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ENEF Working Group Opportunities – Subgroup on Competitiveness of Nuclear Power

Strengths – Weaknesses – Opportunities – Threats (SWOT) Analysis

Part 1: Strengths & Weaknesses

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Acknowledgement

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EXECUTIVE SUMMARY

This report aims at providing a sound background document for the discussion on the competitiveness of nuclear power in Europe on its way to a more sustainable, less carbon intensive and secure electricity production. "Competitiveness" can no longer be restricted to economic attractiveness but should address issues of environmental impact and social acceptance - in short, the degree of sustainability.

The work was focused on evaluating the competitiveness of nuclear power in comparison with other currently available technologies for generation of base-load electricity supply. Examined data originate from studies funded by the EU (e.g. NEEDS) or other international organisations (OECD-IEA, OECD-NEA, IAEA), or from national energy studies and calculations performed by industry, research institutions and NGOs.

This work is regarded as an important element within the multi-stakeholder dialogue of the European Nuclear Energy Forum (ENEF). It integrates the views and the knowledge of different stakeholders. Views and knowledge have been presented and discussed in meetings of the Working Group "Opportunities" - Subgroup on "Competitiveness of Nuclear Power" throughout 2008 or have been reported by individual Subgroup participants to the Commission in 2008-09. The documents entail information/data provided until 2008 while it makes reference to the NEEDS-project where appropriate, e.g. for reflections on indicators and for data updating. Some environmentalist groups decided to leave the ENEF process in May 2009. This report has therefore not been endorsed by them. Nevertheless this report makes several factual references to statements they made and information they provided in the context of the Subgroup Competitiveness, until that time.

Comparisons of energy options should rely on well established methodologies (such as “levelised discounted cost of generation” method for economics and “Life Cycle Assessment” for environmental impacts) and on a set of well defined and measurable performance indicators. A fair number of the contributions collected in this work comply with this request; however complete traceability of all the results reported and discussed here cannot be guaranteed. In this summary, only the main findings on key performance indicators are extracted from the attached full report.

The conclusions, integrally reproduced in this summary, are expressed as a list of “Strengths and Weaknesses”. From the beginning, the Sub-working Group on Competitiveness decided that a “SWOT” approach was appropriate to handle the topic. That means this report is the outcome of Part 1 of the approach: S&W, producing a photography of nuclear energy competitiveness now and in the short term, while O&T (Opportunities and Threats) will be investigated in Part 2 (2010 – 2011), based among others on the analysis of prospective scenarios for Europe energy supply.

MAIN FINDINGS

Economic dimension

Financial requirements

The examples of cost assessments reported here show some dispersion among results; this can be related to varying project conditions (country effect, site effect, etc), varying assumptions (on construction cost notably) and to different financing conditions (impact of the discount rate value on the capital cost). However, the overall picture derived is a lower lifecycle cost for nuclear plants than for gas fired or coal fired plants. The interest in new nuclear plants expressed by several European electricity companies can be understood through this observation: the levelised lifecycle cost with nuclear is estimated lower with a reasonable degree of confidence. This statement was contested by Greenpeace, advancing a wider range of nuclear generation cost values as supporting argument. Since the major part of expenses occur in the initial investment, then risks of unexpected total cost increase are limited over the whole lifetime of the new plant. Actual difficulties in financing new nuclear investments are therefore mainly coming from other reasons than from the “pure economic” analysis, such as, in particular, the unpredictable evolution of political decisions, the unknowns on the long term structural changes in the electricity grid and the biases to the operation of the liberalised electricity market.

Another key feature is that fuel cost represents only a small component (15%) of nuclear power plant generating cost, compared to gas (76%) and coal (41%) fired technologies: nuclear generation seems to show greatest resilience to upside fuel price risks.

Security of supply

Security of supply covers diverse aspects.

Firstly, one can look at the availability and accessibility of the energetic resources, both geographically and in time. Geographically, Uranium is well spread and available in stable regions of the world. The very high density of its energy content also allows easy storage of stocks for years. Time wise, actual known reserves of Uranium are sufficient for around a century at present rate of consumption. Mine exploration, which is restarting, will probably lead to new discoveries. In addition, new technologies of reactors and fuel cycles are under development to improve significantly the utilization of resources, ensuring the long term availability of nuclear fission energy as a contributor to the energy mix.

Secondly, looking to the consumption of non-energetic material resources (such as iron and copper), nuclear plants are most effective due to the high power level of the facilities, allowing a limited consumption of these resources per unit of power produced.

Thirdly, nuclear plants have a demonstrated high load factor in base load mode of operation, where they are most economically competitive. These plants deliver stable and reliable electricity to the customers, ensuring the security of supply of electricity.

Finally one has to note a temporary issue of human resources and supply chain for large equipment, but this should be overcome by industry if it sees the opportunity. It is again an issue of “investment decision” which requires an overall conducive environment.
In conclusion, nuclear energy compares well with other sources of energy from a security of supply point of view, and is a major asset for the EU as a whole, as a region highly dependent of the outside for its fossil fuel supply.

Environmental dimension

Global emissions of greenhouse gases

Most of the available examples suggest a totally superior GHG emissions performance of nuclear, hydro and to a slightly lesser extent - wind power plants as compared to fossil energy technologies, and substantially better than biomass and solar photovoltaics.
The numbers given for nuclear at a level of about 5 to 10 tons of CO_2 eq, per GWh are varying due to key factors such as reference plant technology, front end – in particular – enrichment, and fuel reprocessing: the spread of values given by IAEA (2000) are taken for illustration. The high numbers given by “Sortir du nucléaire” (30-60) can be explained by the assumption that old coal-fired stations serve as back-ups for peak demand. The numbers given for coal are higher by about two orders of magnitude and vary from more than 750 to 1000; compared to coal the numbers for gas are less by a factor of at least 2. Both fossil energy technologies show a high reduction potential, if carbon capture & storage (CCS) will be implemented. The numbers for hydro and wind are as favourable as for nuclear, if major advancements in wind technology are assumed. PV emissions exceed nuclear by about a factor of ten, also subject for reduction due to technology developments/economic breakthrough.

Regional: impact on ecosystems

Integrating aspects of emissions to the atmosphere, land use and waste generation, nuclear energy compares very well with other sources of energy in normal operation. That has to be related to the characteristics of nuclear fuel and fission reaction: high energy density, no generation of SOX and NOX in the effluents. Probabilistic Safety Assessments show lower level of risks of fatalities due to nuclear power compared to historical figures for other sources of energy. In addition, new built Generation III plants, will, by design, ensure that there will be no radioactive release outside the plant fence, would a highly unlikely core melt occur.

Social dimension

The social dimension of sustainability performance involves probably the highest degree of complexity. Here also, the assessment should rely on measurable social impacts of power generation and related fuel cycle facilities, at local, national and regional scales. In this work, some information could be collected on employment, health impacts, local benefits and disturbances, waste confinement requirements in repository. Equity issues are raised since benefits and risks are not the same for different groups of population. The issue holds both as intra-generational (e.g. local population versus all country population) and inter-generational (long term impacts of climate change and waste repositories). But in the end the appraisal of the risks and benefits belongs to each concerned group of population. Perception of risks and benefits is influenced by many individual and social factors. Risk aversion is known to vary from one individual to another, from one country to another. More widely, overall public acceptance of a technology varies according to a complex bunch of influencing factors. These issues are relevant for nuclear waste disposal.

High level waste disposal

The “necessary“ confinement time serves as a social indicator to address the burden placed on the current and future generations to carefully isolate hazardous (toxic, particularly radiotoxic) waste from the biosphere. Although not limited to the use of nuclear energy the requirements for nuclear radioactive waste are challenging given the long confinement times. It is noteworthy that these times relate to the inventory of radiotoxic material. The technical feasibility has been demonstrated by various national and Euratom waste management research programmes and progress is being made towards making deep geological repositories operational by 2030 in some Member States. The opponents state that the waste problems are still unresolved. Implementing effective solutions, as started in Finland, Sweden and France, is therefore important and will impact public acceptance for nuclear power, as shown by the Eurobarometer.

From the material collected here on measurable impacts, an overall positive picture is derived as to nuclear energy, compared with other options. Attempts to express the impacts with aggregated indicators, such as external costs, confirm this picture. However the overall balance between risks and benefits will be assessed differently by different stakeholders. Public acceptance has grown up to about 50% in many European countries and would be higher if solutions to manage nuclear waste are implemented. The material collected probably does not capture the whole complexity of the social dimension. Further investigation will call on the work from the other ENEF working groups dedicated to Risks and to Transparency.

CONCLUSIONS

Strengths

Regarding nuclear energy, on the basis of the examples compiled and evaluated in this report, the following main strengths are stressed:

1. ***In a wide range of scenarios, nuclear energy is currently recognised as the least cost option for base-load centralised generation, even in low CO_2 price scenarios.***

   This will be further analysed in the 2nd part of the SWOT analysis.

2. ***Decommissioning and waste management costs are internalised in the nuclear energy generation costs*** Cost assessments are available for both back-end options.
   The Commission is monitoring the adequacy of decommissioning and waste management funding and is reporting on a regular basis the results to the European Parliament and the Council. New legislation on the Management of Nuclear Waste will define a legally binding level playing field at EU level.

3. ***Nuclear power plants do not emit CO_2, and the use of nuclear power across its lifecycle results in only very small amounts of greenhouse gas emissions***, which gives it a significant boost in competitiveness in a carbon constrained economy.
   The European energy policy recognizes equally the important contribution of energy savings and renewable energies for low carbon economy.

4. ***Nuclear power generation is much less sensitive to fuel price increase than fossil fuels.*** A 50% increase in uranium, coal and gas prices would make nuclear generating costs increase by 3%, coal generating costs by 20% and CCGT generating costs by 38%.
   The cost of uranium has a limited impact on the electricity price and thus, compared to gas and coal fired technologies, nuclear generation seems to show greatest resilience to upside fuel price risks.

5. ***Uranium security of supply is based on resources coming in a major part from politically stable countries. In addition, due to its high energy density, nuclear fuel may be easily stored in small volumes.*** This allows tackling any fuel supply interruption problems and therefore offers additional guarantees on availability of nuclear power plants.

6. ***The major part of the fuel supply chain is based in the EU.*** European companies are global leaders in nuclear fuel fabrication, enrichment, reprocessing and recycling activities which supports nuclear's high level of security of supply.

7. ***High average capacity factors are shown by nuclear power plants in the EU***. These have encouraged plant operators to invest in life time extension and power up-rates which is a progressive and cost efficient way of adding generation capacity in response to increasing energy demands. The safe lifetime management and corresponding research for nuclear safety improvement are continuous priorities to the nuclear industry, in line with the European and international safety requirements.

8. ***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.

9. ***Waste from nuclear power generation is small in volume but challenging with regard to its long term confinement. It is controlled at all stages including collection, treatment, volume reduction, storage and transportation; the impact of radioactive waste management to the biosphere is insignificant to negligible in the short, medium and very long term.*** Progress is made for final disposal of radioactive waste. In 7 out of 16 Member States with NPPs final disposal facilities for LILW are in operation. The Commission is monitoring that each EU Member State establishes and keeps updated a national programme for the safe management of radioactive waste and spent fuel that includes all radioactive waste under its jurisdiction and covers all stages of management. Nevertheless, some groups regard the waste management problem as still unresolved.

10. ***Social benefits of nuclear power include direct employment and positive impacts of stable and predictable cost of electricity on the economy.*** Nuclear energy also supports technological and scientific development in the EU and has lead to many spin-offs and applications with major social benefits, like nuclear medicine and other.

Weaknesses

Regarding nuclear energy, on the basis of the examples compiled and evaluated in this report, <u>the following main weaknesses are stressed:</u>

1. ***Nuclear power is capital intensive, therefore variations in construction costs have significant impact.*** Capital cannot be provided by state aid, which is subject to Community control. Construction delays in nuclear projects can result in substantially higher financing costs, causing cost overruns.

2. ***Public perception and acceptance is an element of volatility.*** This creates uncertainty in the licensing process of nuclear installation. Negative public opinion could in some cases delay, obstruct or stop nuclear energy projects.

3. ***Impact of low frequency accidents could be high***
   A single, rare accident in a nuclear facility could have potentially severe consequences on human health and the environment. To address the risk of accidents, plant safety is built on precautionary measures in design, construction and operation. The aim of these basic safety functions is to protect the plant in the event of incidents and failures, and to limit the consequences of severe accidents. New built Generation III plants will, by design, exclude any release outside the plant, would a highly improbable core melt occur.

4. ***The fact that there is no final repository for High Activity Waste yet in operation creates the perception as if there would be no solution.*** In order to avoid any undue burden on future generations, it is an ethical obligation to proceed with the development of a radioactive waste management programme in each country using nuclear energy.

5. ***Uranium resources are limited as compared to unlimited availabilities of renewable energy resources.*** Uranium resources are finite. IAEA/OECD-NEA

"Red Book" provides detailed quantitative assessment of uranium resources. Reasonable assured resources (RAR) correspond with a range of coverage of about 50 years: RAR together with "inferred" resources would cover about 80 years – "more realistic rates of consumption" would result in an additional 100 years. If all "undiscovered resources" would be considered, the range of coverage would be extended to another 300 years. Advanced reactor and fuel cycle technologies under development (fast breeder reactors and multiple recycling) could extend the ranges of coverage "from hundreds to thousands of years".

6. ***Uranium mining & mill tailings need long-term stewardship***. However, good practices are available in the EU.

7. ***Proliferation concerns are a specific problematic characteristic for the nuclear fuel cycle.*** Therefore, proliferation resistance and physical protection of nuclear facilities and materials are key priorities for the nuclear industry and are subject to international scrutiny within the frame of the Non-Proliferation Treaty (NPT) via International Atomic Energy Agency (IAEA) safeguards system, supplemented by EURATOM in the EU.

8. ***Sufficient Human Resources are critical to use of nuclear energy***
   Retirement of employees who hold knowledge that is critical for the safe design and operation of nuclear facilities can pose a problem. Preserving and transferring this knowledge to successors is a challenge for the nuclear industry. This has been fully recognised and countermeasures are taken or in preparation.

FINAL REMARKS

It has to be recognized that the choice of a technology rather than another potentially brings differing benefits to each stakeholder: electricity consumers, neighbouring population, tax payers, shareholders, future generations, industry and workers, global environment … It is *a priori* difficult to claim that it will generate only winners and no losers. Hence the need of comprehensive evaluations and appropriate social involvement processes to prepare decisions. Hence too the need of a well balanced energy mix, since no single technology can satisfy the whole spectrum of requirements.

