005 and 2050.[26]
  - The Lion scenario storyline envisages extensive international cooperation and a strong role by governments in managing the energy system (including international cooperation and policy harmonisation among governments). These favour technological innovation/transfer and worldwide investment; leading to higher economic growth (despite climate change mitigation policies—see below). In the Lion scenario, European GDP grows 188% between 2005 and 2050, with per capita incomes more than tripling.[27]
- Policy: The Leopard scenario envisages low concern for CO_2 abatement (with no post-Kyoto international agreement). In contrast, the Lion scenario storyline incorporates very high and shared environmental and energy security concerns, leading to strong international agreements (ultimately leading to high policy support for nuclear and renewables).
- Energy prices: Both scenarios include relatively high availability of oil and gas (in Leopard because of the favourable business environment; and in Lion because of international cooperation and policies on hydrocarbon scarcity). Nevertheless, oil prices increase by between 70% (Lion) and almost 120% (Leopard) from 2005 to 2050. European gas market prices increase at a faster rate (130% and 183%, respectively for Lion and Leopard). European coal prices increase by 60% in the Leopard scenario and just over 90% in the Lion scenario.[28]

One important set of assumptions for determining the choice of technology is relative technology cost, but the costs used in the scenario analysis are not reported in the study documentation. Other relevant technology-specific assumptions include:

- Nuclear: The Leopard scenario assumes a “favourable context for nuclear development” reducing costs by 30%. The report is not explicit about the cost assumptions in Lion, but these are assumed to be at least as optimistic.[29] The Lion scenario envisages a high level of cooperation among limited suppliers of nuclear technology, along with strong government support as a result of high concerns about climate change and energy security. Due to these features, a lower discount rate is assumed for nuclear in this scenario to reflect higher support and reduced uncertainty. In contrast, the lower government engagement in Leopard is expected to mean a continuation of “current uncertainty and ambivalence”. Government is seen as essential for any nuclear

25 Including the four EFTA members (Iceland, Liechtenstein, Norway, Switzerland), non-EU Balkan countries (Albania, Croatia, Macedonia, Montenegro and Serbia), former Soviet republics (Armenia, Azerbaijan, Belarus, Georgia, Moldova and Ukraine) and Turkey.

26 Growing at 2.1% pa in 2005–2020, 1.3% 2020–2035 and 0.9% 2035–2050. Note, Russia and a number of other former Soviet republics are included in the definition of Europe.

27 GDP grows at 3.1% pa in 2005–2020, 2.3% 2020–2035 and 1.8% 2035–2050. Note, Russia and a number of other former Soviet republics are included in the definition of Europe.

28 The lower prices for coal in the Leopard scenario may be due the favourable business environment in Leopard; whereas the Lion scenario is focused on policies on hydrocarbon scarcity, which may not support coal availability.

29 All other scenarios in the study (Elephant, Giraffe) also report a “favourable context for nuclear development”.

renaissance. Assumptions regarding nuclear moratoria (including continuation or termination) are represented in the model, but the details are not reported. New nuclear designs are also apparently represented.[30]

- Renewables: The Lion scenario envisages government incentives and increased cooperation for renewables, and lower discount rates are assumed. It is unclear what is assumed in Leopard in regard to existing policies in Europe.

- CCS: Assumptions on CCS are not made explicit. From the results, it appears CCS is available from 2020 (~100 Mt CO_2) in the Lion scenario, which appears to be highly optimistic. CCS is not used up to (and including) 2035 in the Leopard scenario, but it is not clear whether this is because the technology is not assumed to be available, or if climate policy is not strong enough to support deployment.

- Electrification: No explicit assumptions.

- Energy efficiency: The Lion scenario incorporates a high policy focus on energy efficiency and climate change, whereas Leopard does not. In combination with the high levels of innovation in Lion (and lower levels in Leopard), this leads to a reduction in final energy intensity averaging 2.2% per annum (compared to 1.1% in Leopard). Note, it is not possible to extract the relative impact of energy efficiency policies, autonomous improvements, price-induced impacts from changes in the price of energy commodities, and additional efficiency induced by climate change policy.[31] The decrease in the Lion scenario appears very rapid, but not necessarily inconsistent with the very high economic development in this scenario.[32]

SCENARIO RESULTS

Energy demand and electrification

Total final energy demand in Europe increases slightly between 2005 and 2050 in both the Leopard (15%) and Lion (5%) scenarios. In the Lion scenario, most of the increase occurs before 2020, and demand declines between 2035 and 2050. As mentioned above, energy intensity is reduced at a rapid rate in the Lion scenario (as a result of innovation and a policy focus on efficiency and climate change), consistent with a scenario of rapid economic development with high technological innovation. Most of the growth in final energy demand occurs in the buildings sector[33] (which grows 43% in Leopard and 35% in Lion by 2050), with a decrease in demand in industry, and demand in the transport sector roughly unchanged. Levels of electrification increase at a similar rate in both scenarios, increasing from 17% in 2005 to almost 31% in Leopard and 33% in Lion by 2050. Electrification rates increase in all sectors, to 32% in industry 15-16% in transport and 37% (Leopard) to 41% (Lion) in buildings by 2050.

As a consequence, in both scenarios electricity demand roughly doubles between 2005 and 2050 to around 7,700–7,800 TWh. Of this, transportation is estimated to consume around 800–900 TWh.

Electricity generation and the role of nuclear

The share of nuclear generation declines rapidly from 2005 to 2035 in the Leopard scenario then increases slightly. In the Lion scenario, the share of nuclear decreases slightly to 2020, then grows steadily, reaching 31% in 2050 (see Figure 2.5).[34] In absolute terms, installed capacity increases from 177 GW in 2005 to 182 GW in Leopard and 424 GW in Lion by 2050. Notably, the study does not appear to consider possible limits to the rate of deployment of nuclear installations.[35] In comparison, generation from renewables increases from

30 For example, a related publication discusses Generation IV coming on line progressively from 2040-2050 (WEC 2006) [6].

31 However, the very low concern about efficiency and climate in Leopard suggests that most of the reduction in intensity in this scenario is autonomous and/or induced by energy price changes, and appears to be in line with historical developments.

32 Note also, the definition of Europe in these scenarios includes Russia, in which there may be more opportunities for efficiency improvements and structural change.

33 Actually, buildings plus agriculture.

34 This initial decline followed by an increase is mirrored in the EU; with the share of nuclear in Russia's energy mix roughly stable.

35 Stating that "[i]t could be worthwhile to explore further what this nuclear power revival in the EU would mean in terms of building programmes and fuel-cycle facilities".

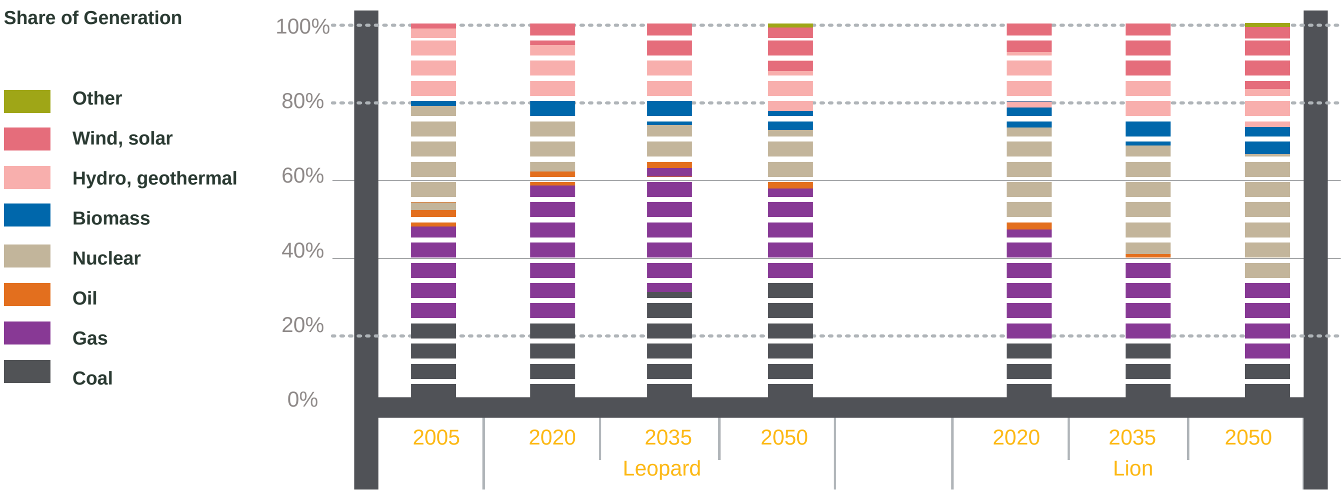

Figure 2.5 Share of electricity generation, WEC Leopard and Lion scenarios

21 to 32% in Lion (26 % in Leopard), and installed capacity increases from 320 GW to 1298 GW in Lion (966 GW in Leopard). While substantial, the scenario documentation notes that the shares of renewable generation are not particularly optimistic compared to some national and EU targets. The share of fossil generation increases slightly in Leopard (to 60%), but declines to 36% in Lion. It is worth noting again that the definition of Europe in this study includes Russia, and the report notes some divergence between these regions, with a smaller contribution from nuclear in Russia and a larger contribution from coal-fired generation.[36] The necessary investment in grid infrastructure for the different scenarios is only discussed very briefly, without any quantification.[37]

Summary of factors driving nuclear energy deployment in the WEC scenarios

We now turn to understanding which assumptions are driving the deployment of nuclear in the two scenarios. Driving the potential market for nuclear generation is the net growth in energy demand, driven by assumptions of very rapid economic and energy intensity development in Lion, and slower economic and energy intensity improvement in Leopard. Combined with the increasing rate of electrification, across all sectors but particularly in buildings, this leads to a doubling of total demand for electricity. The extent to which nuclear supplies this demand is determined partly by assumptions of improvements in the cost competitiveness of nuclear, but to a greater extent by the level of government support (in terms of policies for climate change mitigation and energy security) and cooperation in the industry—which also affect the assumed discount rate used for nuclear technologies in the scenario modeling.[38] The competitiveness of other low-emissions technologies, such as CCS and renewables, does not appear to have a strong influence on nuclear deployment. Notably, the level of emissions abatement in these scenarios is only modest (in Lion, energy-related CO_2 emissions are reduced by 26% by 2050), which would likely lead to a smaller role for CCS and renewables compared to some of the other scenarios reviewed here.[39]

36 “Nuclear power is revitalising in the EU in all scenarios, passing coal in almost all scenarios. This is not happening equally in Russia where the performance of coal is stronger.” [3]

37 For example, “[w]hatever the energy mix, a strong long-term infrastructure investment policy, especially for energy transmission, is required. The flexibility of grid systems should be substantially improved to service the effects of the required large-scale transformations in power generation.” [3]

38 While not quantified, this is also reflected in the Leopard scenario where nuclear deployment varies within Europe, with “…strong nuclear revivals…” in some EU countries.

39 The level of deployment of renewables in the Leopard scenario is stated to be driven partly by the higher fossil fuel prices. However, other statements raise some doubt about this driver, for example: “…differences in oil, gas, and coal prices between the high and low cooperation scenarios [e.g., between Lion and Leopard] are too low to significantly alter improvement in competitiveness of nuclear and renewables in the high cooperation scenarios.” It is not clear the extent to which existing policies are assumed to continue (such as the ETS or national/community renewable policies), and/or whether the primary driver is domestic energy security.