Responding to such needs, ENEF was launched by the European Commission in 2008 as a multi-stakeholders process. And this report is primarily the outcome of the contributions delivered by the participating stakeholders working in the subgroup Competitiveness under the umbrella of the Opportunity Working Group.

But this work also makes reference when possible to third-party assessments and well established methodologies, which are quite essential: OECD (IEA-NEA) multi-country generation cost methodology (lifecycle levelised discounted cost) for economics, LCA (Life Cycle Assessment) for environmental performance, risk assessment methods such as PSA (probabilistic safety assessment), then aggregating tools such as MCDA (multi-criteria decision analysis) traceable process. To develop, share and promote such approaches, EC-driven exchange programs such as ExternE and NEEDS have been quite helpful.

As a result, the bundle of evidence collected in this report is generally supportive: nuclear power can be pursued and developed wisely in the EU, for the benefit of most stakeholders.

This report has still to be complemented with the results of Part 2 (opportunities and threats), but it can already be used as a reference document. It can be challenged, but any opposing argument should rely on sound and referenced information and assessment methodology.

PREFACE

This report aims at providing a sound background document for the discussion on the competitiveness of nuclear power in Europe on its way to a more sustainable, less carbon intensive and secure electricity production. "Competitiveness" can no longer be restricted to economic attractiveness but should address issues of environmental impact and social acceptance - in short, the degree of sustainability. Therefore, the document and the respective collection of data are organized along the different aspects of sustainability and an associated set of indicators, in particular. This set of indicators has been adopted as already used by NEA in “Risks and Benefits of Nuclear Energy”, 2007 [13].

This document is regarded as an important element within the multi-stakeholder dialogue of the European Nuclear Energy Forum (ENEF). It integrates the views and the knowledge of different stakeholders. Views and knowledge have been presented and discussed in meetings of the Working Group "Opportunities" - Subgroup on "Competitiveness of Nuclear Power" throughout 2008 or have been reported by individual Subgroup participants to the Commission in 2008-09.

The contributions of different stakeholders and sources comprise different degrees of scientific quality, i.e. in-house, intra-community and open/published/peer reviewed. The documents entail information/data provided until 2008 while it makes reference to the NEEDS-project where appropriate, e.g. for reflections on indicators and for data updating. Some environmentalist groups decided to leave the ENEF process in May 2009. This report has therefore not been endorsed by them. Nevertheless this report makes several factual references to statements they made and information they provided in the context of the Subgroup Competitiveness, until that time.

This document constitutes the result of the first phase on the assessment work by the Subgroup. This phase is technology-driven with a focus on base-load energy options meeting the demand in the current mostly centralized electricity generation grid. The second phase is scheduled to start by the beginning of 2010 following a scenario-driven approach where decentralized energy production and smart grids, potentially intelligent demand-side management ("smart meters"), will also be considered.

The first phase assessment includes the whole life cycle of nuclear energy and alternative energy technologies ("from cradle to grave"), and among other sources refers to some published Life Cycle Assessments. It is limited to technologies which are currently used in OECD countries (plants being operated) or can be used/deployed commercially in the near future (next years until 2030); longer term foreseeable developments and trends having a significant impact on the assessment are mentioned - addressing a time horizon beyond 2030 to 2050 with acknowledgment of a certain level of uncertainty.

The document - besides compilation – roughly tries to evaluate and cross compare data and modelling assumptions and points to factors which dominate results. This is done to a greater degree of detail for a few indicators judged as being of paramount importance, i.e. CO2 emissions, costs, and waste issues.

Furthermore, the document identifies areas of consensus and divergence with regard to both data at the level of orders-of-magnitude and overall judgments, and by this paves the way for further discussions and work. Although sometimes arbitrary, it distinguishes between "strength and weaknesses" as well as "opportunities and threats" when drawing overall conclusions based on an "objective" review of the material provided and evaluated.

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1. Objective and Scope

This report aims at evaluating the competitiveness of nuclear power in comparison with other currently available technologies for generation of base-load electricity supply in a European low carbon economy and global supply security context. It provides a summary of data from a large variety of sources on the competitiveness of different energy technologies in Europe in terms of their performance in economic, environmental and social dimensions. These data originate from studies funded by the EU (e.g. NEEDS) or other international organisations (OECD-IEA, OECD-NEA, IAEA), or from national energy studies and calculations performed by industry, research institutions and NGOs.

The collected data are presented either in the form of summary evaluations from different stakeholders (Chapter 2) or in the form of evaluations on specific economical, environmental or social dimensions (Chapters 3-5). Ways of aggregation are briefly addressed (Chapter 6).

In both cases, the data are organised as much as possible according to a common set of energy technology indicators as defined by the Swiss Paul Scherrer Institute (PSI) in the context of its work on energy sustainability projects (see Figure 1 hereafter). Ideally, the indicators should meet a number of requirements, i.e. they should be: measurable, logically independent, balanced, inclusive but manageable, possible to extend, monitor and update, consistent, and compatible with intended uses. Thus, the intention is not to produce a complete set of indicators but rather a representative one. The set provided is rather compact and was intended to serve both for communication purposes as well as an input to Multicriteria Decision Analysis (MCDA) evaluating various technological options. For these specific uses it was essential to define the indicators in a manner enabling differentiation between the various technologies and minimizing the overlaps. It should be noted that allocation of some indicators to the economic, environmental or social dimensions is partially arbitrary since specific indicators may exhibit characteristics that reflect more than one dimension. For this reason establishment of the criteria and indicator set including its hierarchy is preferably done together with stakeholders.

Figure 1: Energy technology-specific indicators used for evaluating the competitiveness of nuclear power in comparison to its base-load electricity supply alternatives[1] (Hirschberg et al., 2004; ILK, 2004)

	Impact Area	Indicators	Unit
Economic dimension	Financial requirements	Production costs	c/kWh
		Fuel price increase sensitivity	Factor
	Resources	Availability	%
		Geo-political factors	relative scale
		Long-term sustainability (energetic resource lifetime)	Years
		Long–term sustainability (non-energetic resource consumption)	kg/GWh
		Peak load response	relative scale
Environmental dimension	Global warming	CO_2 equivalents	tons/GWh
	Regional environmental Impact	Change in unprotected ecosystem area	km^2/GWh
	Non-pollutant effects	Land use	m^2/GWh
	Severe accidents	Fatalities	fatalities/GWh
	Total waste	Weight	tons/GWh
Social dimension	Employment	Technology-specific job opportunities	person-years/GWh
	Proliferation	Potential	relative scale
	Human health impacts during normal operation	Mortality	years of life lost/GWh
	Local disturbance	Noise, visual amenity	relative scale
	Critical waste confinement	Necessary confinement time	thousand of years
	Risk aversion	Maximum credible number of fatalities per accident	max fatalities/accident

[1] Sortir du Nucléaire made a remark that the approach used here to evaluate competitiveness in the broader context of sustainability (Figure 1) does not address industrial capacities to develop technologies, political effects of use of certain technologies (e.g. uranium mining in Niger), lifetime and toxicity of nuclear waste, morbidity (rather than mortality).

Most recent developments include more extensive sets of indicators, accommodating the research carried out by social scientists and thus resulting in a substantially larger number of social indicators including some having less “technocratic” character than the ones in the Figure 1. We refer here to the work carried out within the NEEDS project (Hirschberg et al., 2008) and by research institutes in co-operation with an electric utility (Roth et al., 2009). The set of criteria and indicators generated in NEEDS was subject to a European stakeholder survey and received a highly positive feedback. However, due to practical reasons in the current report we stay with the earlier work as the primary reference for the overall indicator set. The full quantitative set of indicators in the co-operative project with the electric utility is not publicly available while the full set of NEEDS-indicators is limited to highly advanced future (year 2050) electricity generating technologies. In both cases, the effort and complexity involved in generating the indicators is incomparably higher than for the case above.

Finally, Chapter 7 summarises the values for these different indicators from the examples in the preceding chapters in a qualitative sense, resulting in the identification of the main relative strengths and weaknesses of the use of nuclear power vis-à-vis its competitors for base load electricity supply.

SWOT Analysis is a strategic planning method used to evaluate the *Strengths, Weaknesses, Opportunities,* and *Threats* involved in a project or in a business venture. It involves specifying the objective of the business venture or project and identifying the internal and external factors that are favourable and unfavourable to achieving that objective (see Figure 2).

Figure 2: Concept of SWOT Analysis

	Helpful to achieving the objective	Harmful to achieving the objective
Internal origin	**S**trengths	**W**eaknesses
External origin	**O**pportunities	**T**hreats

Although Chapters 8 of the **current Part 1** report already proposes some main *Opportunities* and *Threats* for/to a successful use of nuclear power, their full evaluation will only be accomplished in the Subgroup’s future work on energy scenarios, and documented in the **subsequent Part 2** of the SWOT Analysis Report.

We note the system-level innovation implied for the European electricity system by the official and binding EU 20% of total energy from renewables target. We suggest, however that the bulk of the transformative potential of that target will actually only be seen in the years after 2020. The proportion of renewables will increase, but the grid will not yet have changed its fundamental structure so as best to accommodate intermittent renewables. In addition various major renewable infrastructures which formally might be included within the target will not actually be complete and generating in the year 2020. Therefore any fundamental transformation of the architecture and operations of the European electricity system will occur closer to 2030 than 2020 and as such we see a clear role for continued investment in centralised base-load electricity generation in the present decade. Notwithstanding the fact that such capacity will remain in use for many decades, we see the electricity transmission and distribution system evolving in coming decades around today's core of centralised base-load power. In this report we shall therefore consider the importance of nuclear energy in such contexts, while noting that future nuclear technologies may be better suited economically and technically for more flexible operation. As our year of interest is 2020 we shall focus on nuclear energy as a source of base load power in liberalized European electricity market similar to those seen today, but with more interconnections between countries and regions in order to foster a better operation of this market.

The relevant technological options considered in this report are: *coal and lignite fired plants, nuclear power plants, hydro plants, gas fired CCGT plants, biomass fired plants, geothermal units and large-scale offshore wind turbines* (but, for example, not photovoltaics).

In summary, the competitivity of nuclear energy can only be judged in a fair and unbiased way by evaluating its generic strengths, weaknesses, opportunities and threats in comparison to other energy technologies on the basis of a common framework of economical, environmental and social impact indicators supplied with information from different sources and stakeholders:

- The data used to identify main ***Strengths*** and ***Weaknesses*** are taken from a large variety of different sources with often different objectives, different periods of time and often differing methodologies and underlying assumptions. A comparison of such data therefore only allows the identification of general trends and overall strengths and weaknesses, but the information is of course not sufficient to be applied to the specific circumstances of individual countries or projects.

- ***Opportunities*** and ***Threats*** to a successful use of nuclear power have not been examined in detail at this stage of the SWOT Analysis. While the work on *Threats* is largely within the mandate of the ENEF Risk Working Group, the *Opportunities* will be evaluated in the second phase of the Competitiveness Subgroup's work, and will be summarised in the forthcoming Part 2 of the SWOT Analysis Report.

Greenpeace challenged the overall approach, considered that the proposed indicators are inadequate and arguing that a “more systemic approach”, namely energy scenarios, should be chosen from the beginning, encompassing generation, transmission and distribution, and giving room to the promising “smart grids” concepts, taking benefit from future deployment of distributed generation technologies.

In addition, **Sortir du Nucléaire** raised the following issues:

- Energy issues should not be addressed in terms of the capacity of different energy sources to meet existing demand, but to think in terms of energy services which ought to be decoupled from energy production.
- The usefulness of centralised energy production with regard to achieving energy security is questioned. Small decentralised production would provide a better balance of electricity supply in case individual units fail.
- Sustainability evaluation cannot only consist in the evaluation of individual aspects of sustainability, but needs an integrated evaluation.

The Competitiveness Subgroup is aware that much more indicators could be taken into account. The indicators used in this report are meant to be representative, understandable and as little overlapping as possible.

Concerning the work on energy scenarios, as proposed by Greenpeace, the Subworking Group agreed that this work will be undertaken in the second phase of the Subgroup’s work and summarised in the forthcoming Part 2 of the SWOT Analysis Report as mentioned before.

2. Examples of Summary Integrated Evaluations

In this chapter are displayed comprehensive performance tables on power generation technologies, including a number of economic, environmental and social performance indicators. They illustrate how the practice of integrated evaluations has developed in the past decade.

The first following table is used as a reference work. It shows the complete set of indicators generated by PSI (Paul Scherrer Institut) and valid for the current (reflecting the situation around year 2000) electricity generation park in Germany. The indicators are representative for the average performance characteristics for these technologies. The same applies to the associated energy chains. The quantitative indicators used are based on a systematic, multi-disciplinary, bottom-up methodology. The overall approach is process-oriented, meaning that the technologies of interest, and their features, are explicitly represented. Thus, methods such as Life Cycle Assessment (LCA), Impact Pathway Approach (IPA) and Probabilistic Safety Assessment (PSA) were employed along with state-of-the-art database developed by PSI and partners. Most of the indicators originate from model-based assessment but in few cases expert judgement was used. The uncertainties may be substantial but the indicators are sufficiently robust to allow comparisons that aim to establish an internal technology ranking. Some of the numerical values, e.g. 500 years for nuclear energetic long-term sustainability, will be further explained in the respective sections.

Interpretation for SWOT: Evaluations employing a variety of indicators result in a differentiated picture of the merits and drawbacks of the currently available electricity supply options. No single technology exhibits superior properties for all criteria. However, most indicators show nuclear energy in favourable light. From a comparative perspective current nuclear energy, operating under conditions prevailing in a highly industrialized country like Germany, exhibits favourable economic performance in terms of production costs and low sensitivity to fuel price increases. The evaluations of environmental performance, based on LCA and IPA demonstrate low impacts at global, regional and local levels. Within the western world nuclear also has an excellent safety record, reflected in very low estimates of expectation values for accident risks, in fact much below the experience values for fossil energy carriers. In relative terms the weaker points of nuclear energy are in the social sphere.

In a similar way, when they are planning new investments in power generation, the power companies and their regulators usually consider the economics, environmental performances and social impacts of the different possible options. The generation technology is selected on the basis of an integrated evaluation. Such evaluations are based on a number of performance indicators: generation costs, emissions to the atmosphere, natural resource consumption, etc. For environmental indicators, the normalised methodology of LCA is now extensively applied, however not often published.

Hereafter reported evaluations 2.1, 2.2 and 2.3 have been performed and given to the SubWG by European power companies.