Contributions to emissions abatement

As mentioned, the Lion scenario leads to 26% reduction in energy-related CO_2 emissions by 2050 compared to 2005.[40] Electricity sector emissions are reduced by 36% or around 720 Mt CO_2 to 1.28 Gt CO_2 despite electricity output doubling over the period 2005 to 2050. No quantification of the contribution of different options relative to 2005 is provided in the scenario report. In the Leopard scenario, emissions increase by around 7% over the period 2005–2050, and electricity sector emissions increase 47%. In 2050, electricity sector emissions are 1.65 Gt CO_2 higher in Leopard than Lion. The report does not quantify the contribution of nuclear or other options, but it is possible to make an estimate using the available information, and literature assumptions on power plant efficiencies and emission factors. On this basis, the additional 242 GW of nuclear capacity in Lion is estimated to contribute around 1 Gt CO_2 of abatement relative to Leopard in 2050. On the same basis, renewables and CCS contribute around 350 and 50-100 Mt, given that CCS and renewables both contribute significantly in the Leopard scenario, and fuel switching accounts for the remaining difference.[41] We can also estimate, very roughly, the amount by which emissions would increase if none of the 424 GW of nuclear was installed, which equates to around 550 Mt CO_2 assuming nuclear is replaced by the same proportion of coal, gas (both with CCS) and renewables as in the rest of the electricity mix (or around 1650 Mt CO_2 if we assume renewables and CCS cannot expand, but fossil fuels are increased proportionally). Clearly, this is a very rough and speculative estimate, in which other changes would be expected, thus serving only as an illustration.

Global developments

The WEC scenario study presents pathways of future global energy system development consistent with the developments for Europe discussed above. The global Leopard and Lion scenarios incorporate the same driving assumptions regarding government engagement and international cooperation, but these translate into some different outcomes across different regions, based on regional circumstances. As noted above, global greenhouse gas emissions increase in both scenarios: by 88% in the Leopard scenario, and by 35% in the Lion scenario. Globally, the share of nuclear generation increases from 15 to 19% in the Lion scenario, but declines to 7% in the Leopard scenario (from 2005 to 2050).[42] Total global generation increases strongly, from around 18 to 64 PWh (Lion), such that global nuclear generation increases approximately 4-fold in the Lion scenario, with installed capacity increasing to almost 1650 GW by 2050. In the Leopard scenario, global capacity increases to around 640 GW. In both cases, Europe accounts for around 26–28% of global capacity in 2050, and is thus likely to remain an important driver for global nuclear industry developments. Asia accounts for 45-49% in 2050 in these two scenarios.

40 It is reported that the EU contributes a large part to the decrease in overall European emissions in this scenario.

41 Offset by slightly higher electricity generation in Lion (0.7%).

42 Note, there is a slight inconsistency in the scenario documentation. It is stated that in the Leopard scenario that the global contribution of nuclear is "…boost[ed]… to 11%...", on p.14 in [4] when in fact the share of generation declines to 7% in 2050 (based on p.54, 63, 72, 81, 90 in [4]).

2.4 Scenarios
Nuclear Energy Outlook

The NEA's Nuclear Energy Outlook [7] presents Low and High scenarios of nuclear energy deployment. The outputs of the NEO scenarios are generally reported only at the global scale (with a couple of exceptions), and thus this review discusses primarily global results. Unlike the other studies, the NEO scenarios are not developed in an integrated way—i.e., they were not developed with a methodology that accounts for interactions/competition in the energy system, and which fully quantifies the main energy system variables and ensures a consistent technical perspective.

ASSUMPTIONS AND DRIVING FORCES

- Economic and other: Some elements of the NEO scenarios are based on selected scenarios from the IEA (WEO, ETP), EIA, IAEA, and IPCC. These scenarios themselves adopt a range of future storylines for demographic, economic and technological development. Thus, the NEO scenarios were not developed with a single set of driving forces in mind.

- Policy: The NEO scenarios do not necessarily adopt the policy assumptions from the set of scenarios on which the NEO scenarios are based, which cover a range of assumptions from a continuation of existing policies to stringent global mitigation. Instead, the NEO High scenario assumes a high level of concern for climate change and energy security, with the widespread implementation of carbon trading schemes. The scenario documentation does not list any specific policy assumptions for climate change or energy security.

Technology-specific assumptions include:

- Nuclear: The Low scenario assumes the replacement of existing plants when they reach the end of their operating lives, with some expansion after 2030; while the High scenario assumes construction of additional reactors based on national plans and statements. In the High scenario it is assumed that there is good initial experience with the construction of new nuclear plants, while the experience is poor in the Low scenario. Moreover, it is assumed that political and public acceptance is high in the High scenario and low in the Low scenario. These assumptions are reported for the global scale, and no discussion is provided as to how they translate to regional or country-level assumptions for Europe. No explicit assumptions on technology cost appear to enter the scenario definition.

- CCS is assumed to be successful for coal-fired plants in the Low scenario, and "not very successful" in the High scenario. Renewable energy production is assumed to be at the "high end of expectations" in the Low scenario, and at the "low end of expectations" in the High scenario.

- Efficiency and electrification: The NEO scenarios are based on electricity demand projections from selected scenarios (from the IEA (WEO, ETP), EIA, IAEA, and IPCC). These scenarios assume a range of technology and efficiency drivers, and cover a fairly wide range of possible futures.

SCENARIO RESULTS

Energy demand and electrification

As mentioned above, the NEO scenarios are based on energy and electricity demands from a range of scenarios. Global electricity demand in these scenarios ranges from 25–39 PWh in 2030 and from 32–64 PWh in 2050.[43] These broad ranges illustrate the divergent driving assumptions among the set of underlying scenarios. In a number of places the NEO focuses on the ETP Baseline scenario[44] (designated "ETP 0" by NEA), where global electricity demand reaches 47 PWh in 2050.

Electricity generation and the role of nuclear

Global nuclear capacity expands in the High scenario to around 600 GW in 2030 and 1400 GW in 2050. In the Low scenario, global capacity is roughly steady until 2030, and expands to 580 GW by 2050. This corresponds to a share of global generation of 9% (Low) and 22% (High) based on the 'ETP 0' scenario. In 2050, OECD Europe accounts for approximately 330 GW in the High scenario (and 125 GW in the Low scenario).[45] The NEO does not discuss the

43 Total primary energy supply ranges from 17 to 36 Gtoe.

44 Note, this refers to the baseline from the ETP 2006 report, not to be confused with the Baseline from the ETP 2010 analysed in this review.

45 In the High scenario, most of the capacity is in OECD countries (around 390 GW in North America and 195 in OECD Pacific), with a total of 200 GW in China and India.

implications for the installation of other technologies, such as fossil generation, CCS, or renewables.

Summary of factors driving nuclear energy deployment in the NEO scenarios

As mentioned above, the NEO scenarios were not developed in an integrated way that accounts for interactions/competition in the energy system and which fully quantifies the main energy system variables. Thus, the scenario documentation presents no findings on the contribution of other technologies. In addition, the NEO reports one set of nuclear deployment scenarios (Low and High) which do not vary according to the total electricity or energy demand across the range of scenario studies used to define demands (as mentioned above). Simply put, there is a much clearer and direct relationship between the assumptions listed above and the results of the scenarios:

- in the High scenario, additional reactors are constructed and there is good experience with this construction; CCS and renewables are deployed less;
- in the Low scenario, there is poor experience with construction of new reactors, and thus reactors are only replaced to 2030, with a small expansion thereafter; CCS and renewables are more successfully deployed.

Contributions to emissions abatement

The study provides an estimate of the annual global savings in emissions that would result in the High and Low scenarios, on the basis that nuclear generation replaces traditional coal-fired generation (without CCS). On this basis, the report estimates that nuclear generation is already reducing emissions by 3 Gt CO_2 in 2007, rising to 12 Gt CO_2 in the High case and almost 5 Gt CO_2 in the Low scenario by 2050. These estimates must be treated cautiously, because if greenhouse gas emissions are a concern, then the most likely alternative to nuclear is not traditional coal-fired generation.[46] However, if we take at face value the assumptions from the High scenario—that is, CCS is not very successful and renewables are deployed below expectations—then a high contribution to abatement could nonetheless arise. From the information given in the NEO scenario documentation, it is not possible to estimate the contribution in an energy system which includes renewables and CCS (since the scenario was not developed in an integrated way that considers in quantitative terms the potential role of other technologies).

Global developments

As mentioned, the NEO scenarios report primarily global results. OECD Europe represents a large share of global capacity deployment in both scenarios (21-24% in 2050), with OECD countries in general dominating development of the global industry in the High scenario, despite large gains in developing countries.

46 The arguments given for assuming traditional coal-fired generation is the most likely alternative are: that baseline scenarios include a large amount of new coal-fired generation; and nuclear and coal are both capable of supplying baseload generation.

2.5 Scenarios
NEEDS scenarios

The NEEDS (New Energy Externalities Development for Sustainability) scenarios analysis [8] presents a number of scenarios, of which the BAU (or Reference) and the 450 ppm scenarios are reviewed here.

ASSUMPTIONS AND DRIVING FORCES

- Economic: In both scenarios, GDP growth in the EU27 averages around 1.7% between 2005 and 2050,[47] equating to an overall increase of 113% between 2005 and 2050.[48] The tertiary sector and non-energy-intensive industry grow the fastest.
- Policy: In the 450 ppm scenario, the EU27 is assumed to reduce domestic CO_2 by 71% from the 1990 level by 2050. The BAU scenario assumes no limits on CO_2 emissions, but continuation of national policies for renewables, and the implementation of a carbon tax of €10/t CO_2.
- Import energy prices increase slowly from 2005-2050 (oil prices increase around 15% in real terms between 2005 and 2050, gas around 53% and coal by around 11%).

One important set of assumptions for determining the choice of technology is technology cost. Costs from NEEDS are reported in Figure 2.6.[49] Other relevant technology-specific scenario assumptions include:

- Nuclear: Policies are specified at the country level on the basis of existing and stated policies. These include

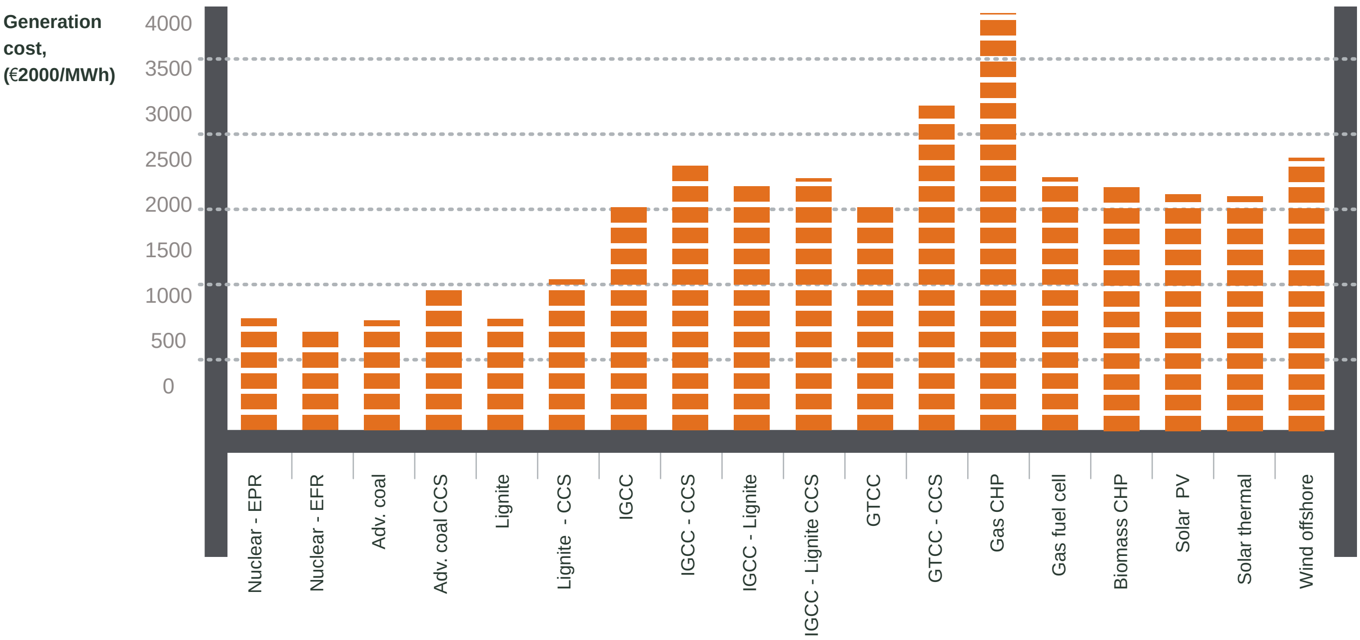

Figure 2.6 Generation costs in the NEEDS scenarios, 2050 [9]

Note: Costs vary across the countries. It is assumed that the technology costs in the study documentation refer to year $€_{2000}$ (since this index year is used for other inputs (e.g., see Table 7 in [8])). It is not clear whether the fuel prices used in these estimates correspond to the fuel costs used in the scenario development.

47 With annual averages of 2.2% for 2005-2010, 2.1% for 2010-2020, 1.8% for 2020-2025, 1.7% for 2025-2030, 1.5% for 2030-2040, and 1.2% from 2040-2050.

48 Note, the documentation reports 188%, but this is not consistent with the annual rates of 1.2–2.2 % in the report text (p. 32 and Table 6 in [8]). It is also very high, considering that these scenarios envisage a declining population (Table 6 in [8]).

49 Note, these technology costs correspond to those reported in [9]. The description in the NEEDS project documentation in [10] indicates that these correspond to a common set of harmonised technology data used in the scenarios, in addition to being used for Multi-Criteria Decision Analysis. However, discussion with the developers of the NEEDS scenarios indicates that there were some slight variations to these cost assumptions, with the exception of the solar technologies where significantly higher cost estimates were applied in the scenario development [11].

nuclear phase-outs in Germany, the Netherlands, Belgium and Sweden. Assumptions for other countries are not described, although some statements imply that nuclear is confined to those countries already using the technology.[50] Although not explicitly mentioned, it appears that 4th generation reactors are assumed to be commercially available before 2040 in the scenarios.[51]

- Costs for nuclear vary slightly across countries (for example, generation costs for EPR in Italy are €30.5/MWh compared to €30.1/MWh in France, Germany and Switzerland). [9]

- CCS availability is not described in detail in the scenario documentation, but it appears that this technology is available for coal and gas in all scenarios (and based on the results appears to be available on a large scale before 2020).[52] "[M]inimum" use of renewables is assumed in line with national policies in the BAU scenario. No additional support for renewables mentioned for the 450 ppm scenario.

- Strong electrification of buildings and industry, particularly in the 450 ppm scenario.

- Efficiency: Implementation of energy saving measures is assumed in the 450 ppm scenario, although there is some energy conservation in the BAU scenario. Note, it is not possible to determine the contribution of assumed energy efficiency policies or technology developments versus efficiency (and intensity reduction) induced by climate change policy.

SCENARIO RESULTS

Energy demand and electrification

Between 2000 and 2050, final energy demand increases 35% in the BAU scenario and 19% in the 450 ppm scenario. Energy intensity declines at an average annual rate of 1.13% in the BAU scenario and 1.42% in the 450 ppm scenario.[53] These rates are quite moderate and comparable to historical developments. However, the rate in the 450 ppm scenario appears to be relatively low for a scenario with an ambitious CO_2 mitigation goal; with the additional efficiency measures described in the 450 ppm scenario having only a moderate impact (for example a 12.7% reduction in residential sector demand from energy savings and the use of higher efficiency end-use devices relative to BAU).

On the other hand, the rate of electrification increases strongly in the 450 ppm scenario, reaching 40% by 2050 (compared to 24% in the BAU and 19% in 2000). This result is driven by electrification in buildings and in the industrial sectors (to 52% and 56%, respectively in 2050 in the 450 ppm scenario, from 27% in 2000). Electrification rates in the BAU scenario reach around 30% in industry and 38% in buildings, indicating that much of the additional electrification in the 450 ppm case is in the industrial sector. Electricity contributes a small share in transportation (9% 450 ppm and 2% BAU). These levels of electrification in industry and buildings are among the highest seen in the scenarios analysed in this review, and appear quite ambitious.[54] Moreover, one would expect high levels of electrification to correlate with higher levels of end-use efficiency, but as noted above the level of efficiency improvement (and intensity reduction) is relatively low.

The combined impact of increasing final energy demand and higher levels of electrification is an increase in electricity demand of 110% in the 450 ppm case between 2010 and 2050, to around 6100 TWh (and an increase of around 40% in the Baseline). Half of the increase occurs in one decade (2040–2050).

50 "…the restriction in use of nuclear energy to countries already using nuclear energy…[is] crucial for the limited nuclear contribution."[8]

51 With over 30 GW of installed capacity by 2040.

52 For example, over 50 GW of CCS capacity is installed by 2020 in the 450 ppm scenario.

53 Assuming the correct interpretation of the growth in GDP (see above).

54 The specific explanations in the documentation include the reduced use of conventional gas and oil boilers in buildings, and increased use of condensing boilers, heat pumps and 'advanced electric appliances'; while in the industry sector, the use of electric-arc furnaces is mentioned.

Electricity generation and the role of nuclear

The share of nuclear generation in the 450 ppm scenario declines from 32% in 2000 to 22% in 2030, spikes back to 29% in 2040, then declines again to 21% by 2050 (see Figure 2.7).[55] In the BAU scenario, the share remains roughly constant from 2030–2050. In absolute terms, installed capacity decreases in BAU from 137 GW in 2000 to 117 GW in 2050, although generation remains roughly unchanged.[56] In the 450 ppm scenario, capacity increases to 186 GW, made up of 155 GW Gen II and III, and 31 GW Gen IV fast breeder reactors in 2050.[57] In comparison, generation from renewables increases from 15 to 23% (20% in BAU), and installed capacity increases from 160 GW to 587 GW (306 GW BAU). The share of fossil generation increases slightly in both scenarios by 2050, although in the 450 ppm scenario this is almost entirely natural gas-fired generation (77% of capacity with CCS). CHP grows strongly in both scenarios to a share of around 20–25% in 2050, with gas-CHP with CCS assumed to be available in the 450 ppm scenario. There is no discussion of grid developments and infrastructure needs in the different scenarios (although there is an interesting statement regarding nuclear and grid stability—see below).

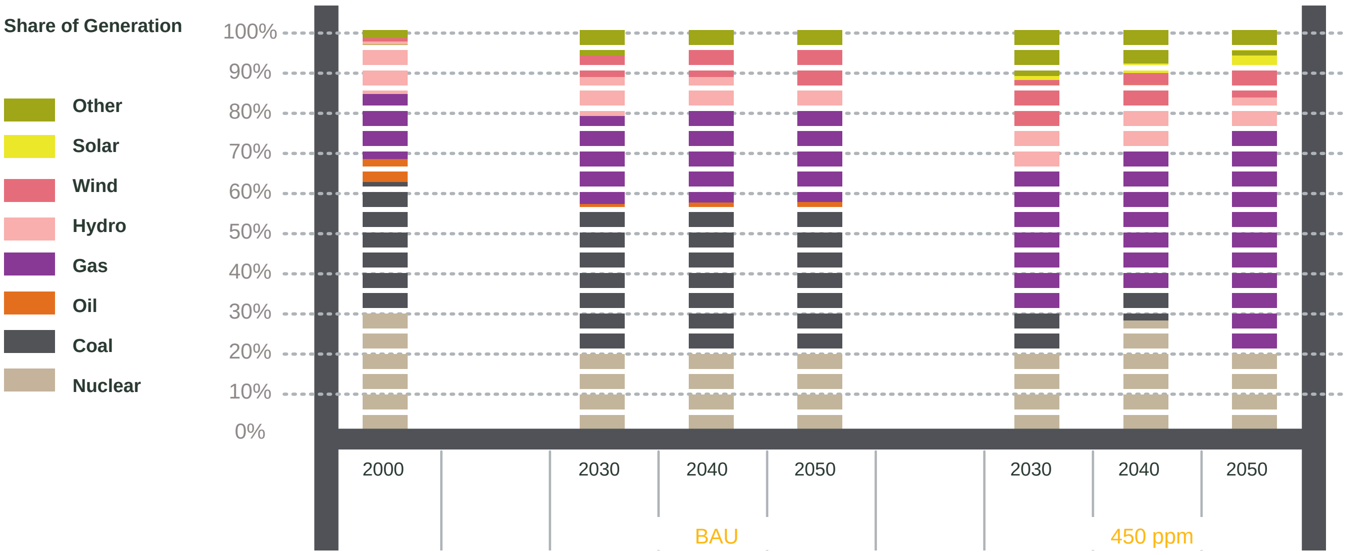

Figure 2.7 Share of electricity generation, NEEDS BAU and 450 ppm scenarios
Note, 'Others' includes biogas, geothermal, wave/tidal, and hydrogen.

Summary of factors driving nuclear energy deployment in the NEEDS scenarios

On the basis of the assumptions and results summarised above, we can begin to develop a hypothesis of the driving forces behind the deployment of nuclear in the BAU and 450 ppm scenarios. In these scenarios, the potential market for nuclear energy is large, due to continuing economic growth (averaging 1.7% pa), moderate reductions in energy intensity (around 1.4% pa), and the very high levels of electrification (rising from 19% to 40% in the 450 ppm case). The competitiveness of nuclear appears to be supported by relatively low costs (see Figure 2.6), although assumptions regarding country-level policies appear to restrict deployment—in particular, phase-outs in Germany, the Netherlands, Belgium and Sweden (assumptions for other countries do not appear to be described).[58] Similar to

55 This can be attributed to a 40% increase in electricity demand between 2040 and 2050 in this scenario, but only a 4% increase in nuclear generation in the same period.

56 Capacity factors increase from an average of 75% in 2000 to 90% in 2050.

57 Which are already in operation in 2040, which seems very ambitious.

58 In the discussion of the BAU scenario, it is noted that nuclear output increases in France, the Czech Republic and Finland, (offsetting the impact of the phase-outs), revealing some of the country-specific assumptions.

some of the other studies, these assumptions appear to be among the most important influences on the level of nuclear deployment.[59] However, the scenario documentation also hints to a link between grid stability and nuclear deployment: "[Beyond 2030] …the required grid stability [is] crucial for the limited nuclear contribution."[60] Turning to the impact of policy, we observe that the climate policy in the 450 ppm case favours additional deployment of 69 GW, including deployment of advanced 4th generation plants, primarily at the expense of coal-fired generation. Looking at other technologies expected to be supported by a climate policy: renewables do not play a strong role in these scenarios, reaching only 23% of generation in the 450 ppm case; however CCS is available very early in the 450 ppm scenario (30 GW in 2020), enabling a high share of fossil generation despite the stringent climate policy (including gas-CHP-CCS plants)—this potentially reduces the need to shift to other low-carbon options such as nuclear and renewables. However, as in some of the other scenario studies, these may be secondary to the effect of restrictions on nuclear deployment.[61]

Contributions to emissions abatement

The 450 ppm scenario leads to a 71% reduction in energy-related CO_2 emissions compared to 1990 (with carbon prices reaching €$_{2000}$ 850/tCO_2). In the BAU scenario, emissions increase to almost 5000 Mt CO_2, while in the 450 ppm case they are reduced to 1260 Mt CO_2. The scenario documentation presents a breakdown of the contribution of different technology options, including nuclear, to total abatement in the 450 ppm case relative to BAU from 2000 to 2050. This shows that nuclear contributes approximately 260 Mt CO_2 in 2050, or around 7% of total abatement (recalling that there are 69 GW additional nuclear capacity in the 450 ppm scenario relative to the BAU scenario). Of further interest is the level of emissions that would prevail without nuclear, but this cannot be determined without access to the modeling tools used to develop the scenario. However, we can make a very preliminary estimate by assuming nuclear generation is replaced by generation from other technologies in proportion to their contribution to total generation in 2050. The impact on emissions ranges from 35 Mt CO_2 (if we assume nuclear is replaced by the same proportion of coal, gas (both with CCS) and renewables as in the rest of the mix) to 450 Mt CO_2 (if we assume renewables and CCS cannot expand, but coal and gas are added in proportion to the original mix).[62] This is of course a highly speculative estimate, and other scenario variables would be expected to change under such circumstances (such as energy prices, demands, emissions).