Full set of PSI's quantitative indicators applicable to Germany

Economic Indicators

Impact Area/ (Weight)	Indicator	*Unit*	Lignite	Hard Coal	Oil	Natural Gas	Nuclear	Hydro	Wind	PV
Financial Requirements	Production cost	*c/kWh*	3.3	3.0	3.1	3.6	2.1	7	9	60
	Fuel price increase sensitivity	*Factor**	1.6	1.5	1.8	1.8	1.3	1.0	1.03	1.1
Resources	Availability (load factor)	*%*	80	80	80	80	80	40	20	9
	Geopolitical factors	*Relative scale*	100	80	20	40	80	100	100	100
	Long-term sustainability: Energetic	*Years***	400	2000	100	100	500	∞	∞	∞
	Long-term sustainability: Non-energetic (Cu)	*kg/GWh*	13	11	12	4	5	1	38	230
	Peak load response	*Relative scale*	20	50	100	100	10	30	0	0

Environmental Indicators

Impact Area	Indicator	*Units*	Lignite	Hard Coal	Oil	Natural Gas	Nuclear	Hydro	Wind	PV
Global Warming	CO_2-equivalents	*tons/GWh*	1220	1080	884	559	10	4	10	86
Regional Environmental Impact	Change in unprotected ecosystem area	*km²/GWh*	0.032	0.039	0.061	0.016	0.0017	0.0009	0.0029	0.011
Non-Pollutant Effects	Land use	*m²/GWh*	52	106	335	47	7	92	28	65
Severe accidents	Fatalities	*Fatalities/GWh*	5.7E-7	2.1E-5	4.5E-5	1.0E-5	2.3E-6	3.4E-7	1.1E-8	1.1E-7
Total Waste	Weight	*tons/GWh*	84	180	11	2	15	24	23	66

Social Indicators

Impact Area	Indicator	*Units*	Lignite	Hard Coal	Oil	Natural Gas	Nuclear	Hydro	Wind	PV
Employment	Technology-specific job opportunities	*person-years/GWh*	0.21	0.86	0.47	0.65	0.16	1.2	0.36	6.6
Proliferation	Potential	*Relative scale*	0	0	0	0	100	0	0	0
Human Health Impacts (normal operation)	Mortality (reduced life-expectancy)	*YOLL/GWh*	0.061	0.068	0.12	0.023	0.005	0.011	0.007	0.020
Local Disturbances	Noise, visual amenity/	*Relative scale*	10	8	6	2	4	5	7	0
Critical Waste confinement	"Necessary" confinement time	*Thousand years*	50	50	0.1	0.01	1 000	0.01	1	50
Risk Aversion	Maximum credible number of fatalities per accident	*max fatalities/ accident*	10	500	4500	100	50000	2000	5	100

* Increase of generation cost generated by a doubling of fuel price
** Ratio (Resources/Production) at the current rate of production

Source: Hirschberg et al., 2004; ILK, 2004.

2.1. Eurelectric 2005 Snapshot of energy technologies

Background: The following table is extracted from the Eurelectric Role of Electricity Project [1] and provides general information about operational performance, emissions and costs of different energy technologies. Data are based on 2005 prices.

	Hard coal	Lignite	IGCC	Gas	Nuclear PWR and BWR	Hydro run-of-river plant	Hydro pumped storage plant	Hydro storage Plant
Efficiency (%)	46	43.5	46.1	57.8	35.1	90	80	90
Emissions (g/kWh)								
- CO_2 (g/kWh)	728	944	727	349	0	0	0	0
- NO_x (g/kWh)	0.56	0.71	0.52	0.26	0	0	0	0
- SO_2 (g/kWh)	0.56	0.71	0.56	0.01	0	0	0	0
Cost of electricity (€-ct/kWh)	4.11	3.72	4.79	4.44	4.3	4.1	6.3	7.8
Equivalent full load hours per year (h/a)	7,500	7,500	7,000	6,000	7,900	7,000	2,500	2,000
	Wind on-shore	Wind off-shore	Biomass Stand Alone	Biomass Co-combustion	Solar Parabolic Through Technol.	Solar Central Receiver System	Solar Dish/ Engine System	Solar PV
Efficiency (%)	43	44	32	45	14	13.5	16.7	14
Emissions (g/kWh)								
- CO_2 (g/kWh)	0	0	0	0	0	0	0	0
- NO_x (g/kWh)	0	0	0.96	0.69	0	0	0	0
- SO_2 (g/kWh)	0	0	0.24	0.69	0	0	0	0
Cost of electricity (€-ct/kWh)	8.75	7.62	8.77	6.39	17.2	17.9	38.4	62.2
Equivalent full load hours per year (h/a)	2,000	3,750	7,500	7,500	2,496	2,847	1,955	1,000

Source: Eurelectric Role of Electricity Project [1].

Interpretation for SWOT: For the purposes of this report, the Eurelectric table delivers information on two SWOT indicators: cost of electricity ("production cost") and emissions of greenhouse gases. In the former case, nuclear performs about equal to the fossil and hydro options, and clearly better than wind-offshore and biomass. In the latter case, nuclear and the renewables perform clearly better than the fossil options. It is, however, important to mention that the analysis performed by Eurelectric on greenhouse gas emissions is not across lifecycle, but limited to the actual production phase. Full LCA are presented in Chapter 4.

2.2. All Indicators (Electrabel contribution)

Background: The following table gathers information provided by Electrabel on its power plants, based on coal, CCGT, wind, solar and hydro technologies. Data are based on prices from end of 2007. Source: Electrabel, [37]

Dim	Impact Area	Indicator	*Unit*	COAL	CCGT	WIND	Solar PV	HYDRO
	Financial Requirements	Production cost	*c/kWh*	4,0 - 5,0	4.75	7,5 - 13,5	35 (SP) - 50 (B)	4,0 - 7,0
		Fuel price sensitivity	*Factor of increase[1]*	1.5	1.75	1	1	1
	Resources	Availability	*%*	85 - 90	90 - 95	> 95	> 95	85-90
		(load factor)		(98)	(95)	(20-30)	(12)	(40)
Economy		Geopolitical factors	*Relative scale*	MEDIUM	MEDIUM	MEDIUM/ HIGH	MEDIUM/ HIGH	MEDIUM/ HIGH
		Energy resource lifetime	*Years*	180 - 500	50 - 150	∞	∞	∞
		Nonenergetic resource consumption	*kg/GWh*	6	5	40	70	1
		Peak load response	*Relative scale*	MEDIUM	HIGH	NO	NO	LOW
	Global warming(BAT)	CO_2-equivalents	*tons/GWh*	950 - 750	360	0 (9-25)	0 (60)	0 (8)
	Regional Environmental Impact	Change in unprotected ecosyst. area	*km^2/GWh*	0.04	0.015	0.003	0.01	0.001
Environment	Non-pollutant Effects	Land use	*m^2/GWh*	50	50	30	1200	90
		Land occupation	*km^2/GW*	0.06 (*)	0.03	125	25	100
	Severe Accidents	Fatalities[2]	*Fatalities/GWh*		0.1	0.0001		0.003
	Total waste	Weight	*tons/GWh*	5	2	25		25
	Employment	Technology-specific job opportunities	*Person-years/ GWh*	2.5	0.6	0.4	1?	1.2
	Proliferation	Potential	*Relative scale*	NA	NA	NA	NA	NA
Social	Human Health normal operation	Mortality (reduced life-expectancy)	*Years of life lost/GWh*	0.07	0.02	0.01	0.02	0.01
	Local Disturbance	Noise, visual amenity	*Relative scale*	HIGH	HIGH/ MEDIUM	MEDIUM	LOW	MEDIUM
	Critical Waste Confinement	"Necessary" time	*Thousand of years*	?	?	?	?	?
	Risk Aversion	credible number of fatalities	*Max. fatalities/ accident*	?	?	?	?	?

[1] Increase of production costs due to doubling of fuel costs.
[2] Expected damages due to severe accidents, expressed in fatalities per unit of energy.

<u>Interpretation for SWOT:</u> Although nuclear is not included in this table, it is nevertheless possible to draw some general conclusions for the purposes of this report: Comparing the renewables , i.e. wind and hydro, with the fossil options (coal, CCGT) reveals that, typically, the disadvantages of the renewables are their higher production costs, intermittency (low load factors), high consumption of material resources and large effects on the environment (land occupation, local disturbance). The typical disadvantages of the fossil options are their high fuel price sensitivity, limited energetic resource lifetime and high greenhouse gas (GHG) emissions.

2.3. All Indicators (Vattenfall contribution)

<u>Background</u>: The following table gathers information provided by Vattenfall from several of its in-house studies, incl. Environmental Product Declarations (EPD) across the lifecycle of its existing Swedish nuclear power plant projects, Nordic hydropower projects and Nordic wind power projects, [2-6].

Source:	Vattenfall's EPDs (Environmental Product Declarations according to ISO 14025)		http://www.environdec.com/reg/021/	http://www.environdec.com/reg/026/	http://www.environdec.com/reg/088/	http://www.environdec.com/reg/115/	http://www.environdec.com/reg/107/
Economy		**Unit**	**Forsmark's nuclear power**	**Ringhals' nuclear power**	**Vattenfall's Nordic hydropower**	**Vattenfall's Nordic wind power**	**Vattenfall's electricity from peat-fuelled CHP in Uppsala**
	Long-term sustainability: Non-energetic resource consumption (excluding rock, gravel, sand, soil and water)	kg/GWh	1,120	1,084	1,018	7,872	25,909
Environment		**Unit**	**Forsmark's nuclear power**	**Ringhals' nuclear power**	**Vattenfall's Nordic hydropower**	**Vattenfall's Nordic wind power**	**electricity from peat-fuelled CHP in Uppsala**
Global Warming	Greenhouse gases	ton CO_2-eq./GWh	3.7	3.7	4.2	13.5	632.0
Regional Environmental Impact	Change in unprotected ecosystem area	see sheet Biotope change					
Non-pollutant Effects	Land use	m^2/GWh	13	16	24,000	9	14,000
Severe Accidents	Fatalities	not calculated according to proposed definition, but risk assessments have been performed and potential emissions due to accidents calculated per kWh. See Vattenfall's EPDs at www.envirodec.com					
Total waste (excluding rock, sand, soil, waste water etc and material that is recycled or reused)	Weight	ton/GWh	0.27	0.23	2.0	0.97	2.6
Social		**Unit**	**Forsmark's nuclear power**	**Ringhals' nuclear power**	**Vattenfall's Nordic hydropower**	**Vattenfall's Nordic wind power**	**electricity from peat-fuelled CHP in Uppsala**
Human Health Impacts (normal operations	Mortality (reduced life-expectancy)	not calculated according to proposed definition, but you'll find life cycle emissions of substances impacting health in our EPDs. See Vattenfall's EPDs at www.envirodec.com					
Proliferation	Potential		See Vattenfall's EPDs for nuclear at http://www.environdec.com/reg/021/ and http://www.environdec.com/reg/026/				

Local Disturbance	Noise		Noise has been measured in the surroundings of the NPP at Forsmark. The level of noise is dependent on wind direction, temperature, etc., with a maximum of 38 dB (A)2 at the gate.	been measured in the surroundings of the Ringhals NPP. The level of noise is dependent on wind direction, temperature, etc., with a maximum of 45 dB (A)2 at the closest inhabitation.	characteristic outdoor noise from hydropower generation is the sound of streaming water at above ground stations. These sound levels are, however, lower than pre regulation and more often than not	Measurements show that Vattenfall's wind power plants operate below limits in present regulations, i.e. in most cases max 40 dB(A) adjacent to the closest living quarters.	Noise from the plant is mainly caused by fans, compressors, and vehicle transports. Noise measurements show that traffic is the principal source of noise in the CHP surroundings.
Critical Waste Confinement	Necessary confinement time		See Vattenfall's EPDs for nuclear at http://www.environdec.com/reg/021/ and http://www.environdec.com/reg/026/				

Source: Vattenfall AB Generation Nordic Certified Environmental Product Declaration EPD of Electricity from Forsmark Nuclear Power Plant 2007-11-01; from Ringhals Nuclear Power Plant (NPP) 2007-11-01; from Vattenfall's Nordic Hydropower, 02.2005; from Vattenfall's Nordic Wind Power 2007-02-01 and from peat-fuelled CHP in Uppsala March, 2006, [2-6].

Interpretation for SWOT: Vattenfall's contribution confirms the general results from the previous "all indicators" evaluations by other stakeholders, i.e. that nuclear seems to perform better than fossil, hydro and wind in terms of consumption of material resources and GHG emissions (across lifecycle).

3. Economic Dimension

In this part on the economic dimension, two features of nuclear power are investigated as compared to alternate means of production: first the cost of electricity generation, including all lifecycle components from initial investment to final decommissioning, second the security of supply in the short run as well as in the long run. That is, we try to answer the question: how affordable and how available nuclear power is likely to be, now and in the next decade.

3.1. Financial requirements

Financial requirements along the lifetime of a power plant include the initial investment, operation and maintenance, fuel procurement, waste treatment and disposal and end of life decommissioning cost. All expenses along the lifetime are time discounted to a reference year (usually the decision year) before addition to calculate a lifecycle production cost of electricity. Power plants will be operated for 30 years at least (CCGT) or even up to 60 years (nuclear). Fuel and operation costs have to be estimated over long periods (e.g. up to 40 years) which introduces some uncertainty in the lifecycle cost estimates. Consequently, decision makers have to consider several scenarios (GDP growth rate, geopolitics, energy prices, regulatory changes, etc...) and select the most robust option with respect to all possible future scenarios.

Examples of assessment given hereafter include estimates produced in 2008 by several European utilities and by other sources. Generally, costs will vary following time variations of main inputs. The main parameters influencing the total cost are: construction cost, investment financing conditions (interest rate, return on equity), fuel prices (gas, coal), CO_2 emission cost. There are other sources of variability in the estimated costs, for instance site specific or country specific circumstances. For those reasons, consistency between different assessments from different sources is generally difficult to check.