Global developments

The NEEDS scenarios consider only developments in the EU-27, and thus do not report any global energy system developments.

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59 For instance, in some of the other scenarios presented in the NEEDS documentation, the impact of cancelling the phase-outs and allowing a larger expansion of nuclear is analysed. In such a scenario with a similar 450 ppm target, this results in an expansion of nuclear capacity to 307 GW in 2050. However, no 4th generation is supported under such a case, although the reason for this is unclear.

60 Grid stability is not discussed elsewhere in the scenario study report. It is unclear if the statement is saying that requirements for grid stability support nuclear, or limit the role of nuclear. The latter seems less likely given that it would probably occur only under circumstances with high levels of intermittent generation (for example, see ETP BLUE hi REN sensitivity), whereas the share of renewables in the NEEDS scenarios is quite low.

61 It appears that the combination of restrictions on nuclear and low deployment of renewables necessitates a high deployment of gas with CCS (rather than coal, as seen in the Power Choices and ETP BLUE Map scenarios) to meet the stringent abatement target.

62 The emission factors for generation technologies are calculated from efficiencies in NEEDS project documentation [9], standard emission factors for fossil fuels [12] and assumptions regarding carbon capture rates consistent with other literature.

3 Synthesis

Nuclear energy continues to be used in Europe in all the scenarios analysed in this review, contributing at least 17% of generation in 2050 (and 117 GW of installed capacity). The highest share of nuclear reported is 31% in 2050 (and 424 GW). Figure 3.1 summarises the contribution of different generation options across the scenarios.

Figure 3.1 Electricity generation and capacity by technology, selected scenarios

Note: Nuclear capacity in the NEO scenarios is 125 GW (Low) and 330 GW (High) (but no estimate is provided for generation or capacity of other technologies). For the WEC scenarios, capacity estimates for solar and "Other RES" (tidal/wave and geothermal) are all included in "Wind". Furthermore, the WEC scenario documentation does not distinguish between capacity with and without CCS (and all are reported under "Coal" and "Gas" above). For the PC scenarios, capacity estimates for oil-fired generation are included in "Gas".

Synthesis

Table 3.1 provides a summary of the factors contributing to the observed levels of nuclear deployment, and the approximate size and direction (↓,~,↑) of the contribution of each driving assumption. Some observations can be synthesised regarding the impact of driving forces and technology assumptions on nuclear deployment across these scenarios. For the size of the electricity market:

- Economic growth and energy intensity reductions tend to correlate in the scenarios (with the exception of the NEEDS scenarios), such that those scenarios envisioning high economic growth also exhibit the largest reductions in energy intensity. This is consistent with much of the scenario literature, and is consistent with the idea that faster growth coincides with greater innovation, faster replacement of capital stock and structural changes. As a consequence, the divergence in energy demand across the scenarios is much smaller than the divergence in economic growth and energy intensity, and together these assumptions are less important for determining the size of the market for nuclear.

- The extent of electrification is very important for the size of the market for nuclear; the success of electric mobility and large-scale electrification of industry and buildings seem to influence whether electrification levels are on the order of 30% or above 40%.

Regarding the success of nuclear in market, the following observations are synthesised from the scenarios:

- Nuclear generation is assumed to be relatively cheap in all scenarios. As a result, nuclear is deployed in all scenarios (although there is quite a range of divergence). Realising these cheap costs is likely very important for achieving the projected levels of deployment, requiring success in controlling capital expenditure costs, long operating lifetimes and high load factors.

- Political limits on deployment play a large role in constraining nuclear in all scenarios (with the possible exception of WEC Lion): Table 3.2 synthesises the assumptions on nuclear availability (where they are reported). Moreover, sensitivity analyses presented in the scenario reports suggest that these political constraints come into play before competition from CCS, renewables or CHP has a significant impact (although different assumptions about these technologies may change this). The role of renewables depends on renewable and climate policy assumptions (those scenarios with weak climate policy generally assume a continuation of current renewable support), while the success of CHP depends on whether gas-CHP-CCS options are assumed to be available (otherwise the contribution of CHP in stringent mitigation scenarios is limited by biomass availability).

- Climate policy is also important for nuclear deployment. In the absence of strong climate policy, coal prices appear to influence the contribution of nuclear. Other policy assumptions (e.g. for energy security) are generally not described in detail across the studies.

Overall, we can also make some observations on reliability of the scenarios:

- While the estimates for nuclear deployment in the NEO scenarios are not necessarily implausible compared to other scenarios, the lack of an integrated approach in these scenarios means little information about the impact of drivers and competition with alternatives is represented in these estimates.

- The level of electrification in the PC scenario appears to be highly ambitious in terms of the transportation market (with 90% of car energy demand supplied with electricity in 2050). This also leads to optimistic assumptions on overall energy efficiency and intensity. Lower estimates for electrification of transportation would likely reduce the size of the electricity market (and require more abatement activities elsewhere), and thus reduce the absolute contribution from nuclear. In contrast, the NEEDS 450 ppm scenario is also optimistic on the level of electrification (but in industry and buildings), but pessimistic in terms of overall energy intensity, which seems inconsistent with the overall storyline and the high level of electrification. A faster rate of energy intensity reduction would reduce the market size, potentially increasing the relative contribution of nuclear. The WEC Lion scenario is optimistic about both economic growth and energy intensity, but these balance to a large degree and may be appropriate given the inclusion of Russia in the European region in this study. The ETP scenario documentation appears to contain some discrepancies in energy and electricity demand and electrification rates, however they do not appear to have a major influence on the potential role of nuclear.

- The global assumptions on support for nuclear in Lion appear optimistic and, although it is unclear how they translate to Europe and specific countries, they clearly imply major changes to some country-level nuclear policies. On the other hand, the global cap on nuclear capacity in the ETP scenarios appears arbitrary (although not necessarily unrealistic). The level of the cap (1200 GW) is lower than the level of global deployment in the Lion (1650 GW), NEO High (1400 GW) and PC (3350 GW) scenarios. The PC scenario implementation of barriers to nuclear in Europe appears to be well designed, whereas the global nuclear developments for the PC scenario are very ambitious (and apparently inconsistent regarding new nuclear designs). The NEEDS scenarios appear to be highly optimistic regarding the availability of CCS in the near term (already 30 GW in 2020) and 4th generation nuclear (already 30 GW in 2040), given some of the challenges facing the development of these technologies. The WEC Lion scenario may also be optimistic regarding early deployment of CCS.

- Few insights are provided by the studies on the level of electricity grid investment required for the various scenario outcomes.

Overall, looking across the scenarios, if we account for: i) a ‘central’ level of political support for nuclear; ii) a moderate increase in electrification; iii) an ambitious climate policy; and iv) the realisation of relatively cheap generation costs that ensure nuclear is a highly cost-competitive CO_2-free generation source, then a level of nuclear deployment in EU27 or OECD Europe of 160-170 GW in 2050 does not seem unreasonable. The scenarios indicate that higher levels of electrification would likely increase this slightly, but realising significantly higher levels of deployment would require major changes in political and popular support.

Contribution to abatement and global developments

Across the scenarios, each additional GW of nuclear capacity in 2050 contributes to abatement by around 4 Mt CO_2 (relative to the corresponding reference scenario)[63] however since nuclear is also readily deployed in most reference scenarios the absolute additional contribution is relatively modest (with the exception of the WEC Lion scenario). One final observation is that the scenarios present diverging views on Europe’s relative role in global nuclear development (see Figure 3.2). In some scenarios (such as NEO and WEC), Europe accounts for 20-30% of global capacity independent of the level of deployment in Europe. In other scenarios (such as the PC and ETP BLUE Map scenarios), an expansion of nuclear in Europe coincides with a much larger expansion globally, leading to a relative decline in Europe’s share of global capacity. This has important implications for the influence of Europe, and the needs of Europe, on the development of the global nuclear industry.

Europe’s share of global nuclear capacity

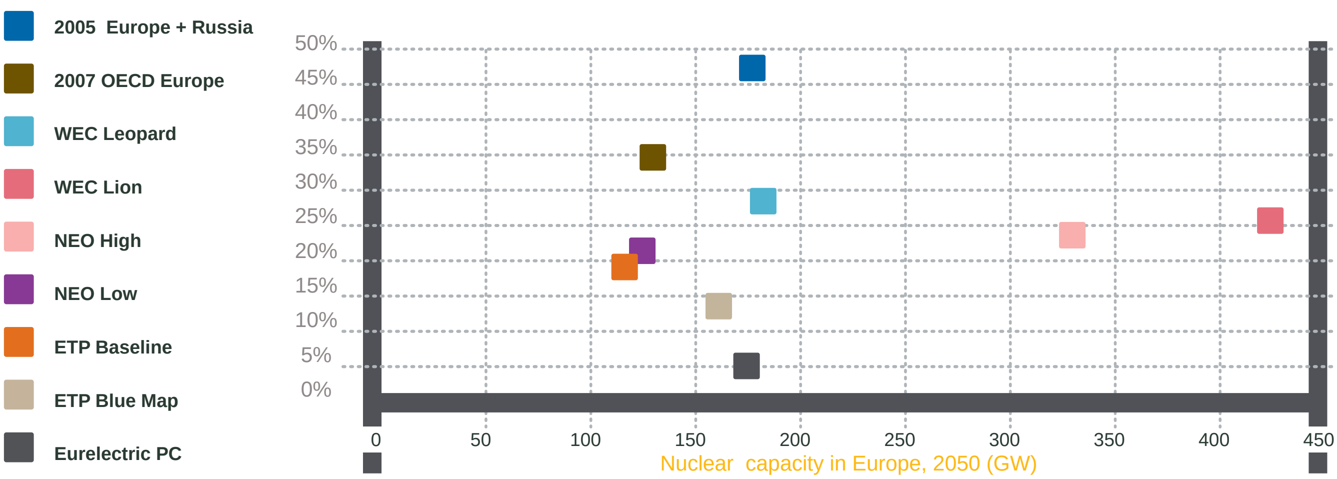

Figure 3.2 Scenario estimates of European nuclear deployment, and share of global deployment, 2050

63 To be precise: in the NEEDS scenarios 3.8 Mt CO_2/GW; in the WEC scenarios 4.1 Mt CO_2/GW; and in the ETP scenarios 4.4 Mt CO_2/GW.

Scenario Initial nuclear capacity, GW (year)	Market size			Nuclear competitiveness and availability			Overall deployment, 2050 (GW)
	Economic development	Energy intensity and demand	Electrification (share) Electricity production (TWh in 2050)	Limits on Technology (non-cost barriers) (see also Table 3.2)	Technology costs	Policy (climate: price/t-CO_2 in 2050)	
Power Choices 134 (2005)	Doubling of GDP, 2010–2050 (1.8% pa) ↑↑	Strong reduction in intensity (2.5% pa), energy demand declines ↓↓↓	Strong electrification (transportation), expanding electricity sector and nuclear (45%) 5200 ↑↑	Phase-out in 2 countries, no nuclear in 10 countries, limited sites in others ↓	Cheap, but costs increasing for additional new sites; costs of alternatives (coal) increase ↑	Strong climate policy (€$_{08}$103/t) ↑↑	175 ↑↑↑
PC Baseline 134 (2005)	As above (1.8% pa) ↑↑	Moderate reduction in intensity (1.7% pa), demand roughly constant ↓↓	Moderate electrification, but electricity production still relatively high (29%), 4700 ↑	As above ↓	As above ↑	Weaker policy (but stronger in ETS sectors) (€$_{08}$42/t) ↑	162 (est) ↑↑
NEEDS 450 ppm 138 (2000)	113% increase 2005–2050 (1.7% pa) ↑↑	Mild reduction in intensity (1.4% pa), slight increase in demand ↓/↓↓	Strong electrification (buildings and industry), (40%), 6100 (net) ↑↑	Phase-out in 4 countries: apparently restricted to current nuclear countries ↓↓	Cheap, Gen IV avail. early; but CCS available very early ↑	Strong climate policy (€$_{00}$850/t) ↑↑	186 ↑↑↑
NEEDS BAU 138 (2000)	As above (1.7% pa) ↑↑	Mild reduction in intensity (1.1% pa), increase in demand ↓	Mild electrification (24%) 4200 (net) ~	As above ↓↓	Cheap ↑	Very weak climate policy (€$_{00}$10/t) ~	117 ~
ETP BLUE Map 130 (2007)	63% increase 2007–2050 (1.1% pa) ↑	Moderate reduction in intensity (1.8% pa build., ind., trans.), demand declines ↓↓	Moderate electrification (30% in build., ind., trans.) 4306 ↑	Apparent phase-out in 4 countries, restrictions in others, global cap ↓ (↓↓↓ at high cap.)	Cheap, highly competitive with CO_2 target ↑	Strong climate policy (US\$$_{08}$175/t) ↑↑	162 ↑↑
ETP Baseline 130 (2007)	As above (1.1% pa) ↑	Mild reduction in intensity (0.9% pa build., ind., trans.), slight increase in demand ↓	Moderate electrification (~27% in build., ind., trans.) 5168 ↑	As above ↓ (↓↓↓ at high cap.)	Cheap, but other technologies are competitive ~	Weak in some parts of OECD Europe (US\$$_{08}$83/t) ~	117 ~
WEC Lion 177 (2007)	188% increase 2005–2050 (2.4% pa) ↑↑↑	Rapid intensity reduction (2.2% pa) ↓↓↓	Moderate electrification (33%) 7800 ↑	Not discussed. Strong government support/cooperation ~	Cheap, low discount rate ↑↑	Strong interest in CC and energy security ↑↑	424 ↑↑↑↑↑
WEC Leopard 177 (2007)	87% increase (1.4% pa) ↑↑	Mild intensity reduction (1.1% pa), increase in demand ↓	Moderate electrification (31%) 7700 ↑	Not discussed. Limited government support/cooperation ↓	Cheap ↑	Less interest in CC and ES ↑	182 ↑↑↑
NEO Low 130 (2006)	NA, total increase in demand for Europe not reported. Moderate, based on figures for 'ETP 0' (see Section 2.4) ↑			Replacement and expansion ↓	↑	None mentioned ~	125 ↑
NEO High 130 (2006)	As above ↑			New capacity, public acceptance ~	↑	High concern, carbon trading ↑↑	330 ↑↑↑↑

↑/↓: ceteris paribus impact on nuclear deployment

Table 3.1 Summary of driving forces and assumptions for the scenarios

Synthesis

Scenario Study	Austria	Belgium	Bulgaria	Cyprus	Czech Republic	Denmark	Estonia	Finland	France	Germany	Greece
Power Choices	X	P-O		X		X	X			P-O	X
ETP	?	?	NA	NA	?	?	NA	?		P-O?	?
NEEDS	X?	P-O	?	X?		X?	X?			P-O	X?
Using Nuclear 2008											

Scenario Study	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Poland	Portugal	Romania
Power Choices		X		X		X	X			X	
ETP	?	?		NA	NA	?	NA	P-O?		?	NA
NEEDS	?	X?	?	X?	?	X?	X?	P-O	X?	X?	?
Using Nuclear 2008											

Scenario Study	Slovakia	Slovenia	Spain	Sweden	United Kingdom	Iceland	Norway	Switzerland	Turkey
Power Choices						NA	NA	NA	NA
ETP	?	NA	P-O?	P-O?		?	?	?	?
NEEDS	?	?	?	P-O	?	NA	NA	NA	NA
Using Nuclear 2008									

x/x? = no nuclear (explicit assumption)
? = not reported, but likely "no nuclear"
P-O = phase out
P-O? = nuclear phased out (observed result), but unclear if this is an explicit assumption
? = not reported
? = not reported, but likely nuclear allowed
= nuclear allowed (explicit assumption OR observed result)
NA = country not included in European region in the scenario study

Table 3.2 Scenario assumptions on nuclear moratoria, phase-outs and availability
Note: current use of nuclear is based on IAEA [13].

Part II:
DRIVERS AND CONDITIONS

4.1 Drivers for contribution of nuclear energy to the 2050 low-carbon energy system in the EU

Security of supply

Nuclear energy contributes to strengthening security of supply in Europe by providing almost one third of the European Union's (EU) electricity reliably and at stable, predictable and competitive prices. Uranium security of supply is based on diversified resources coming predominantly from politically stable countries and processed by international consortia. In addition, due to its high energy density, nuclear fuel may be easily stored in small volumes at domestic facilities. Reprocessing of used fuel to recover unused uranium and plutonium can lead to savings of up to 25% of natural uranium. Beyond conventional electricity use, nuclear energy can also contribute to energy security in the transport sector. In the near future, substitutes to gasoline and diesel will have to be developed, including synthetic liquid fuel from ultra-heavy hydrocarbons, coal or biomass, hydrogen in fuel cells or electricity in plug-in hybrid electric vehicles. In all cases carbon-free electricity or hydrogen will have to be supplied by nuclear energy and renewables. In the long term, the uranium resource base can be further extended by extraction from unconventional sources, by recycling and by improved uranium utilisation in units currently under construction and in future Generation IV reactors, including fast breeders. In the long term, it is also possible to use thorium as a fuel, which is more abundant in nature than uranium.

Many utilities in the EU have decided to increase the power output of existing reactors. The intention is to operate all nuclear power plants throughout their full, safe technical and economic lifetimes by means of plant modernisation. Besides the economic and security of supply advantages, long-term operation (LTO) contributes to sustainability and minimises CO_2 emissions.

DRIVERS

The European Commission (EC) is estimating that "over the next ten years, energy investments in the order of € 1 trillion are needed, both to diversify existing resources and replace equipment and to cater for challenging and changing energy requirements". Ensuring a secure energy supply for the next decades is one of the main priorities of the EU's energy policy. The competitive position of important European sectors also depends on the availability of secure and reliable energy at affordable prices. Moreover, with the increasing use of intermittent renewable energy sources, stable baseload electricity, as generated by continuously operated nuclear power plants, will help maintain the stability of the system. Nuclear power plants also have the ability to vary output (load-follow) when compensation for large fluctuations in renewable energy is required to ensure grid stability.

RECOMMENDATIONS

- The EU's 2050 energy strategy should underline the key role that nuclear power can play in ensuring European security of supply.
- To ensure security of supply, efforts should be made to progress in all aspects of nuclear technology, in particular in guaranteeing the safe long-term operation of existing nuclear reactors and in facilitating the financing, construction and operation of new plants.
- The nuclear industry should continue its efforts to increase the availability factors of NPPs, and hence continuously drive the sector towards improving its performance record.

4.2 Drivers for contribution of nuclear energy to the 2050 low-carbon energy system in the EU

Transition to low-carbon fuels

The EU has decided that in order to achieve the decarbonisation of the electricity and transport sectors by 2050, it must make a shift to low-carbon energy technologies. Substitution of fossil fuels, increased use of electricity and energy efficiency improvements in the power plants will be driving this transition in the energy sector. It must be ensured that the additional provision of electricity generation does not come to the detriment of the EU's goal to curb GHG emissions but should be provided by low-carbon energy sources such as nuclear energy. The new designs of nuclear reactors proposed on the market offer attractive features which encourage the renewal and expansion of the European nuclear fleet: very high level of safety, competitiveness, flexible operating conditions, better fuel utilisation and extended lifetime. Successful utilisation of currently available reactors will be a key step towards the development of new generation GEN IV reactors. The sustained competitiveness of current reactors and the development of GEN IV reactors are both key features of the EU's Strategic Energy Technology Plan (SET-Plan).

DRIVERS

Successful deployment of a European fleet of reactors with the highest safety level is the result of continuous improvement of past reactor designs, taking into account experience feedback of the first realisations and also the result of innovation. Ensuring sustainability of new reactor designs requires innovation in the aspects of uranium utilisation and waste minimisation across the fuel cycle. As to GEN IV reactors, most of the necessary technology has been proven at the experimental or demonstrator level, but not yet commercially deployed. Moreover, with the need for a new European grid system to support not only traditional power loads but to allow for the integration of renewables at local and regional levels there is renewed interest in smaller (100-300 MW) units for generating electricity from nuclear power.

RECOMMENDATIONS

- According to the EC, investments in power generation should lead to nearly two thirds of the electricity coming from low-carbon sources by the early 2020's. In its Energy Roadmap 2050, the EC should confirm that the EU's long-term energy strategy is inclusive of all low-carbon energy sources. Nuclear investment, as part of this strategy, should be facilitated at the EU and the Member States level. Furthermore, the corresponding grid infrastructure and storage capacity investment cannot be neglected in that respect.

- European R&D in nuclear energy on operating and currently constructed reactors should be promoted in the EU research programmes. EU fission research funding should be kept at a level commensurate with the potential of nuclear to make a major sustainable contribution to future low-carbon energy supplies.

- To successfully prepare the deployment of GEN IV nuclear reactors, the good achievement of ESNII (SNETP) projects is key. In particular, the construction of the ASTRID prototype is of major importance. It is also essential to pursue research on complementary technologies such as the development of ALLEGRO as the demonstrator of the Gas-cooled Fast Reactor to reach higher temperature applications, ALFRED as the demonstrator of the Lead-cooled Fast Reactor and MYRRHA to be an experimental demonstrator of ADS (XT-ADS) technology for transmutation purposes.

4.3 Drivers for contribution of nuclear energy to the 2050 low-carbon energy system in the EU

Competitiveness

As concluded in the ENEF Competitiveness SWOT Report Part I, nuclear energy is currently recognised in a wide range of scenarios as the least-cost option for baseload centralised generation, providing electricity at stable and predictable prices. As such, it contributes to the competitiveness of European industry. Nuclear energy also supports technological and scientific development in the EU and has led to many spin-offs and applications with major social benefits. These contribute significantly to local, regional and national economies, as well as to the prosperity and wellbeing of citizens and communities. Nuclear new build projects will mean new jobs and services, the further development of local communities and financial investment that can impact positively upon other business sectors. A growing nuclear industry is a catalyst for sustained socio-economic development at every level. It also provides a platform for the exporting of European technological excellence across the world.