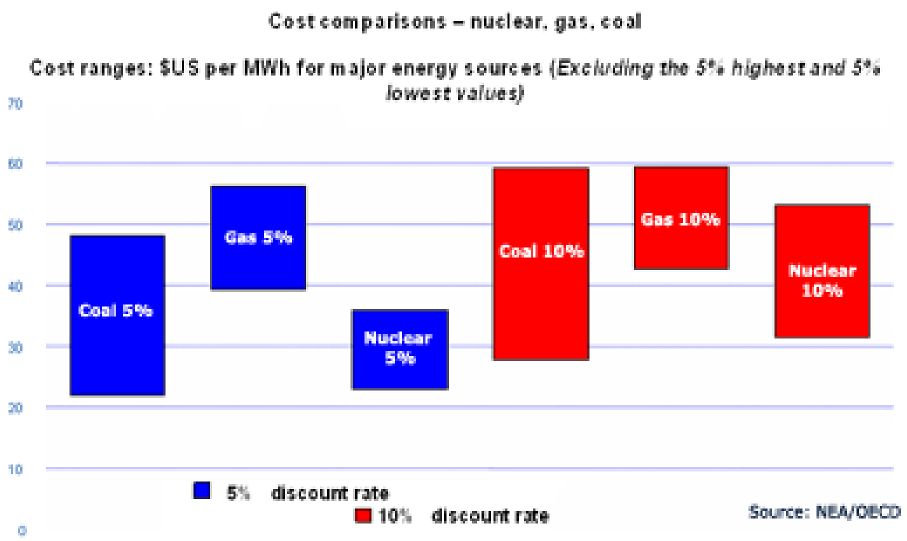
Between 2008 and 2010, the financial crisis has generated many price falls in the short term; the question is how much that changes the long term perspective. Two observations would encourage to say the long term perspective is not significantly modified: first, the oil price has quickly recovered up to 70-80 USD/barrel after a short dip down to 40, second the climate change policy and the renewables policy in Europe do not seem to falter, so that CO_2 price is likely to recover also up to 20 Euro/t and higher after 2012.

3.1.1. Production costs

This chapter presents results of production cost calculations as performed by different stakeholders over the last few years. Although some of the key contributing factors have become highly dynamic in the recent past, e.g. fossil fuel prices and construction costs (and again "less dynamic" following the post September 2008 global financial crisis), some general trends can nevertheless be detected.

The latest international reference available in 2008 is the 2005 OECD IEA/NEA study on Projected Costs of Generating Electricity [7]. The costs of generating electricity were calculated using the levelised lifetime cost method and generic assumptions such as economic lifetime of 40 years, average load factor for base-load plants of 85% and discount rates of 5 and 10%. Underlying costs data are from more than 130 power plants. At a 5% discount rate nuclear energy is cheaper than coal in 7 out of 10 OECD countries and cheaper than gas in all but one:

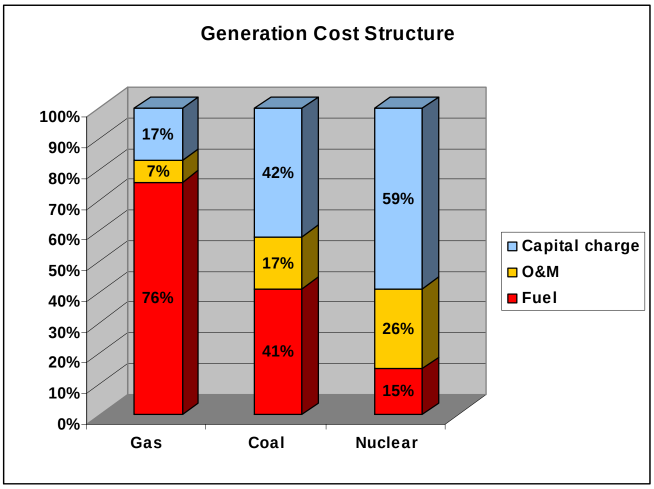
Ranges of electricity production costs in OECD countries



Source: OECD IEA/NEA, 2005, [7]

The same OECD IEA/NEA study [7] shows the structure of generation costs for gas, coal and nuclear. In view of recent significant increases in prices of oil, gas, coal and uranium, it is important to evaluate the structure of generation costs for different energy technologies in order to assess their vulnerability to fuel price fluctuations and resulting impact on their competitiveness (see also Chapter 3.1.2). While fuel accounts for merely 15% of nuclear generation costs, it accounts for more than three quarters of the costs of gas technologies:

Generation Costs Structure



Source: OECD IEA/NEA, 2005, [7].

The two figures reported here illustrate a key feature: since nuclear power is more capital intensive (share of capital charge in total cost), the total generation cost is more sensitive to the discount rate value, which explains the greater variation of nuclear total cost when discount rate value is changed from 5% to 10%. This observation holds in all further estimates shown hereafter. In real business cases, discount rate value is a proxy of the cost of capital (combination of return on equity and bank loan interest rate).

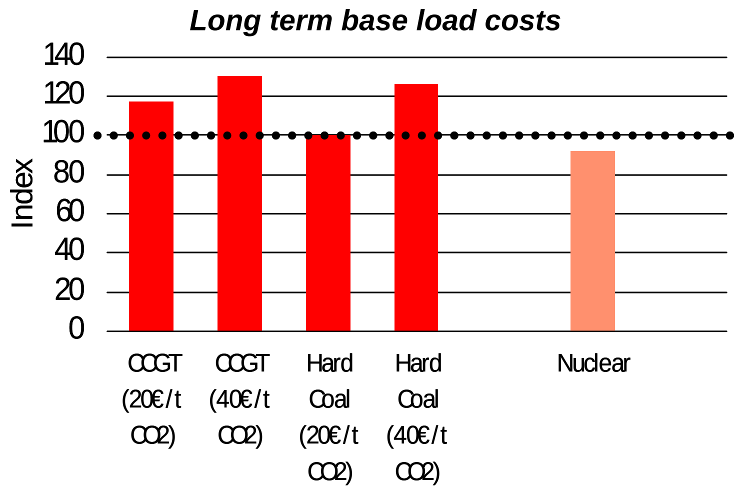
An updated OECD assessment has just been published in March 2010 and could not be taken into account in this study.

In addition to such international reference exercises, there is a broad literature on comparative electricity generation costs of nuclear and other options. In spite of the extensive cost basis for comparisons the matter is not trivial since costs are not always fully transparent and assumptions in cost calculations differ between various studies.

The generation cost structures have not significantly changed since 2005. However, generation cost absolute values have changed significantly, increasing for each generation technology as shown hereafter by 10 examples of estimates published in 2008.

<u>The 1st example</u> in this chapter is taken from an E.ON 2008 study [36] and shows that, for new power plant projects, nuclear competitiveness in terms of production costs vis-à-vis coal is largely determined by the future carbon price, vis-à-vis gas (CCGT) by future gas prices. In all cases nuclear appears cheaper than CCGT, while coal would be cheaper than nuclear if CO2 emissions were not charged.

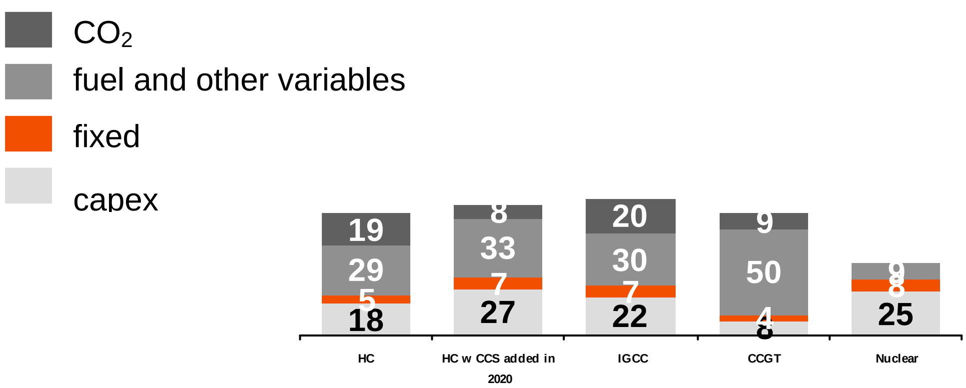
"New NPP are an economic option – especially because of internalized CO2-costs"



Source: E.ON (2008).

<u>The 2nd example</u> is taken from a CEZ 2008 study [38] and confirms the above view by E.ON with only different relative contributions of the individual cost elements due to different local settings:

Full costs of a new power plant EUR/MWh[3]

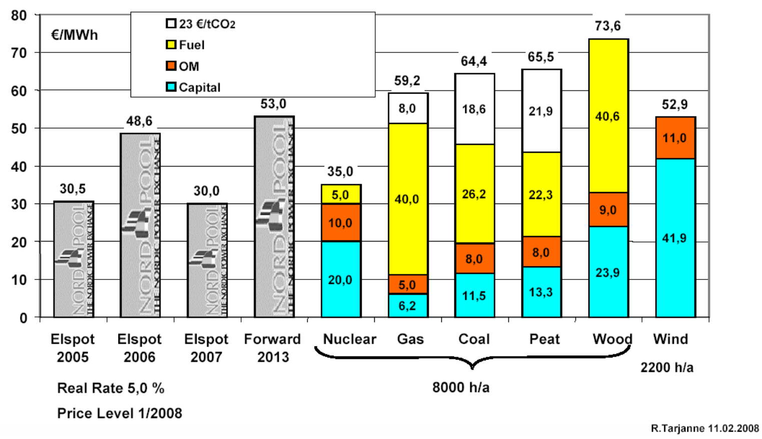


Source: CEZ, 2008, [38].

[3] The full costs reflect the fuel price and CO2 price as in Q1 2008.

<u>The 3rd example</u> is taken from a 2008 study by the Finnish Lappeenranta University of Technology [8] and compares the economical competitiveness of various power plant alternatives (nuclear, CCGT, coal-fired, peat-fired, wood-fired and wind). The calculations are carried out by using the annuity method with a real interest rate of 5 % per annum and a fixed price level as of January 2008. With an annual baseload utilization time of 8000 hours (corresponding to a load factor of 91,3 %) the production costs for nuclear electricity would be 35,0 €/MWh, for gas based electricity 59,2 €/MWh and for coal based electricity 64,4 €/MWh, when using a price of 23 €/tonCO_2. Without emissions trading the production cost of gas electricity is 51,2 €/MWh and 45,7 €/MWh for coal electricity, while nuclear remains the same (35,0 €/MWh). Therefore, at least under Finnish conditions, nuclear is with and without carbon prices the most competitive base-load supplier in terms of production costs. Regarding renewables, independent of the issue of much smaller load factors, wind has higher production costs than nuclear, mainly due to twice as high capital costs:

Electricity production costs at 23 €/tonCO_2



Source: Lappeenranta University of Technology, 2008, [8].

The relatively low cost values obtained here for capital intensive technologies (nuclear, wind) are to be related to the relatively low value of 5% (real) for capital cost, assumed by Lappeenrata University as pure interest rate, while many utilities will rather use values of 8% to10% .

<u>The 4th example</u> is taken from a 2008 evaluation by the German Federal Ministry of Economics and Technology of the role of nuclear energy with regard to ensuring a sustainable electricity supply in Germany [41] and shows average production costs for different energy technologies:

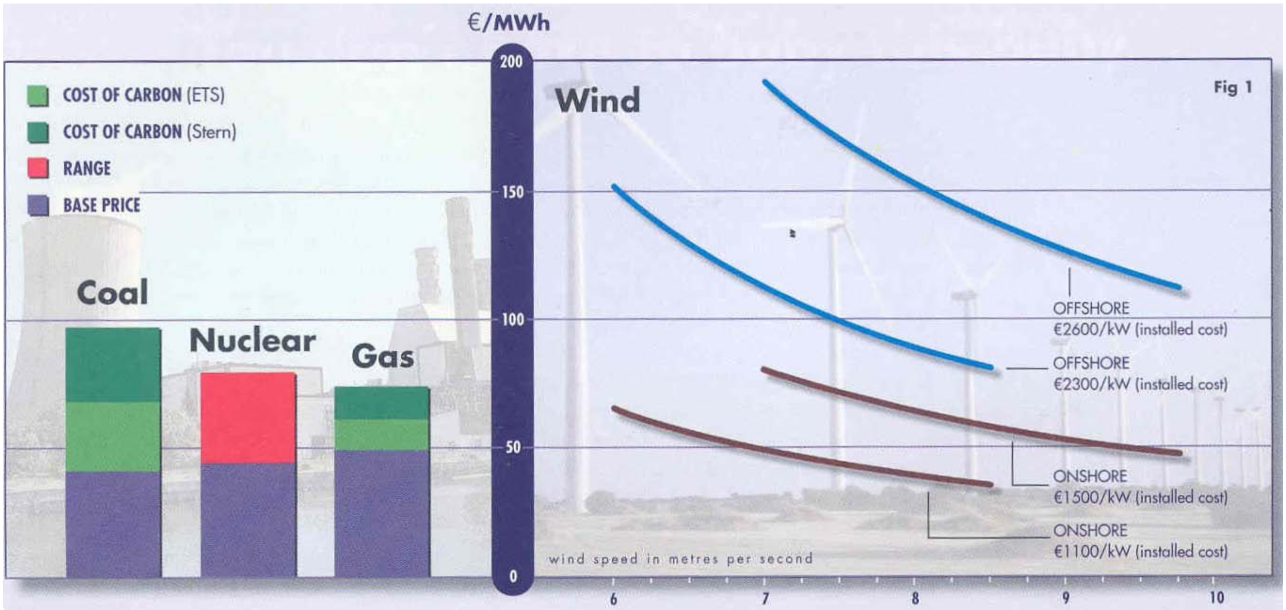
Average electricity production costs in Germany (cents/kWh)

Lignite	***2.40***
Nuclear energy	***2.65***
Coal	***3.35***
Hydro	***4.30***
Natural Gas	***4.90***
Wind	***9.0***
Photovoltaïcs	***54.***

Source: BMWI, 2008, [41].

CO_2 costs are not included in these figures and the cost figures for electricity generated from wind and photovoltaic technologies are the ones according to the German Renewable Energy Sources Act (Erneuerbare Energien-Gesetz (EEG)). Production costs are cheapest when electricity is generated in nuclear, lignite and hydro power plants, which together provide almost all of Germany's current baseload supply.

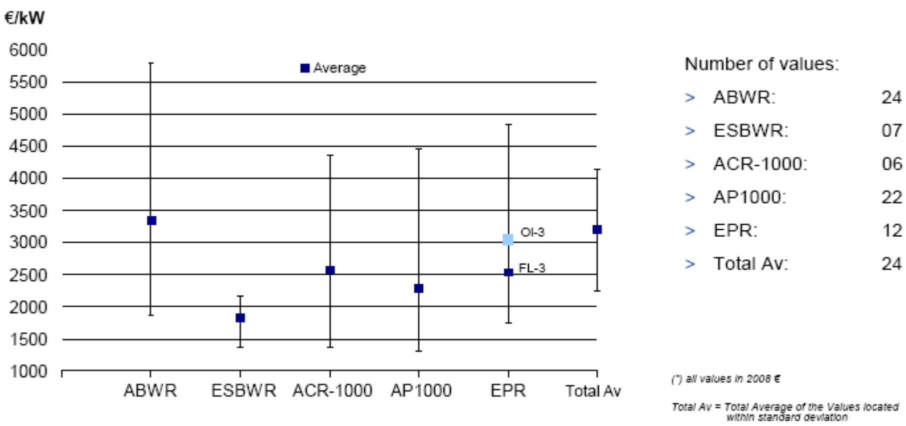
<u>The 5th example</u> is taken from Greenpeace contribution from April 10th 2008 making reference to Wind Power Monthly 2008. It can be seen that a range from 40 to 80 €/MWh is mentioned for nuclear power cost.



Source: Greenpeace/Wind Power Monthly 1-1-2008

Analysing one of the constituents of the above-outlined generation costs, capital charges, **the 6th example** shows the spread in investment costs (“overnight costs”) needed for new nuclear generation for different types of reactors:

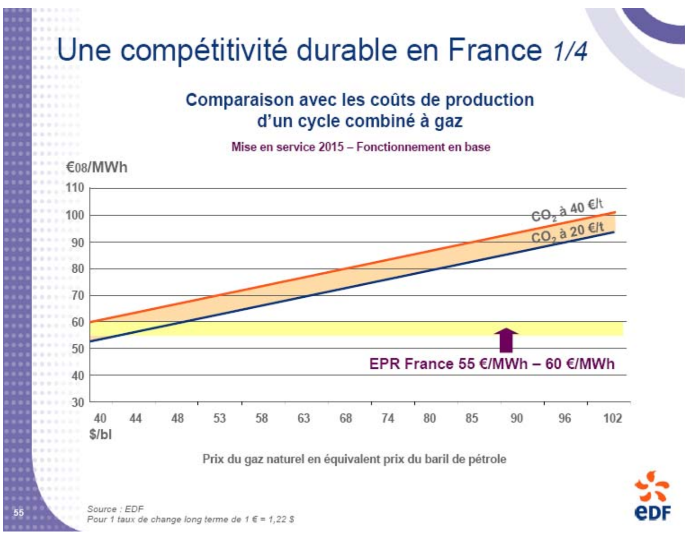
Overnight Costs Comparison



Source: RWE, 2008, [42]

These ranges correspond more or less to plant-specific values recently mentioned in literature, such as initial (2005) estimate of 2000 €/kW for the Flamanville EPR and 1950 €/kW for the Belene AES-92 VVER-1000, [43].

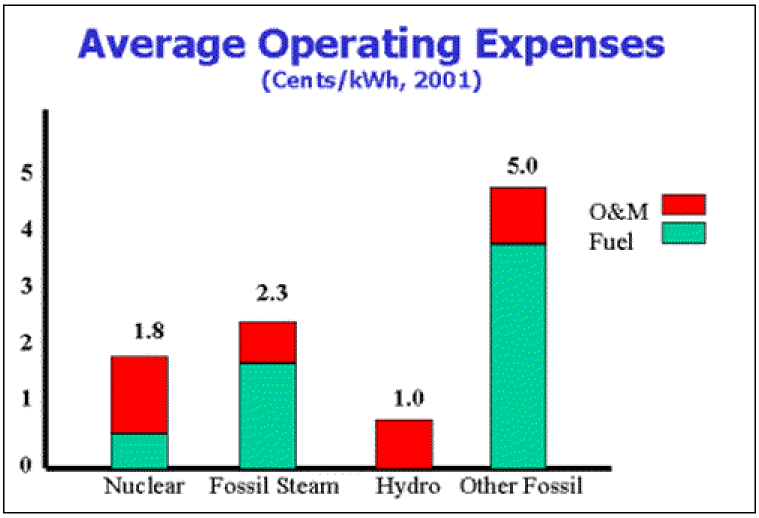
The 7th example is given by EDF presentation to investors in December 2008. Based on a re-estimated construction cost of 4 Billion Euros (2007), i.e. 2600 €/kW, the total cost of production for the new Flamanville-3 plant would be 54 Euro/MWh. For the next EPR plant in France, EDF estimated a slightly higher cost between 55 and 60 Euro/MWh. Projected oil prices and associated gas prices then showed that nuclear plant was cheaper than a CCGT plant in most likely scenarios.



Source: EDF, 2008, [46]

The 8th example is taken from a study by the European Commission's Joint Research Centre (JRC) on the relative cost structure of different energy technologies in terms of Operation & Maintenance (O&M) costs and fuel costs [21] on the basis of data from US power plants (in USD-cents/kWh). O&M costs are very variable for nuclear plants, depending on factors such as plant size and age but on average account for 20% of the LCOE[4]. Other relevant factors include the regulatory regime and the efficiency of the plant operator. Liberalization of electricity markets has helped in introducing best practices in reducing O&M costs throughout the industry, while maintaining or improving high safety standards. Nuclear shows the lowest costs, as compared to the fossil technologies. The study also shows that large margins for further reduction of non-fuel O&M costs have been identified for nuclear and they are in the process of implementation. This approach would allow an additional 20-30% reduction, though much dependent on national regulations and standards:

Operation & Maintenance Costs – nuclear, fossil steam, other fossil, hydro



Source: JRC, 2008, [21].

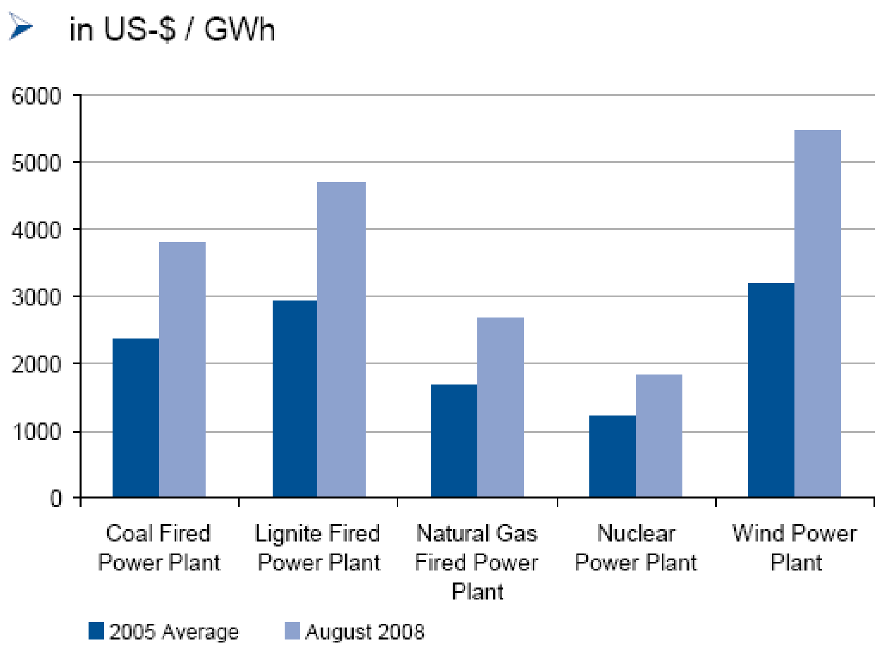
An important conclusion can be drawn from this comparison of operating expenses: the plants to be called in priority to supply the power on the grid are first Hydro, second Nuclear, because of lower marginal cost ("merit order"). They are the preferred plants for baseload supply.

[4] The levelized cost of electricity (LCOE) is the price needed to cover both the operating and annualized capital costs of the plant and is used as a marker for economic viability.

The 9th example deals with the increases in raw material costs in recent years and the effect on the new power plant projects.

Until the global financial crisis, which came to the forefront of the business world and world media in September 2008 with the failure and merging of a number of US financial companies, the costs for raw materials and commodities – such as steel, alloys, copper – increased dramatically from ~2005 onwards. The following summary evaluation by IKB, the Deutsche Industriebank, shows, prior to the September 2008 global financial crisis, the material related cost jump for new power projects in terms of US-$/GWh; the jump is similar for all energy technologies, with nuclear being relatively less sensitive. The order of magnitude of the cost increase: between 1,000 and 3,000 US$/GWh, i.e. between 1 and 3 US-$/MWh is notable however limited, compared with total costs of generation between about 50 and 100 US-$/MWh. The current (post September 2008) global financial crisis so far resulted in reduced material costs and electricity demand, which, again, affects all generation technologies in a similar way.

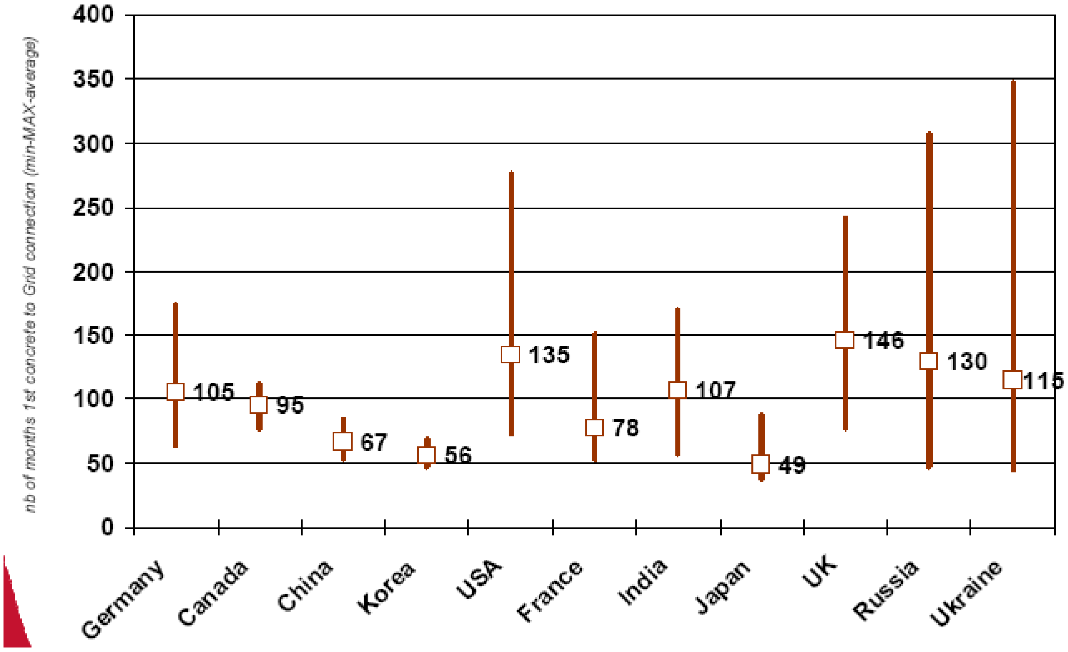
Price jump for new power projects



Source: IKB, 2008, [48].

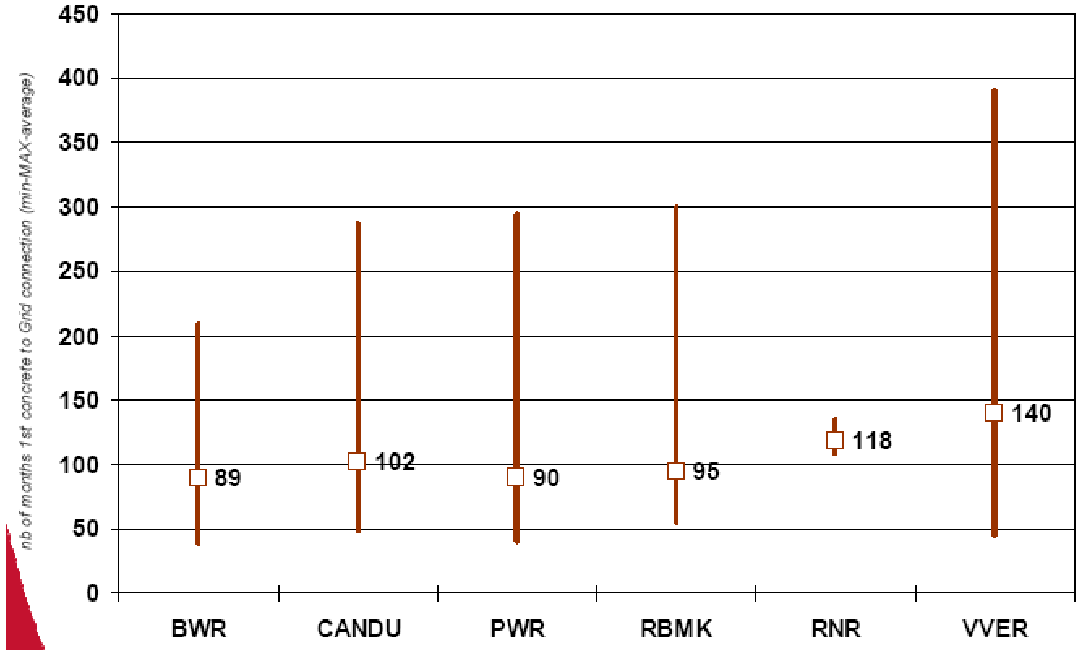
The 10th example deals with the reliability of “nuclear cost estimates”, such as the above ones on overnight investment costs. As it is well known, the nuclear industry had in various countries a history of major construction delays causing Billions of € in cost overruns. The average time actually taken before electricity was generated was almost always higher than original forecasts, resulting in often substantially higher financing costs. The following figures show average implementation schedules for NPPs by country and by reactor type, respectively:

Average implementation schedule by country



Source: AREVA, 2007, [44].

Average implementation schedule by reactor type



Source: AREVA, 2007, [44].

Further statements on production costs:

Sortir du Nucléaire quotes the Rocky Mountain Institute, [58] as follows: a kWh produced by a NPP costs 14 US cents (without including the costs related to insurance, waste management and decommissioning), whereas wind energy, with only 7 cents per kWh, has grown more competitive.

As far as the_decommissioning and waste management costs are concerned, views differ significantly:

- Sortir du Nucléaire underlines that the costs are huge (€482 million were estimated in 2005 to decommission the 70 MWe heavy water and gas cooled French reactor in Brennilis) and, especially in the case of waste management and storage, "just impossible to calculate."
- In contrast, recent OECD/NEA estimates mention that the costs for disposal of high level waste / spent fuel are in the range of 78.000 – 310.000 €/ton Uranium. Total waste management costs for NPPs are estimated by OECD at 0.03 – 0.13 €cents/kWh. The financing of radioactive waste management is based upon the polluter pays principle and, at least in the EU, internalised in the electricity price. In other words, funds are generally built up from electricity generation revenues to pay for future disposal, e.g.: Sweden € 0.001/kWh, [60].