DRIVERS

Innovation for nuclear technologies remains a main driver both for the competitiveness of nuclear energy in the European market and for the competitiveness of the European industry in world competition. It can be anticipated that important development efforts on materials (structural material and fuel material) will be key for the improvement of nuclear reactor reliability and performance. Maintaining competitive generation costs for new nuclear reactors will be a crucial driver for long-term nuclear deployment. The economics of nuclear power are dependent on total investment costs, which are determined by both construction costs and the discount rate. A reduction in lead time also has a significant impact on total costs, in particular at a higher discount rate. Construction delays, on the other hand, have a lower impact on costs, provided that total budget remains constant. Moreover, the competitiveness of EU's nuclear industry will be driven by global developments. While China, India, the US and other world players are adopting aggressive development plans for both nuclear and renewable energy, a key objective of the long-term energy strategy should be to sustain the global competitiveness of the EU's industry and promote its growth, in Europe and in foreign markets.

RECOMMENDATIONS

- The EC should propose financing instruments which will encourage wider nuclear financing and thus contribute to the competitiveness of new nuclear projects.
- The EU's energy and trade agendas should be linked in order to sustain the leading role of European industrial players globally.
- The nuclear industry must ensure that the cost of new nuclear reactors remains competitive.

4.4 Drivers for contribution of nuclear energy to the 2050 low-carbon energy system in the EU

Strong global growth of nuclear energy capacities

Several of the reference studies, discussed in Part I of this report, show that global nuclear power capacity is projected to grow dramatically:

- In the EURELECTRIC Power Choices (PC) scenario, the global share of nuclear generation increases from 16 to 28% (from 2005 to 2050) as “third and fourth generation designs mature”. Simultaneously, total global generation increases very strongly, such that global nuclear generation grows approximately 8-fold, with installed capacity increasing by almost 3000 GW (compared to a net increase of 40 GW in the EU27). One implication of such a large global deployment is that industry developments are likely to be driven by global, rather than EU needs.

- According to the IEA ETP BLUE Map scenario, the global share of nuclear generation increases from 14 to 24 % (from 2007 to 2050). This corresponds to an increase from 374 GW to 1200 GW. The report estimates that this would require annual gross capacity additions of 30 GW, which appears to be quite plausible compared with the average of approximately 25 construction starts per year in the 1970’s. OECD Europe’s share of global installed capacity decreases from 35% to 14%, indicating again that global forces are likely to drive much of the future development in the nuclear industry.

- In the WEC study, the global share of nuclear generation increases from 15 to 19 % in the Lion scenario, but declines to 7% in the Leopard scenario (from 2005 to 2050). Total global generation increases strongly, such that global nuclear generation increases approximately 4-fold in the Lion scenario, with installed capacity increasing to almost 1650 GW by 2050. In the Leopard scenario, global capacity increases to around 640 GW. In both cases, Europe accounts for around 26–28% of global capacity in 2050, and is thus likely to remain an important driver for global nuclear industry developments. Asia accounts for 45-49% in 2050 in these two scenarios.

DRIVERS

Over 60 power reactors are currently being constructed in 15 countries plus Taiwan. Most reactors on order or planned are in the Asian region, although there are plans for new units in Europe, the USA, South America and Russia. China is planning an impressive increase in nuclear capacity to 70-80 GW by 2020 and India’s aim is to add 20 to 30 new reactors by 2020. Strong global growth of nuclear capacity will create opportunities for utilities by strengthening the competition between vendors. The market developments will also imply growing opportunities for the nuclear supply chain industry. However, the challenge for the European industry will be to remain at the forefront of technology and business development.

RECOMMENDATIONS

- In view of upcoming discussions on the multi-annual financial framework (MFF) 2014-2020 and on the 8th Framework Programme for Research and Development, the EU needs to ensure an appropriate network of nuclear R&D infrastructures, covering all aspects of the safe long-term use of power plants and the development of new, safe, competitive and sustainable reactor technologies. This is necessary in order to preserve technological and industrial leadership.

- EU researchers and companies need to increase their efforts to remain at the forefront of the growing international nuclear market.

4.5 Drivers for contribution of nuclear energy to the 2050 low-carbon energy system in the EU

Other applications of nuclear energy

Increasingly, climate policies will encourage the modification of fossil-fuel-based industrial processes towards the use of low-carbon energy supplies. These processes typically require large and continuous amounts of energy in the form of heat, electricity or hydrogen. Examples of such processes include: the large scale production of hydrogen for synthesising fertilisers, for refining heavy crude oil, for optimising the production of synthetic hydrocarbon fuels from coal or biomass, or for other industrial processes. With regard to heat processes, district heating with nuclear reactors is already implemented in some European countries and this application could be expanded to other places, either by cogeneration of electricity and heat, or by heat only generation. Moreover, the transport sector is likely to rely increasingly on electricity, whether in the form of fully-electric or hybrid vehicles, or by using battery power. Nuclear power can contribute to such transformations via generation of either electricity or process heat for the production of hydrogen or other synthetic fuels.

DRIVERS

Further demand for hydrogen for industrial processes and the transport sector will be an important driver, as energy for hydrogen production can be delivered by low-carbon energy technologies, such as nuclear and renewables. However, investment in new industrial processes will be driven by economics. The substitution of fossil fuels by low-carbon ones will be driven by the higher prices of fossil fuels and carbon emissions. High temperature gas-cooled reactors (HTR) have long been identified as an appropriate supplier of high temperature nuclear heat for process applications, and a first prototype of such a reactor coupled to a process heat application could be built around 2020.

RECOMMENDATIONS

- The EC should foster HTR research and development through the SET-Plan.
- The European Sustainable Nuclear Industrial Initiative (ESNII) launched under the SET-Plan on 15 November 2010 is seeking funding of up to €10 billion. Financial support for this initiative should be ensured from public and private sources.
- Industry support (from the nuclear sector but also from the electro-intensive industries) is needed to launch a large-scale demonstration for coupling of a nuclear reactor with industrial process heat applications in order to prove technical feasibility and operability as well as acceptability for licensing and economic competitiveness.
- The nuclear industry should work on the development of competitive designs of smaller reactors to meet the likely demand.

5.1 Conditions for nuclear energy development in Europe

Nuclear safety

Nuclear safety can be defined as the best-balanced combination of human activity, technology, regulation and organisation. A safe nuclear power plant is a plant that is designed, operated, maintained and decommissioned according to strict nuclear safety standards, rules and procedures. National Safety Authorities are in charge of setting the regulations and rules for nuclear power plant safety and controlling their application. The holder of an operating licence for a nuclear power plant has the sole and absolute responsibility for its safe operation. The level of safety is being continuously raised through plant safety upgrades, experience feedback, continuous improvement of organisations and procedures, etc. The paramount priority is to maintain the plant in a safe condition. International nuclear safety organisations (IAEA & WANO) are continuously assessing nuclear safety in all NPPs, to monitor operating excellence. All EU regulators are represented in ENSREG which was created in 2007 and has already played a crucial role during the preparation of the Safety Directive. Global nuclear power plant operating experience amounts to more than 13,000 reactor years.

DRIVERS

The national regulators and the EC are currently taking initiatives to harmonise nuclear regulation within the EU. On 25 June 2009, the Council adopted a Directive establishing a new Community framework for nuclear safety. European utilities are participating in the harmonisation of safety requirements for Generation II and III reactors, and are involved in setting standards for new Generation III+ reactors in Europe.

RECOMMENDATIONS

- The nuclear industry must continue the safe operation of all nuclear installations.
- The nuclear industry should continue its efforts in harmonising safety requirements and thus support the European Community framework for nuclear safety.
- Taking into account the forecasted increased interest in new nuclear build, safety standards for the design and operation of new nuclear reactors should be developed by the industry in conjunction with ENSREG and the European Institutions.
- Harmonised conditions for the safe long-term operation of nuclear power plants should be developed throughout the EU, based on an initial EC recommendation. The conditions should be defined in co-operation with the industry and the national regulatory authorities.

5.2 Conditions for nuclear energy development in Europe

Radioactive waste management

Radioactive waste management is a key element of the sustainable use of nuclear energy. R&D programmes have provided a series of viable technical solutions for the different types of radioactive waste. Short lived low and intermediate level waste (LILW) is typically disposed in near surface disposal facilities. Most EU Member States with nuclear power plants currently operate disposal facilities to deal with these categories of waste. As far as high-level waste (HLW) and spent fuel (if considered as waste) are concerned, there is a worldwide scientific and technical consensus that deep geological disposal represents the safest and most sustainable option. Progress on disposal projects is being made in Finland, Sweden and France. It is likely that by 2025 these countries will have operational disposal facilities. Recycling of spent fuel before final storage is an option to reduce the volume and toxicity of high-level waste and optimise the use of fissile materials. National policies and national programmes for radioactive waste management have to be established and Member States have to engage in providing political support to enable the establishment of the appropriate facilities.

DRIVERS

Safe management of radioactive waste is a clear expectation of EU citizens. Timely decisions regarding national waste management programmes, with clear indications concerning final repositories for HLW, are an essential element of the safe and sustainable management of nuclear waste. Implementing HLW disposal will also improve public and political acceptance of nuclear energy and thus facilitate nuclear new build programmes. It will also fulfil the political necessity to dispose of the legacy waste. The industry is ensuring that financing for back-end activities is available when needed and that safety is given priority in all waste management activities. However, political decisions at national and EU level would be helpful.

RECOMMENDATIONS

- Most EU Member States have yet to take decisions regarding the disposal of high-level radioactive waste and (where appropriate) spent fuel. All countries should develop and implement national radioactive waste programmes, including final disposal, in order to assure safety in the long term. This should be done in accordance with the proposed EU Directive on the management of spent fuel and radioactive waste, the adoption of which is supported by the nuclear industry.
- Member States should ensure that geological disposal is implemented without undue delay. Such decisions should be taken in an open and transparent way with appropriate public participation.
- The relevant national authorities should ensure the implementation of all steps of radioactive waste and spent fuel management up to final disposal.
- The nuclear energy industry must continue to ensure that financial provisions are available for the implementation of waste management programmes and that safety remains the priority.

5.3 Conditions for nuclear energy development in Europe

Public acceptance and involvement

Public acceptance is one of the prerequisites for gaining political support and for obtaining favourable decisions on new build. The results of the Eurobarometer surveys show that the greater the level of knowledge, the more favourable the opinion citizens have of nuclear energy. Informing the public and engaging them in debate remains, therefore, just as important as ever. In many EU countries public support for nuclear energy is increasing, which could be a clear signal that when nuclear energy issues are debated openly, the general public tends to become more favourable.

DRIVERS

Perception of risks drives public attitudes towards nuclear energy. In addition to concerns regarding safety, security and non-proliferation, radioactive waste is the main concern with regard to the use of nuclear energy. However, as the opinion polls show, it is also the issue which, if solved, can sway the opponents of nuclear energy towards a more favourable opinion. Therefore, national programmes for the management of radioactive waste and spent fuel should be defined, implemented and communicated to the general public in all Member States.

The EU is aiming to decarbonise its economy by 2050 and at the same time maintain Europe's competitiveness. Nuclear energy is set to be a major contributor to these goals, currently providing around one third of the EU's electricity and two thirds of its low-carbon electricity. Climate change is a major environmental concern for the general public. If more efforts are made to persuade the public of the environmental credentials of nuclear energy, increased public support could be achieved.

RECOMMENDATIONS

- The key contribution of nuclear to the EU low-carbon energy mix should be highlighted by EU decision-makers: the general public should be better informed that nuclear is part of the solution if EU Member States want to mitigate the effects of climate change.
- The national public authorities and the nuclear energy industry should support the activities of local committees, partnerships or similar structures active in local discussions on nuclear energy issues. These structures can play an important role in bridging the confidence gap between the nuclear industry and the general public.
- The nuclear industry and public authorities should underline that nuclear technology is more than electricity production. Other important benefits of nuclear technology, i.e. production of heat, hydrogen and desalination, as well as medical and industrial applications should be highlighted.
- Public authorities as well as public and private companies and associations active in the nuclear energy field, should ensure that information about nuclear energy is made available and disseminated to the public in order to encourage the widest possible knowledge about nuclear energy, including in non-nuclear Member States. A particular effort should be made to develop the awareness of the younger generation and their teachers.
- Following the example of many EU Member States, broad public consultations should be carried out for major nuclear projects in order to involve the general public in the decision-making process. A clear legal framework defining the rights and responsibilities of all stakeholders exists at the EU level and has been implemented at national level.
- Nuclear facilities should continue to be as open as possible and allow visits by the general public in order to increase its level of knowledge on nuclear matters. If this is not possible due to security restrictions, information centres should be established close to nuclear facilities and in major cities as well.

5.4 Conditions for nuclear energy development in Europe

Political support

Given the challenges of combatting climate change while electricity consumption is clearly set to grow, decisive action is needed to lower energy-related carbon dioxide emissions. Nuclear as a competitive, safe and reliable low-carbon energy technology is an important contribution to meeting the challenges of the energy security, environmental sustainability and economic competitiveness triangle. In recent years, the EC, the European Parliament (EP) and the Council in its 2007 Conclusions have all three acknowledged this contribution of nuclear energy.

DRIVERS

Long-term political support is a prerequisite for investors, all the more so for long-term investments such as nuclear installations. Without broad and lasting political consensus, changes in government could run the risk of disruptive changes to the regulatory framework, since nuclear projects span several election cycles. Political support and public acceptance of nuclear energy are closely related. To ensure both, the general public needs unbiased and credible information about the opportunities and threats of nuclear energy. Europe-wide polls show that the acceptance of nuclear energy depends also on the ability of governments to deliver credible solutions to address the challenges of nuclear energy, such as the disposal of radioactive waste. Civil society has to be included in the discussions prior to the decision-making. At the European level this could be realised via existing multi-stakeholder bodies such as the EESC and ENEF. In addition, to meet the needs of all stakeholders for sufficient production capacities, human resources and adequate R&D, governments should adapt school and university programmes accordingly.

RECOMMENDATIONS

- Clear political support for nuclear energy should be delivered at European, national, regional and local level. The EU needs a long-term energy strategy, which recognises the contribution of nuclear energy to Europe's low-carbon energy future.
- The EP, which will have an important role in the forming of an energy strategy for Europe until 2050, should include nuclear energy in its vision for a balanced low-CO_2 energy mix.
- The EU should promote the sharing of best practices in terms of the decision-making process with regard to new nuclear projects and continue to support open and transparent procedures with clear responsibilities and timelines.
- Political support and public acceptance of nuclear energy are closely related. Political decisions regarding the issues of public concern, such as radioactive waste management, need to be taken at EU Member States level without undue delay.

5.5

Conditions for nuclear energy development in Europe

Financing of nuclear new build

Nuclear power is one of the most important sources of secure and efficient supply of electricity. However, due to the significant and long-term financing needs associated with the building of new nuclear capacity, the nuclear option seems to represent an achievable strategy only for investors with a robust financial position and strong credit standing. External financing of nuclear projects can be challenging due to the high capital cost and long pay back times, long planning and construction periods as well as the specific nature of nuclear projects (political support, public acceptance). However, it is well accepted that nuclear is an economically competitive source of energy over the long-term.

DRIVERS

The higher the uncertainties anticipated by the investors, the higher the capital costs for nuclear projects. Too many risks can dissuade investors and lenders from financing nuclear projects. Therefore, a stable and predictable legal and regulatory framework, clear national energy policy and stable political background will give a solid basis for nuclear investment. Predictable market conditions are necessary for investors to be able to evaluate the investment.

RECOMMENDATIONS

- In order to boost investment in nuclear energy, clear and sustained political support from the EC and from Governments is needed.
- The importance of a stable and efficient regulatory regime should be underlined.
- For the construction period, the EC should consider implementing multi-source financing schemes, possibly including EURATOM and/or EIB loans and specially developed loan guarantee instruments.
- As the EURATOM loan facility will soon reach its budgetary limit, the EU should consider a rapid renewal of EURATOM loans through the reconstitution and expansion of EURATOM borrowing capacity.
- The EC should identify current market failures and bottlenecks for private investment, reinforce existing financing instruments and establish new ones. It should aim for a level-playing field for all low-carbon energy technologies.
- Long-term contracts between nuclear energy suppliers and users, co-investment and other risk-sharing models can facilitate investment decisions in new nuclear build, while giving predictability for future electricity supplies. They should be authorised as far as they comply with EU competition law. Furthermore, the EU competition rules should be clarified in respect of new build joint ventures.

5.6 Conditions for nuclear energy development in Europe

Licensing harmonisation

In order to enable the industry to take the considerable investments in new reactors, stable and predictable national licensing regimes are indispensable. As construction and operation of new nuclear power plants is an international issue nowadays (international vendors, international utilities, international public awareness etc.), such licensing regimes cannot be installed without a view to international alignment and cooperation.

Standardisation of reactor design can be achieved only by licensing harmonisation. Standardisation will be crucial if nuclear power is to realise its full potential as a major contributor to the clean energy needs of Europe in the coming decades. Such standardisation reduces licensing and construction risks, enhances safety and facilitates design improvements (as the best practice and experience feedback process can be achieved more quickly and more efficiently across reactors of the same design), as well as supports the public debate.

DRIVERS

For nuclear energy to make a significant contribution to the goal of decarbonising Europe's economy by 2050, nuclear energy investment must be facilitated by a strong political and regulatory framework. In order to facilitate reactor design standardisation it is highly desirable that the national licensing procedures are simplified and harmonised within the EU. The process and the steps for applying and granting a construction and operation license should be aligned across Europe. This would contribute to the creation of a single European electricity market and enhance investment in electricity generation. One element in this licensing process for new reactors should be a reactor design clearance.

Keeping in mind that nuclear is a very important political issue and traditionally subject to national sovereignty, the construction and operating license should remain the responsibility of each Member State. However the joint reactor design clearance needs to be valid across Europe and could then be referenced in any licensing application.

The concept of international standardisation of reactor designs could apply to a number of designs, rather than implying one design available throughout the EU. Each vendor who has developed a design would be able to build this design in any European country without necessarily having to adapt it to specific national regulations. The only adaptations – which can never be avoided – would be due to site-specific and operator-specific circumstances.

RECOMMENDATIONS

- The EC should continue its support of ENEF in comparing the licensing processes in Europe, and in identifying, which best practices could be adopted in a harmonised way.
- The EC and national decision-makers should support an EU-level reactor design clearance. At the same time, the construction and operating license should remain the responsibility of each EU Member State.
- The EC should foster exchanges of experience between EU nuclear safety regulators on the licensing of new reactors. A partnership programme could be proposed to this end.
- Standardisation should be promoted by the nuclear energy industry with the support of ENSREG and the European Institutions.

5.7 Conditions for nuclear energy development in Europe

Uranium supply

Uranium resources are well spread over the world, with Australia, Kazakhstan, Russia, Canada, South Africa, USA, Brazil, Niger and Namibia being major producer countries. As concerns uranium supply, the development of nuclear power capacities in Europe until 2050 will be possible if sufficient resources exist over the world and are exploited, and if they are accessible to European consumers, since only a small part is on EU territory. The latest estimate of global uranium resources published by IAEA and OECD/NEA in 2010 "Red Book" shows "identified conventional resources" of 6.3 Mt U (million tonnes of uranium). At the 2008 rate of consumption, these resources are sufficient for over 100 years of supply. However global consumption is projected to increase significantly over the next decades since the global nuclear fleet by 2050 could be up to 3 times larger than now. That means the currently "undiscovered" (i.e. "prognosticated" or "speculative") resources, estimated in the "Red Book" at 10.4 Mt, will have to be confirmed and extracted. In the last years, uranium mine development responded to the market signals of increased prices and rising demand. It is foreseen that, if current price trends are maintained, additional exploration will be stimulated leading to the identification of additional resources of economic interest.

DRIVERS

Improvements can be made in the use of natural uranium: through increased utilisation per kilowatt-hour (kWh) produced in the reactor, thorough depletion of the tails in the enrichment operation or recycling of spent fuel. The consumption of uranium per kWh could be reduced by a factor 2. Advanced reactor- and fuel cycle technologies under development (fast breeder reactors and multiple recycling) could extend resource lifetime from hundreds to thousands of years.

Mining project dynamics are controlled by global uranium market price volatility, project financing, environmental issues such as water consumption and authorisation conditions imposed by the governments where the resources are located. A time lapse of up to 15 years is commonly observed from ore discovery to mine commissioning. A strong market will be necessary for resources to be developed within the timeframe required to meet projected uranium demand.

RECOMMENDATIONS

- The EU in its trade negotiations with the uranium owning countries should systematically raise the issue of investment conditions for European investors.
- Governments should encourage diversified imports, recycling of spent fuel, recycling of enrichment tailings and the development of fast breeder (GEN IV) reactors.
- Both mine operators and utilities should invest in foreign mines. The industry must sustain geological exploration to convert "prognosticated" and "speculative" resources into "identified" resources.
- Research and investment is required to develop new mine projects in a timely manner and to facilitate the deployment of new technologies.

5.8 Conditions for nuclear energy development in Europe

Supply chain

The current state of the global supply chain reflects past nuclear policies and activities in the different countries. In the EU and in North America, where nearly no new build has been commissioned for the last two decades, demand for manufactured equipment and specialised nuclear material supply has been limited to maintenance and replacement activities, such as steam generator replacement. As a consequence, only a few large manufacturing facilities are still operational there, such as those in France and in Spain. When new build programmes are started again, the production of heavy components is the most problematic part of the supply chain, requiring investments in new capacities. In Russia, Japan and South Korea conversely, new nuclear reactors have been commissioned continuously, supporting the business of manufactured equipment. In China, where a strong programme of new builds has been launched, more than twenty new NPPs are currently under construction and still more are planned in the next decade. The Chinese policy is aiming at self-sufficiency so that the supply chain is growing at high speed to match the programme. India is likely to follow a similar path in the next decade. In both cases, it remains to be seen to what extent they can adapt their capacities to a growing export market. New forgings capacities are being built in Japan, China, South Korea, France, Czech Republic, and Russia.

DRIVERS

The scenarios analysed in the first part of this report, (which achieve approximately a 50% global reduction in greenhouse gas emissions by 2050 and realise a share for nuclear generation in the EU electricity mix of roughly 30%) involve between 162 GW (IEA's ETP BLUE Map) and 186 GW (NEEDS) of installed nuclear capacity in Europe in 2050. This means a rate of approximately 5 reactors per year. Globally, the range of nuclear capacity in 2050 spans from 1200 GW (IEA BLUE Map) to 1650 GW (WEC Lion), with an average annual rate of construction of 30-40 GW. This means between 20 and 30 reactors built per year. The supply chain is able to follow that demand. A global average rate of 25 construction starts per year was maintained during the 1970's. Therefore, it is possible to assume that in the coming decades a rate of more than 25 GW globally can be supplied.

European suppliers have to maintain competitiveness. A new investment is dependent on actual orders rather than on uncommitted plans. Since the market is global, it will be driven mainly by the most certain and largest sources of orders, which are coming predominantly from Asia. Asian suppliers will benefit from strong domestic demand.