In general, Sortir du Nucléaire concludes on economical aspects of nuclear competitiveness that "nuclear industry is unable to develop without subsidies and most of the costs are paid by taxpayers". Research would be financed directly or indirectly by state organs, construction financed by state subsidies, waste management carried out by state organs and decommissioning paid by the state.

It is important to note that in the Commission's 2nd Report on the status of implementation of the "Recommendation on the Management of financial resources for the decommissioning of nuclear installations, spent fuel and radioactive waste", adopted by the Commission in October 2006, it has been recognised that all EU Member States have accepted the "polluters pay principle" and have established accordingly a waste/decommissioning management fund. The industry fully accepts its financial responsibility for the backend of the fuel cycle.

The Commission is also preparing a Directive on the Management of Nuclear Waste, which will provide further legally binding guidelines at EU wide level, ensuring a common level playing field.

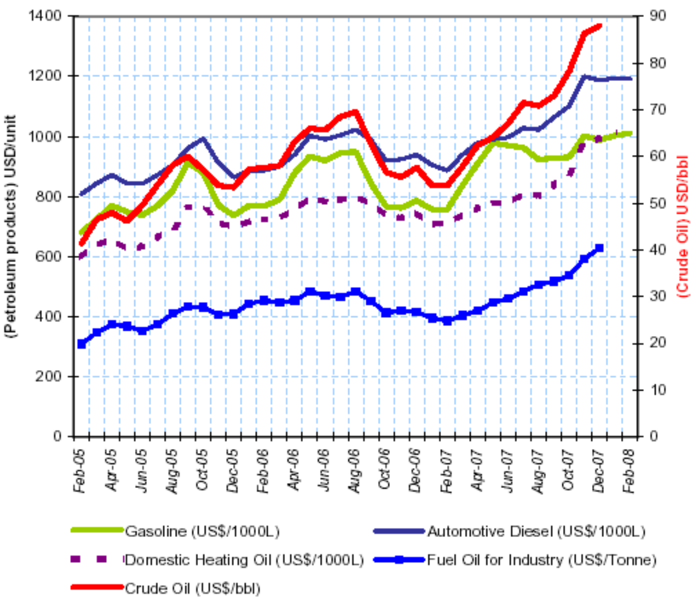
In summary, the examples of cost assessments reported here evidence some dispersion among results; the latter can be related to varying project conditions (country effect, site effect, etc), varying assumptions (on construction cost notably) and to different financing conditions (impact of the discount rate value on the capital cost). However, the overall picture derived is a lower lifecycle cost for nuclear plants than for gas fired or coal fired plants. The interest in new nuclear plants expressed by several European electricity companies can be understood through this observation: the levelised lifecycle cost with nuclear is estimated lower with a reasonable degree of confidence. Since the major part of expenses occur in the initial investment, then risks of unexpected total cost increase are limited over the whole lifetime of the new plant. Actual difficulties in financing new nuclear investments are therefore mainly coming from other reasons than from the "pure economic" analysis, such as, in particular, the unpredictable evolution of political decisions, the unknowns on the long term structural changes in the electricity grid and the biases to the operation of the liberalised electricity market.

3.1.2. Fuel price increase sensitivity

This chapter presents results of studies on trends in fuel prices and their respective impact on the production costs for the different energy technologies as performed by different stakeholders over the last few years.

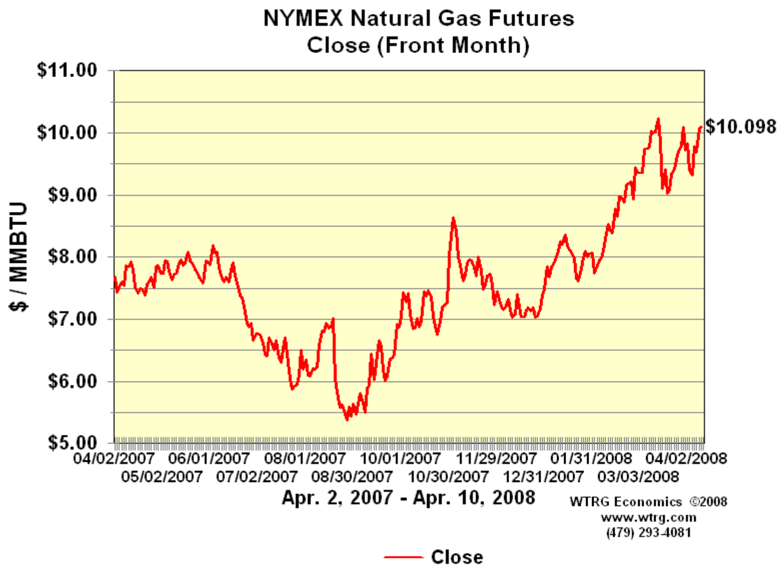
The first four charts show the evolution of prices of oil, gas and uranium in recent years. All types of fuel show an increasing trend in time until 2008 (uranium having "cooled down" significantly from their peak in the first half of 2007).

Evolution of Oil Prices 2005-2008



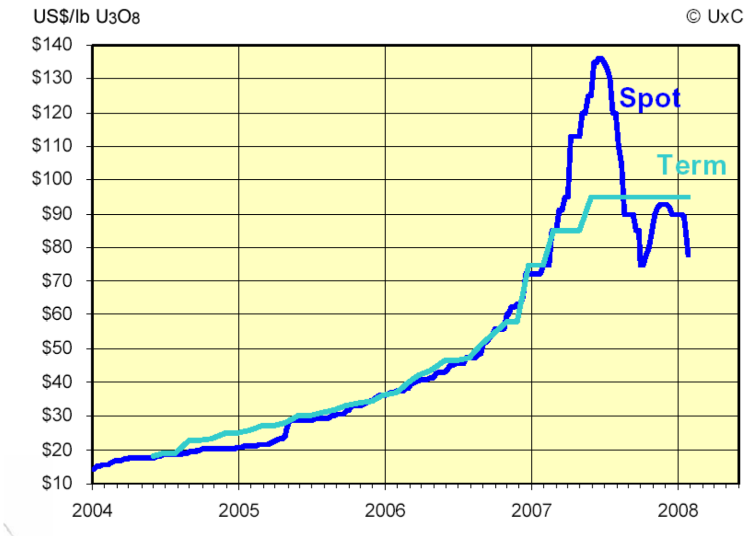
Source: OECD IEA, February 2008, [22].

Evolution of Natural Gas Prices



Source: NYMEX, [23].

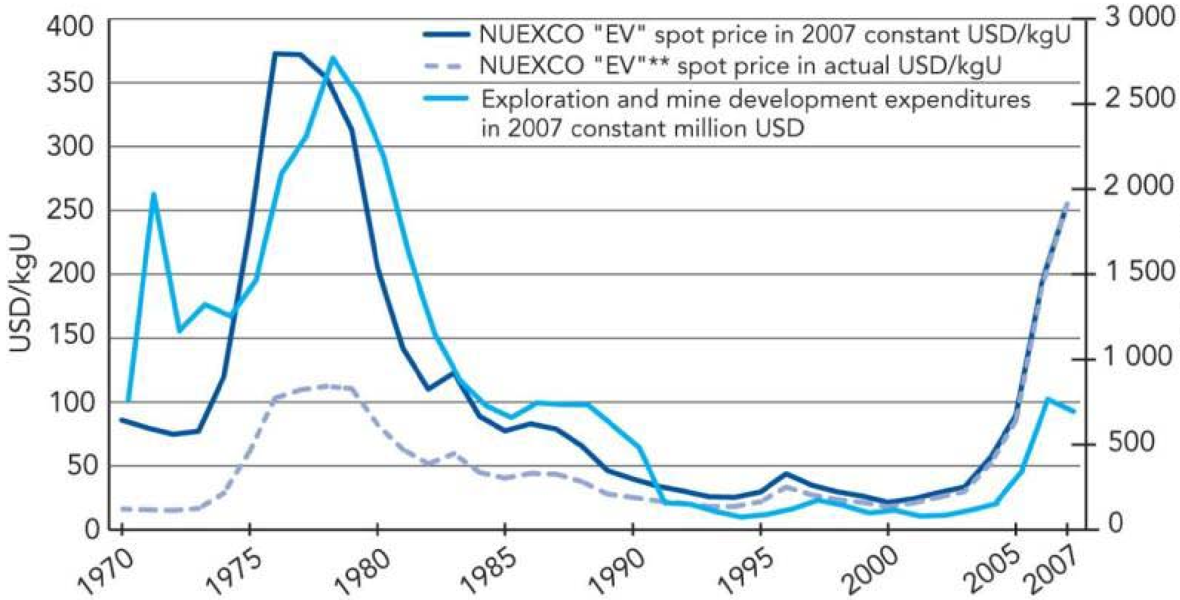
Uranium prices, 2004-2008, Spot UxC U_3O_8 Price & Long-term U_3O_8 Price[5]



Source: Uranium Market Outlook, U_XC 2008, [24].

[5] Since 2008, spot price has fallen down and remained between US$40 and 50 while long term price has remained around 60

Figure 5.3: Average annual uranium spot price, exploration and mine development expenditures, 1970 to 2007*



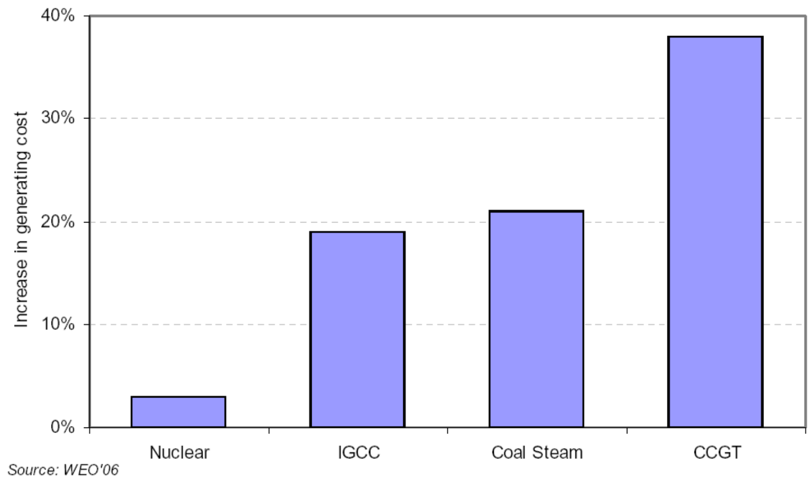
* The 2007 exploration and mine development value is an estimate.
** NUEXCO Exchange Value ("EV") spot price data courtesy of TradeTech (www.uranium.info).

Source: OECD/NEA Nuclear Energy Outlook (2008), [63]

Impact of fuel price volatility
However, as was shown in the previous chapter, fuel costs account for merely 15% of nuclear generation costs (in contrast to 76% for gas). Natural uranium supply as such accounts for even less than 10% of generation costs, the remaining cost originating from the other steps in the nuclear fuel cycle: uranium conversion, enrichment, fabrication of fuel pellets and assemblies, and back-end activities.

Since fuel costs are only a small component of nuclear power generating costs, according to the OECD IEA World Energy Outlook 2006 [9], a 50% increase in uranium, coal and gas prices would increase nuclear generating costs by ~3%, coal generating costs by ~20% and CCGT generating costs by ~38%:

Impact of 50% Increase in Fuel Price on Generating Costs



Source: OECD IEA World Energy Outlook, 2006, [9].

Another illustration of the fuel price volatility impact has been provided by AREVA from an in-house study on impact of fuel price on generation cost [25]. The table shows that fuel price volatility as currently observed induces very different generation cost variations according to the technology. For the same factor 3 variation in fuel price, the gas generation cost impact is about twice that of coal. But in spite of a factor 8 variation instead of 3, the nuclear generation cost impact remains 4 times less than that of coal, 7 times less than that of gas:

Impact of fuel price on generation cost

	2002 indicative values	2007 indicative (**)	**Variation**	**Cost Impact (USD/MWh)**
Uranium Volatility USD/lb U3O8	12.5	100	**Factor 8**	
Resulting fuel cost(*) (USD/MWh)	4.3	10.1		**+5.8**
Gas volatility (USD/MMBtu)	3.5	9.5	**Factor 3**	
Resulting fuel cost (USD/MWh)	23.1	62.6		**+39.5**
Coal volatility (USD/t)	30	90	**Factor 3**	
Resulting fuel cost (USD/MWh)	10.5	31.5		**+21**

(*) including uranium + conversion + enrichment + fuel fabrication
(**) in the higher range

- Assumptions on fuel energy yields:
  - uranium: burn-up 60 GWd/t, heat conversion 36%
  - gas: heat conversion 57%
  - coal: heat conversion 43%
- Indicative fuel price variations as observed in the past decade
- For comparison, total generation costs are in the range 50 - 70 USD/MWh

Source: AREVA, [25].

In summary, due to the fact that fuel cost represent only a small component of nuclear power plant generating cost, compared to gas and coal fired technologies, nuclear generation seems to show greatest resilience to upside fuel price risks.

3.2. Security of supply / resources

Security of supply should be regarded in both short-term and long-term perspective. The issues relevant to the short-term meaning of security of supply first include the technical reliability and availability of the whole electricity supply chain: generation, high voltage transmission and distribution. They also include physical hurdles which could be caused by natural, socio-political or market-related problems as well as cost stability which can be affected by sudden fuel price fluctuations. The long-term security of supply is dependent on total resources in ground (fossil fuels, fissile material, and other key materials such as iron, copper, nickel, etc...for equipments) and on the effective access to those resources. It is also closely related to long-term national energy policies which in turn are affected by important global problems such as fight against global warming and resulting push for low-carbon energy generation. The following examples represent the natural resources market situation relevant to different energy generation technologies. The geo-political factors such as political stability and diversity of energy import sources as well as reserves volumes are considered in the following comparison.

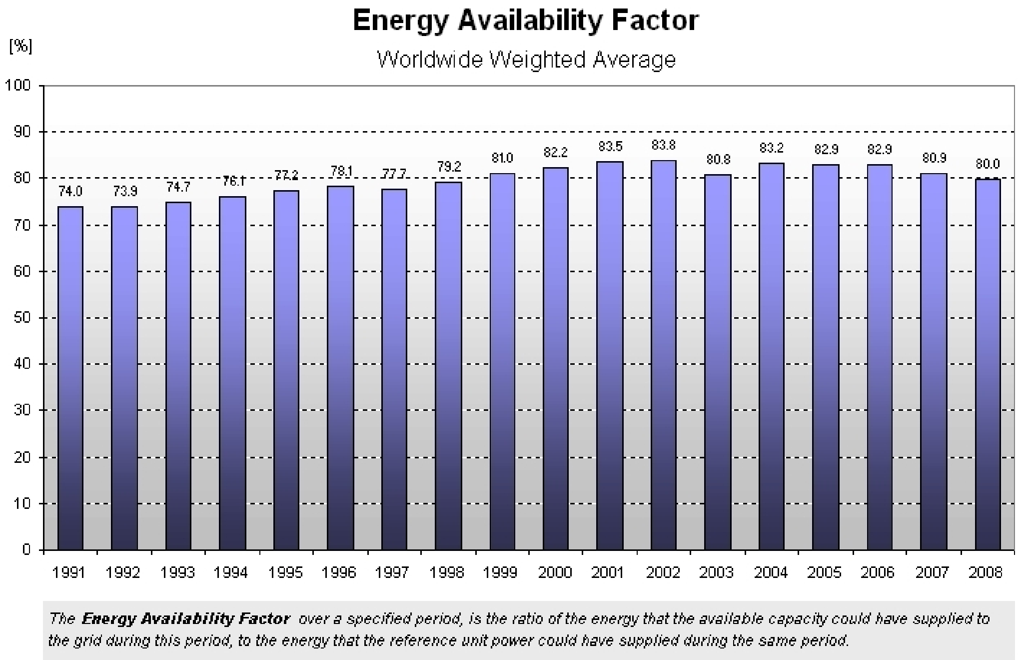
With regard to nuclear energy, short-term security of supply should be viewed through the following characteristics of nuclear power: uranium's high energy density, storability potential, capacity of identified uranium resources to cover the expansion of the sector in the next decades, small proportion of fuel cost in the overall cost structure as well as geo-political diversity of uranium supply sources.

3.2.1. Availability and capacity factor

Nuclear and fossil thermal power plants operate at high load factors, e.g. >75% around the year for **coal-fired plants**. For **nuclear**, the EU-wide average unit availability is 84% for the period 2004-6 and has steadily increased over the last 10-15 years. Availabilities are highest at plants in Finland, Slovenia and Netherlands with >90% in 2004-6 (source: EC-DG.TREN-data and IAEA-PRIS [10]). In recent years nuclear operators were able to significantly increase plant availabilities and thus power output through improvements in operational practices, engineering support and strategic management. Considerable reductions of time when plants are out of service for refuelling and maintenance were achieved and the number of unexpected shutdowns has been reduced.

Consequently, as **the 1st example** shows, the worldwide average availability has risen from 73% in 1990 and remained above 80% all over the last decade:

Average Energy Availability Factors in Worldwide Nuclear Power Plants



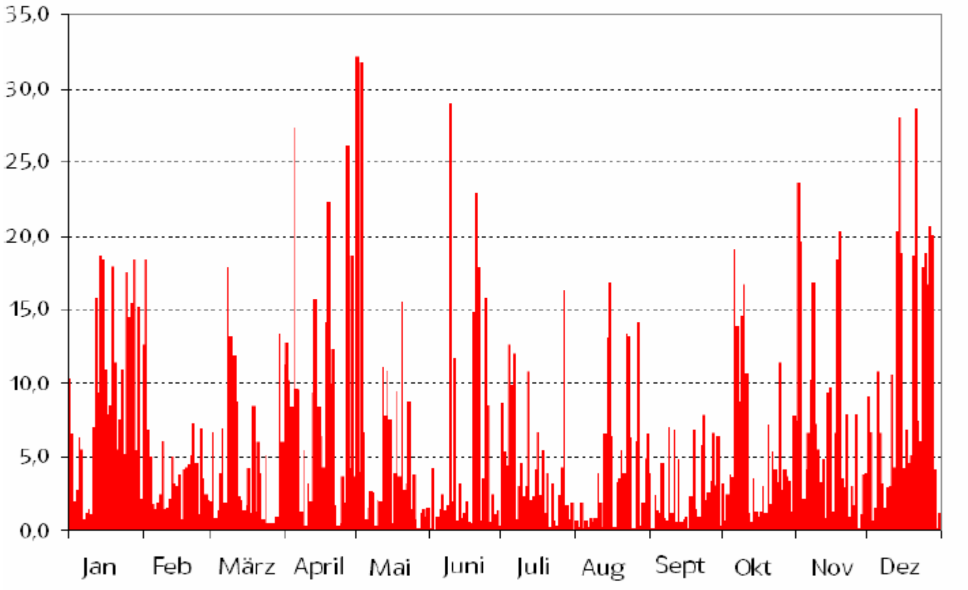
Source: IAEA Power Reactor Information System (PRIS), [10] (status: 2009).

When it comes to several renewable energy sources, including **wind power** and **hydroelectricity**, although the power plant may constantly be capable of producing electricity, its fuel (wind, water) may not be available:

- A hydro plant's production may also be affected by requirements to keep the water level from getting too high or low and to provide water for fish downstream.
- Wind farms are highly intermittent, due to the natural variability of the wind, but because a wind farm may have hundreds of widely-spaced wind turbines, the farm as a whole tends to be robust against the failure of individual turbines. In a large wind farm, a few wind turbines may be down for planned or unplanned maintenance at a given time, but the remaining turbines are generally available to capture power from the wind. Wind farms have capacity factors up to ~35%.

<u>The 2nd example</u> shows the intermittency in the availability of off-shore wind power for supplying electricity in peak demand for German conditions by E.ON across a year:

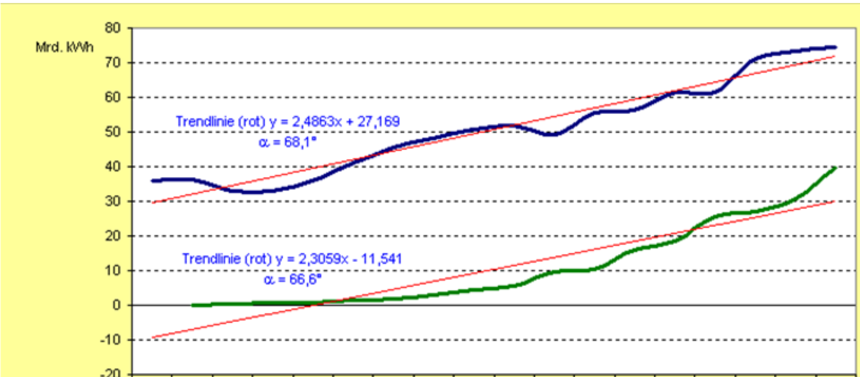
Annual share of daily off-shore wind power [%] in respective daily peak demand in E.ON-grid in Germany



Source: UCTE, 2004, [11].

In order to be able to make efficient use of renewables for the purpose of large-scale electricity supply – there always has to be some backup supply present from "conventional" sources operating at high load factors. Gas turbines are the best form of wind power backup as they can easily be turned on and off. In the following **<u>3rd example</u>**, the strong correlation between electricity generated in Germany from gas and from wind turbines seems to suggest that wind turbines are driving the gas dependence of the power sector, [49]:

Electricity generated in Germany from wind and from gas turbines



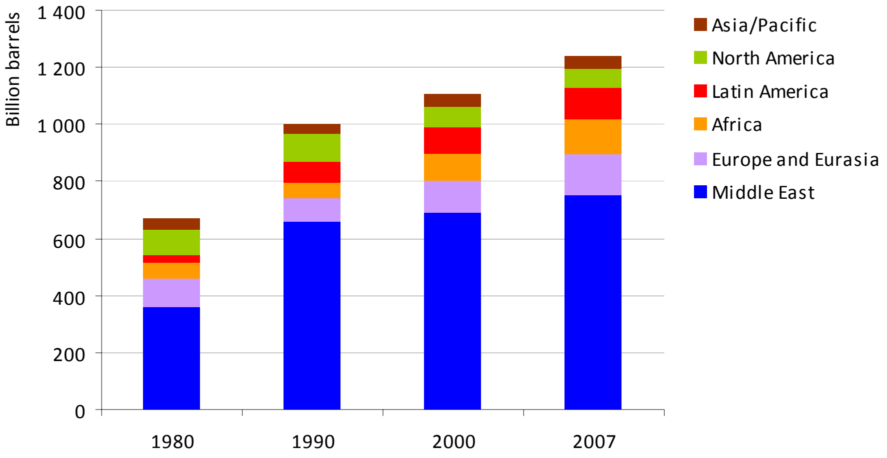
wh	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Erdgas	35,9	36,3	33	32,8	36,1	41,1	45,6	48,1	50,8	51,8	49,2	55,5	56,3	61,4	61,4	71	73,4	74,5
Windkraft		0,1	0,3	0,6	0,9	1,5	2	3	4,5	5,5	9,5	10,5	15,8	18,7	25,5	27,2	30,7	39,5

Source: E. Gärtner, [49].

3.2.2. Access to Resources

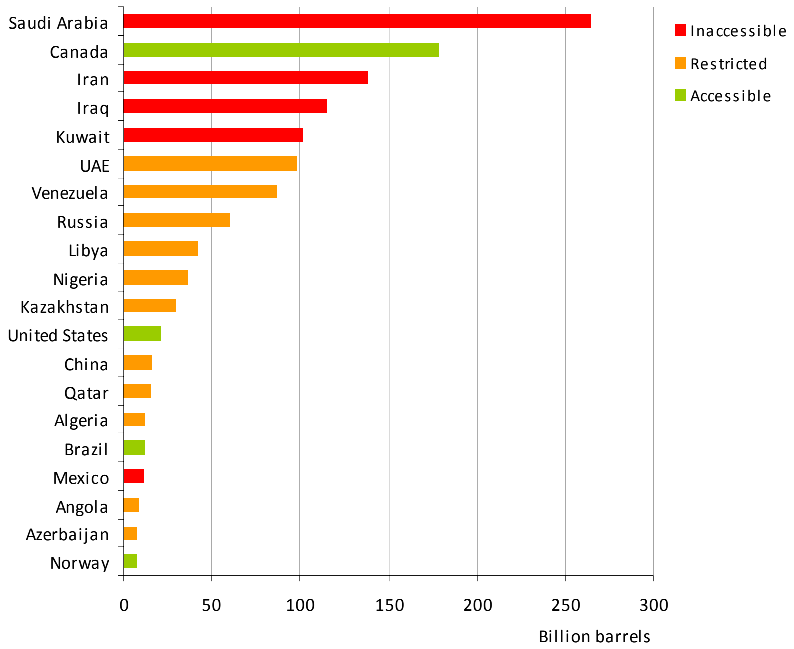
As energy demand grows in net importing countries, their energy security is increasingly linked to the effectiveness of international markets for oil, coal, gas and uranium, and the reliability of their suppliers. The graphs shown are taken from the OECD IEA World Energy Outlook 2008 (for oil, gas, coal) and the OECD/NEA 2007 Red Book (for uranium), and show worldwide proven reserves:

Proven remaining oil reserves by region, 1980-2007 (end-year)



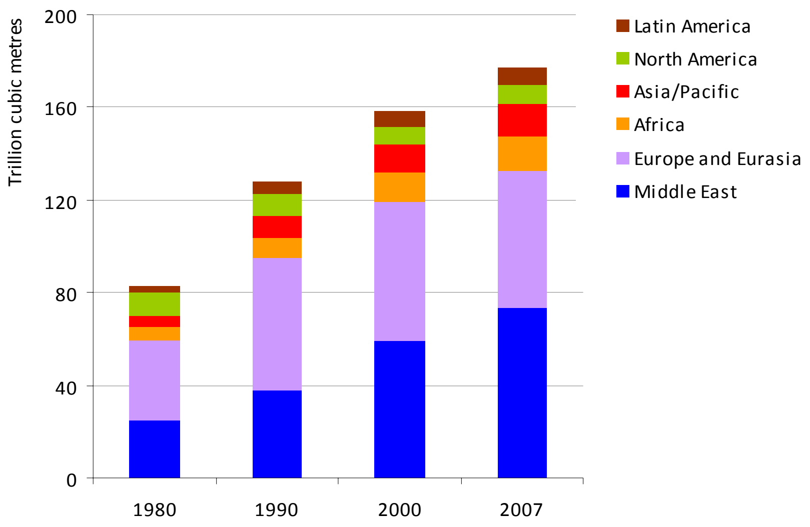
Source: World Energy Outlook 2008, OECD IEA, [50].

Foreign company access to proven oil reserves, end-2007



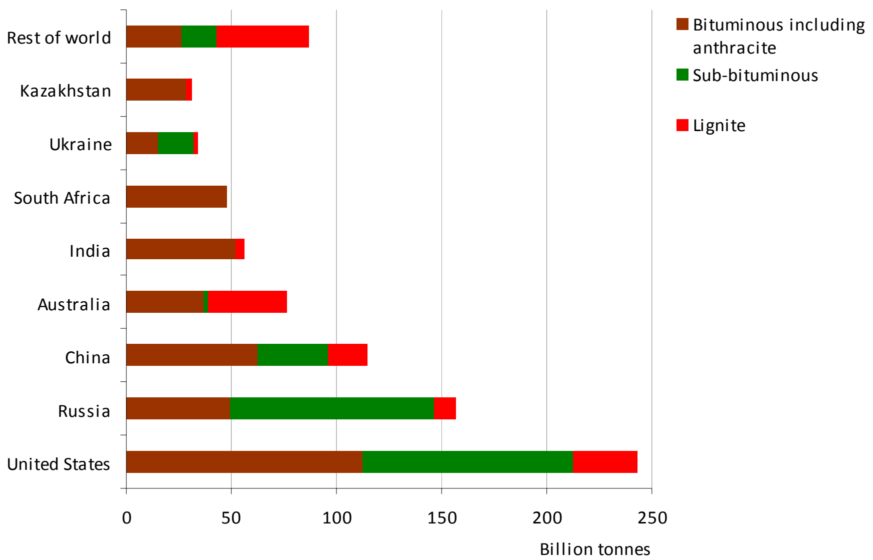
Source: World Energy Outlook 2008, OECD IEA, [50].