RECOMMENDATIONS

- The EU should maintain and develop technical leadership, skills and industrial capacities in the nuclear supply chain. In the rest of the world, self-sufficiency is often a strong industrial objective.
- Strong domestic demand for new reactors in the EU would help the European industry to be competitive on the world market.

5.9 Conditions for nuclear energy development in Europe

Knowledge management

The nuclear industry is facing several challenges related to competences and knowledge which could have an impact on both operation of existing plants and construction of new installations. A significant number of employees in the nuclear sector are going to retire in the next few years. There has also been an insufficient number of students willing to pursue scientific studies because they were attracted by other sectors or because they were not willing to work in the industry. Due to the absence of new nuclear projects in the past decades, skills in nuclear engineering, construction, design, safety studies, nuclear physics, metallurgy, etc. have decreased. With the recent revival of interest in nuclear energy the perception that nuclear science and engineering was not progressive is slowly changing. A career in nuclear research and engineering is once again appearing on young people's radar screens as the industry starts to recruit more intensively.

DRIVERS

Recent initiatives in the area of education and training (E&T) need to be highlighted. In 2010 the European Nuclear Energy Leadership Academy (ENELA) was launched from an initiative within the ENEF and has shown that the industry takes seriously the need to find and train new people to be the leaders of tomorrow. The European Nuclear Education Network (ENEN) was established in 2003 and now has 56 members, mainly technical universities. Its mission is the preservation and further development of expertise in the nuclear fields by higher education and training. Supported by the Council Conclusions of December 2008 on skills in the nuclear field, the European Human Resources Observatory – Nuclear (EHRO-N) located at JRC Petten in the Netherlands was established. SNETP has created an education, training and knowledge management group which will put forward a future framework for nuclear education, training and knowledge management at the European level. It will need to be implemented in a sustainable manner to ensure further development of nuclear energy in Europe.

RECOMMENDATIONS

- The EC should continue to follow-up the 2008 Council Conclusions on the need for skills in the nuclear field, in particular with regard to EHRO-N activities, encouraging best practice sharing and promoting mobility for researchers and nuclear experts.
- National authorities should make every effort to ensure that young generations in schools and colleges are attracted to scientific studies (nuclear physics, thermodynamics, safety studies, metallurgy, mechanics, electricity, etc.). The importance of nuclear energy and the opportunities created by the sector should be promoted towards the public, and especially towards youth.
- The nuclear industry should support partnerships with universities, technical colleges and engineering schools offering programmes with adequate content and lectures, as well as encourage the creation of master degrees in the appropriate disciplines. Research institutes should also be involved in those partnerships in order to attract young people to nuclear research.
- The nuclear industry should encourage the development of entities able to educate or improve awareness of managers on the specific aspects of the management of nuclear installations and boost the specific corporate training.
- The nuclear industry with the assistance of international organisations such as IAEA should organise the transfer of knowledge between generations of employees and promote the use of knowledge management methods.

5.10 Conditions for nuclear energy development in Europe

Environmental impact and information

The EU has a solid framework of environmental legislation at its disposal which also covers the nuclear sector. In addition, the EU has acceded to International Conventions, in particular, the UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, known as the Aarhus Convention. This Convention gives further rights to citizens in environmental matters. The Aarhus Convention was transposed into Community law through Directives 2003/4/EC (information) and 2003/35/EC (participation). Directive 2003/624/EC (access to justice) is still under discussion but both adopted directives contain already some provisions on access to justice. This led to a revision of EU environmental legislation, part of which covers nuclear issues. Another main international instrument in the field of transparency in environmental matters is the Convention on Environmental Impact Assessment in a Transboundary Context ("Espoo Convention").

In addition to the legal instruments, the nuclear industry is committed to communicating to the general public all relevant information with regard to environmental impact. Life-cycle assessment (LCA) is used by the industry to represent the environmental effects of the entire nuclear fuel cycle from uranium mining, through fuel fabrication and operation until decommissioning and waste disposal. As concluded in the ENEF Competitiveness SWOT Report Part I, the overall adverse environmental impact for nuclear energy is significantly lower than for fossil fuels. This is shown by life-cycle analysis comparison of emissions of greenhouse gases, atmospheric pollutants and materials consumption for nuclear and other technologies. Nuclear power generation has as low greenhouse gas emissions as the best renewables.

DRIVERS

The legal framework governing environmental conditions and public participation is well established. The practical implementation of this legislation needs to be ensured. The industry needs to provide accurate environmental information (discharges, dose rates, etc.) and convince the public that its activities are not having an adverse impact on the environment. Environmental impact assessment and Art.37 of the Euratom Treaty (which requires that each Member State is to inform the EC about any releases by air or water and the disposal from the installation of solid radioactive waste) are useful tools in that respect. Moreover, an increasing role for local actors is taking shape in the EU and in the Member States, by federating the networks of the relevant local area or regional communities concerned with the nuclear industry, such as AMAC in Spain, NuLeAF in Great Britain, KSO in Sweden, and GMF at the European level. Similarly, local Commissions have engaged in an active federative approach in France (ANCLI), in Spain and in the United Kingdom. They are currently setting up a European network (EUROCLI).

RECOMMENDATIONS

- The EC should play a key role in support of local communities' networking efforts on nuclear related issues. Networking activities will enhance both the analysis of good practices and the exchange of experience in the EU.
- In accordance with the principles set out in the Aarhus Convention, national authorities should justify decisions made and give feedback on the actual consideration of stakeholders' views in the final decisions regarding construction or dismantling of a nuclear installation.
- Local governments are in a position to promote the participation of citizens in the monitoring of the nuclear industry and to ensure a proper interaction between the forms of representative democracy and participative democracy.
- A major contribution from the nuclear industry should be to further ensure the transparency and openness of nuclear activities across the entire fuel cycle.

5.11 Conditions for nuclear energy development in Europe

Nuclear transport

Transport underpins all the operations of the nuclear fuel cycle – it is the "lifeblood" of the nuclear industry. Whether it is for transporting uranium ore from a mine to a conversion facility, uranium hexafluoride to enrichment, enriched uranium to a fuel fabrication plant, finished fuel to a reactor, spent fuel to a repository or to a reprocessing plant, radioactive waste to a storage or disposal facility – all such movements are essential for maintaining the smooth operation of a nuclear power plant. In order to carry out such movements, suitable containers have to be designed, tested and licensed according to the applicable regulations. The type of container/packaging required is specified internationally using a graded approach depending on the radioactivity content. For high activity shipments (Types B and C) the container has to be robust enough to withstand all credible accidents without releasing radioactive materials into the environment. In addition, the safety and security of shipments are backed up by stringent regulatory and quality assurance procedures. The safety record of the nuclear transport industry is excellent. Despite this, public concerns are still evident, particularly when nuclear shipments pass through population centres or through the territorial waters of non-nuclear states. Such concerns, coupled with the additional regulatory burden imposed on radioactive cargoes, can lead in some instances to carriers refusing to handle this type of shipment. This can lead to problems when there are limited alternatives. The IMO and IAEA have set up an international database to record cases of shipment denials.

DRIVERS

The global expansion of the use of nuclear power will result in a growing number of shipments, to and from new destinations and along new routes. Nuclear transport is a global business. Reliable transport is crucial for the EU's security of supply as the uranium ore needs to be transported from mining countries located outside of Europe. It is vital that nuclear transport continues to be enabled and continues to be safe and secure. This can be achieved most effectively by maintaining a harmonised international regulatory framework, drawn up by the UN agencies, which is uniformly implemented and interpreted in all regions. It is important that public safety and security concerns do not lead to additional constraints being applied which are not proportionate to the risks involved.

RECOMMENDATIONS

- The EU should support the harmonisation of package design licensing procedures such that a container licensed by the Competent Authority of one Member State should be able to be used throughout the EU without having to obtain additional licences.
- Wider dissemination of information relating to the safety of nuclear transport should be ensured. The general public should be encouraged to visit transport facilities which will help allay public concerns. The EC has a role here as well as the industry.
- The EC should pursue logging and investigation of radioactive shipment denials.
- More effective information and education directed towards new carrier personnel should be applied in order for them to fully understand the real risks and precautions.

5.12 Conditions for nuclear energy development in Europe

Nuclear non-proliferation and security

Preventing nuclear proliferation is primarily the responsibility of states but, as major stakeholders, the nuclear industry and scientific community should actively support the measures necessary to strengthen the non-proliferation regime, particularly the international control of the flux of nuclear material and technology.

If the expected expansion of nuclear electricity production worldwide is to succeed, it must take place under strict safety, security and non-proliferation conditions. The European nuclear industry is committed to the exclusively peaceful use of nuclear energy and to export nuclear facilities and related materials, equipment and technology solely in accordance with relevant national export laws and policies, European regulations, Nuclear Suppliers Group guidelines and pertinent United Nations Security Council Resolutions.

DRIVERS

The nuclear industry recognises the importance of public and political support for its activities. Moreover, recent Eurobarometer polls have demonstrated the high level of concern citizens have over nuclear security issues. It is therefore clearly in the interest of the commercial activities and further development of the industry that there are no security or proliferation incidents. Whilst Governments set the regulatory framework, industry should continue to ensure and demonstrate compliance, maintain proper control over sensitive materials and technology, deliver effective training and promote the appropriate security culture. Industry should become more involved in advising Governments and even IAEA on the drafting of regulations, treaties and inspection regimes to ensure that they are effective, make operational sense and do encourage compliance. At the same time industry can have a more active role in promoting the responsible use of nuclear energy in countries aspiring to use nuclear energy by underlining the importance of full compliance with IAEA/Euratom safeguards and the Additional Protocol.

RECOMMENDATIONS

- The nuclear industry should pay special attention and promote proliferation-resistant designs. It should consider IAEA safeguards requirements and discuss safeguards approaches with the inspectorates as early as possible when a facility is being designed.
- The nuclear industry should ascertain that nuclear equipment, material and technology shall be under IAEA safeguards.
- The nuclear community should continue supporting the initiative to use low-enriched uranium in research reactors around the world.

ACRONYM LIST

BAU	business-as-usual
CCS	carbon capture and storage
CO_2-e	CO_2-equivalent
EC	European Commission
EESC	European Economic and Social Committee
EHRO-N	European Human Resources Observatory – Nuclear
EIB	European Investment Bank
ENEF	European Nuclear Energy Forum
ENSREG	European Nuclear Safety Regulator Group
ESNII	European Sustainable Nuclear Industrial Initiative
ETS	emissions trading scheme
EU	European Union
GDP	gross domestic product
GEN IV	generation IV nuclear reactors
GHG	greenhouse gases
Gt	giga-tonne
GW	gigawatt
HLW	high-level waste
HTR	high-temperature reactor
IAEA	International Atomic Energy Agency
IMO	International Maritime Organisation
JRC	Joint Research Centre
kWh	kilowatt-hour
LCA	life-cycle assessment
LILW	low- and intermediate-level waste
LTO	long-term operation
MFF	multi-annual financial framework
MW	megawatt
NPP	nuclear power plant
OECD/IEA	International Energy Agency of the Organisation for Economic Co-operation and Development
OECD/NEA	Nuclear Energy Agency of the Organisation for Economic Co-operation and Development
ppmv	parts per million by volume
SET-Plan	Strategic Energy Technology Plan
SNETP	Sustainable Nuclear Energy Technology Platform
TWh	terrawatt-hour
WANO	World Association of Nuclear Operators
WEC	World Energy Council
WENRA	Western European Nuclear Regulators' Association
UNECE	United Nations Economic Commission for Europe

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