Proven remaining natural gas reserves by region, 1980-2007 (end-year)



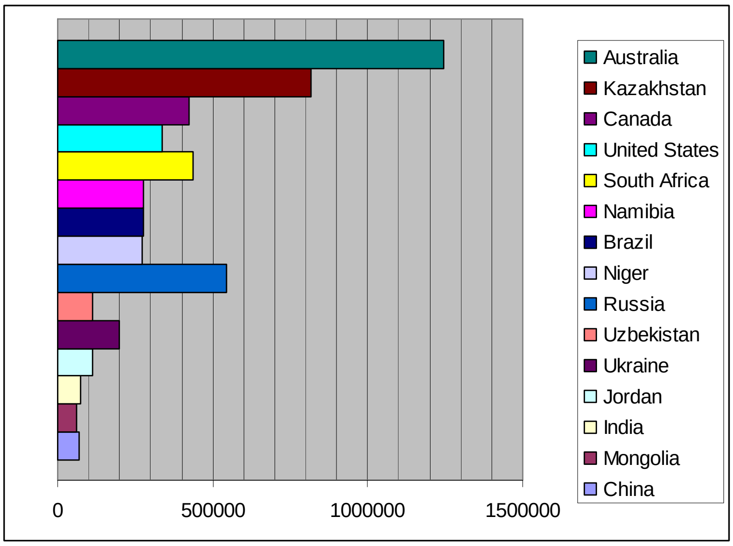
Source: World Energy Outlook 2008, OECD IEA, [50].

Proven coal reserves in leading producing countries, 2005



Source: World Energy Outlook 2008, OECD IEA, [50].

Identified resources of Uranium
in tons of Uranium recoverable at costs <USD130/kgU



Source: OECD/NEA 2007 Red Book, [51].

The biggest oil and gas suppliers for Europe are countries from the Middle East and Russia with usually very restricted access for foreign companies, whereas uranium is imported to Europe in the majority from politically stable and accessible countries, such as Australia and Canada (and practically 100% of the further fuel cycle steps are performed within the EU).

Relevant EU reserves are only available for coal (EU own production for hard coal: 54% in 2004, [26]). Current EU dependency on gas imports is already >50% and is expected to further increase to >80% by 2030, [26].

Gas security of supply is an increasingly growing concern, with the European Union's gas production in the North Sea having peaked already and import dependency from non-European countries growing.

Further, higher energy prices reinforce the economic and energy security benefits of diversifying away from imported oil and gas (see also Chapter 3.1.2).

3.2.3. Long-term sustainability (energetic resource lifetime in years)

Some stakeholders express concern that uranium supply problems are likely to occur even before 2020: “The proved reserves (= reasonably assured below 40 $/ kg Uranium extraction cost) will be exhausted within the next 30 years at the current annual demand. At present, only 42 kt/yr of the current uranium demand are supplied by new production, the remaining 25 kt/yr are drawn from stockpiles which were accumulated before 1980. Since these stocks will be exhausted in the next 10 years, uranium production capacity must increase by at least some 50 % in order to match future demand”, [61].

In contrast, the OECD/NEA “Red Book” [51] provides detailed quantitative evidence that this is not the case for the coming decades, even under the assumptions of a huge nuclear expansion and a non-application of closed nuclear fuel cycles (see chapter 3.2.3, second example for further justification).

For Sortir du Nucléaire, rarefied resource issue is, however, not so much related to uranium supply, but rather to limited industrial capacities and “atrophy of nuclear expertise worldwide”: “…Today, there is only one company in the world that can produce the heavy steel forgings for a reactor core: Japan Steel Works Ltd. in Osaka, which has a two- to three-years backlog (Mycle Schneider, World Nuclear Industry Status Report, 2007). According to some experts, there is also a huge loss of competences. A big part of nuclear engineers worldwide is now ageing; very few nuclear power plants have been built in the last decade. Moreover, the European models are prototypes, for which there is no experience. This can also lead to failures and construction delays, as it is the case for both European EPR” (Mycle Schneider, quoted above; Steve Thomas, « The Economics of Nuclear Power », Nuclear Issues Paper n°5, December 2005).

Conversely, in the recently published Nuclear Energy Outlook [63], OECD/NEA suggests that the quick development of a full set of industry services supporting the rapid development of nuclear development programs “ex nihilo” in many countries in the 1970’s-80’s could without significant difficulties be repeated today.

The 1st example of this chapter gives an overview of three available estimates of energetic resource (fuel) lifetime in years for oil, gas, nuclear and coal. Although all estimates have large ranges due to different underlying assumptions on reserves/production/consumption, nuclear has longest resource lifetime based on current technologies:

Estimates on Energetic Resource Lifetime in Years

	Oil	**Gas**	**Nuclear**	**Coal**
CEZ [27]	n/a	300	1000 (incl. thorium)	200
NEA 2007* [13]	41	65	85-675 (current technology)	155
Electrabel [28]	n/a	50 – 150	n/a	180 - 500

***** Ratio reserves/production 2005 (years)

The 2nd example is taken from the IAEA/OECD-NEA "Redbook" [29] and shows that the concept of economic mineability and range of coverage of uranium (often called resource lifetime) is enigmatic and needs to be used with care. The "Redbook" introduces USD 130/kg uranium as a quasi-threshold value and categorizes resources as "reasonably assured" (RAR) and "inferred", indicates values of 2006 and shows changes compared with 2005. With an annual demand of 0.0665 mio. t of Uranium RAR alone (3.34 mio. t) would correspond with a range of coverage of about 50 years; RAR together with "inferred" (5,5 mio t, from 4.7 mio t reported in 2005) would cover about 80 years. "more realistic rates of consumption" would result in additional 100 years. If all "undiscovered resources" including "prognosticated" and "speculative" (another 10.5 mio. t in total) would be considered, the range of coverage would be extended to another 300 years. "Unconventional U-resources" (mainly phosphate-rock) are estimated to amount to up to 22 mio. t and uranium available in sea water to 4000 mio. t. Advanced reactor- and fuel cycle technologies under development (fast breeder reactors and multiple recycling) could extend the ranges of coverage "from hundreds to thousands of years" [29, p. 89].

Based on this PSI (see full set of indicators, chapter 2) has given 500 years as reasonable number for orientation and as input for multi-criteria decision analysis (MCDA, see chapter 6).

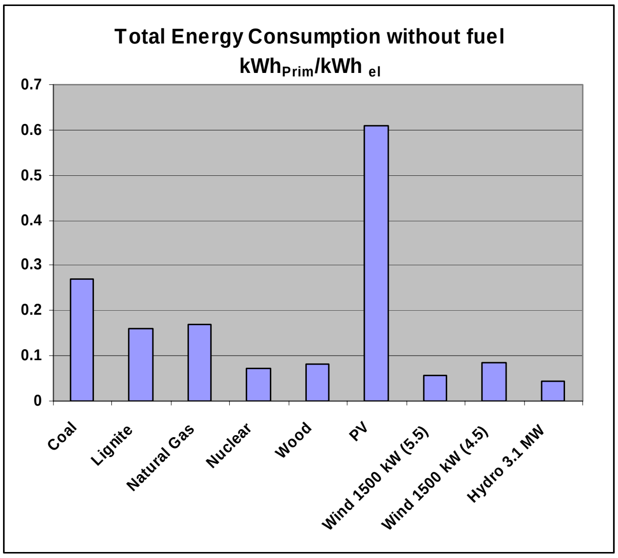
3.2.4. Long–term sustainability (energetic and non-energetic resource consumption)

Independent of the type of fuel used, power generation is always connected with consumption of both energy and material resources for construction, operation and decommissioning of the related power installations. In the case of nuclear, fossil-fired and biomass-fired power plants also the consumption of resources for the fuel extraction must be taken in to account.

<u>The 1st example</u> of this chapter deals with consumption of **energetic resources** and is taken from a recent study on energy intensity of different generation technologies by the University of Stuttgart [14]. The table and the summary histogram show the cumulated energy consumption of power generation for different technologies without fuel as a relation between input and output kWh (energy intensity):

Cumulated Energy Consumption without Fuel			
	Construction and decommissioning/disposal of PP kWh_{Prim}/kWh_{el}	Use without fuel kWh_{Prim}/kWh_{el}	Total without fuel kWh_{Prim}/kWh_{el}
Coal	0.0176	0.2519	0.2695
Lignite	0.019	0.1415	0.1606
Natural Gas	0.0044	0.1655	0.1699
Nuclear	0.0151	0.0578	0.073
Wood	0.0827	0.0003	0.083
PV*	0.574	0.035	0.609
Wind 1500 kW (5.5)	0.054	0.004	0.058
Wind 1500 kW (4.5)	0.0784	0.0065	0.0849
Hydro 3.1 MW	0.0401	0.0045	0.0445

* Crystalline Silicon Solar Cells



Source: University of Stuttgart, 2005/2007, [14].

As can be seen from the above summary histogram, large hydro, large wind and nuclear show best overall lifecycle performance as regards energy intensity. Typically, fossil and some renewables, particularly photovoltaics, show the least favourable performance.

The 2nd example is again taken from the Stuttgart study [14] and demonstrates the resource intensity of energy generation technologies for selected **material resources** which are important in the construction phase of power installations:

Specific Resources and Material Consumption			
	Iron [kg/GWh$_{el}$]	**Copper [kg/GWh$_{el}$]**	**Bauxite [kg/GWh$_{el}$]**
Coal	1700	8	30
Lignite	2134	8	19
Natural Gas	1239	1	2
Nuclear	457	6	27
Wood	934	4	18
PV*	4969	281	2189
Wind 1500 kW (5.5)	3066	52	35
Wind 1500 kW (4.5)	4471	75	51
Hydro 3.1 MW	2057	5	7

** Crystalline Silicon Solar Cells*

Source: University of Stuttgart, 2005/2007, [14].

For iron, best performance is shown in this example by nuclear and wood. For copper, by gas, wood, large hydro and nuclear. For bauxite, by gas and large hydro. Typically, fossil and some renewables show worst performance.

Growing safety and security design requirements may lead to an increase in material needs also for the construction of NPPs, but even if the demands are doubled nuclear performs better than any other generation technology listed. This fact mainly results from the large amount of electricity [GWhe] NPPs produce during their long design lifetime compared to other technologies.

3.2.5. Peak load response

Referring to what was said in Chapter 3.2.1 on power plant availability and the intermittency of many renewables, typically wind, the load characteristics of energy technologies and their dynamics in the existing fuel mix is an important criterion as regards sustainability.

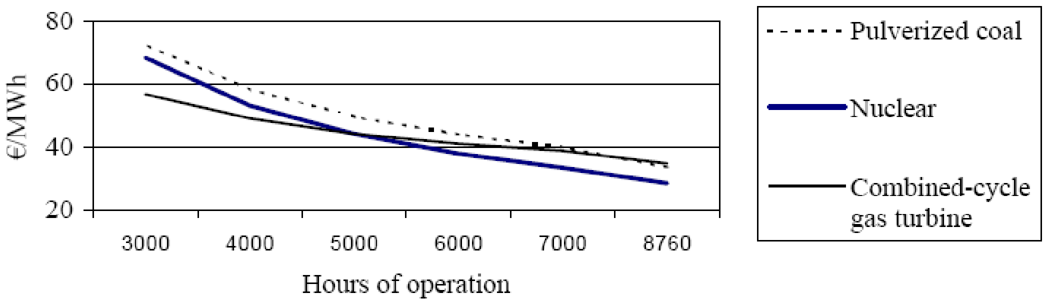
- A baseload plant is a power plant devoted to the production of baseload supply. Baseload plants are used to meet some or all of a given region's continuous energy demand, and generate energy at a constant rate. Baseload plants typically run at all times through the year except in the case of repairs or scheduled maintenance. Examples of baseload plants using *non-renewable* fuels include nuclear and coal-fired plants. Because they require a long period of time to heat up to operating temperature, these plants typically handle large amounts of baseload demand. Among the *renewable* energy sources, hydroelectric and geothermal can provide baseload power.

- The opposite of a baseload plant is a peaking plant. These plants generally run only when there is a high or peak demand for electricity, e.g. during late afternoon or evening. The time that a peaking plant operates may be many hours a day or as little as a few hours per year, depending on the local demand and grid conditions. The equipment and fuels used in baseload plants are often unsuitable for use in peaking plants because the fluctuating conditions would severely strain the equipment. For these reasons, nuclear, geothermal, waste-to-energy, coal, and biomass plants are rarely, if ever, operated as peaking plants. Peaking plants are generally *gas turbines*. Some *hydro plants* can also be operated this way, e.g. by using natural reservoirs and pumped storage.

Best peak load response is shown by gas-fired plants, worst by nuclear and coal-fired plants. This is mainly due to the fact that NPPs are part of a complex electricity system and that these systems differ technically and economically from country to country. Generation-I and many Generation-II NPPs were neither designed, nor expected, to load-follow. However, more recent designs such as modern PWRs, CANDUs and PBMRs are indeed flexible and they all have very good technical capacities for load-following.

However, for economical reasons, nuclear power has been and is likely to remain in most countries primarily a baseload-only-technology, as shown in the following example from France, [52]:

Cost of electricity in €/MWh (France)



Source: DGEMP study, France, 2004, [52].

In other words, considering the size of the initial investment, under most of current electricity systems in Europe, a NPP's competitiveness requires that it essentially operate all year round.

Sortir du Nucléaire states that nuclear's baseload production can also contribute to increase peak load demand: "In France, the oversized base-load capacity production has contributed to a massive development of electric heating, which shows very bad performances regarding energy efficiency. Meanwhile, the energy consumption of French households has kept increasing, which means that seasonal peak demand has a broader impact now, everybody needing electricity at the same time to heat houses and supply an increasing number of electric appliance. France has now been importing electricity from Germany for four years to face this increased demand ; it reached a new consumption record this winter with 92000 MW in one day (for 63 million inhabitants) while during the same period Germany demand was 77000 MW for 82 million inhabitants."

It is important to note that most of the recent studies on different scenarios of the energy systems conclude that for achieving the climate change goals for 2030, there is a need for both base-load and peak load production capacities As well as for increased electrical interconnections.

In summary, security of supply covers diverse aspects.

Firstly, one can look at the availability and accessibility of the energetic resources, both geographically and in time. Geographically, Uranium is well spread and available in stable regions of the world. The very high density of its energy content also allows easy storage of stocks for years. Time wise, actual known reserves of Uranium are sufficient for around a century at present rate of consumption. Mine exploration, which is restarting, will probably lead to new discoveries. In addition, new technologies of reactors and fuel cycles are under development to improve significantly the utilization of resources, ensuring the long term availability of nuclear fission energy as a contributor to the energy mix.

Secondly, looking to the consumption of non-energetic resources, nuclear plants are most effective due to the high power level of the facilities, allowing a limited consumption of these resources per unit of power produced.

Thirdly, nuclear plants have a demonstrated high load factor in base load mode of operation, where they are most economically competitive. These plants deliver stable and reliable electricity to the customers, ensuring the security of supply of electricity.

Finally one has to note a temporary issue of human resources and supply chain for large equipment, but this should be overcome by industry of it sees the opportunity. It is again an issue of “investment decision” which requires an overall conducive environment.

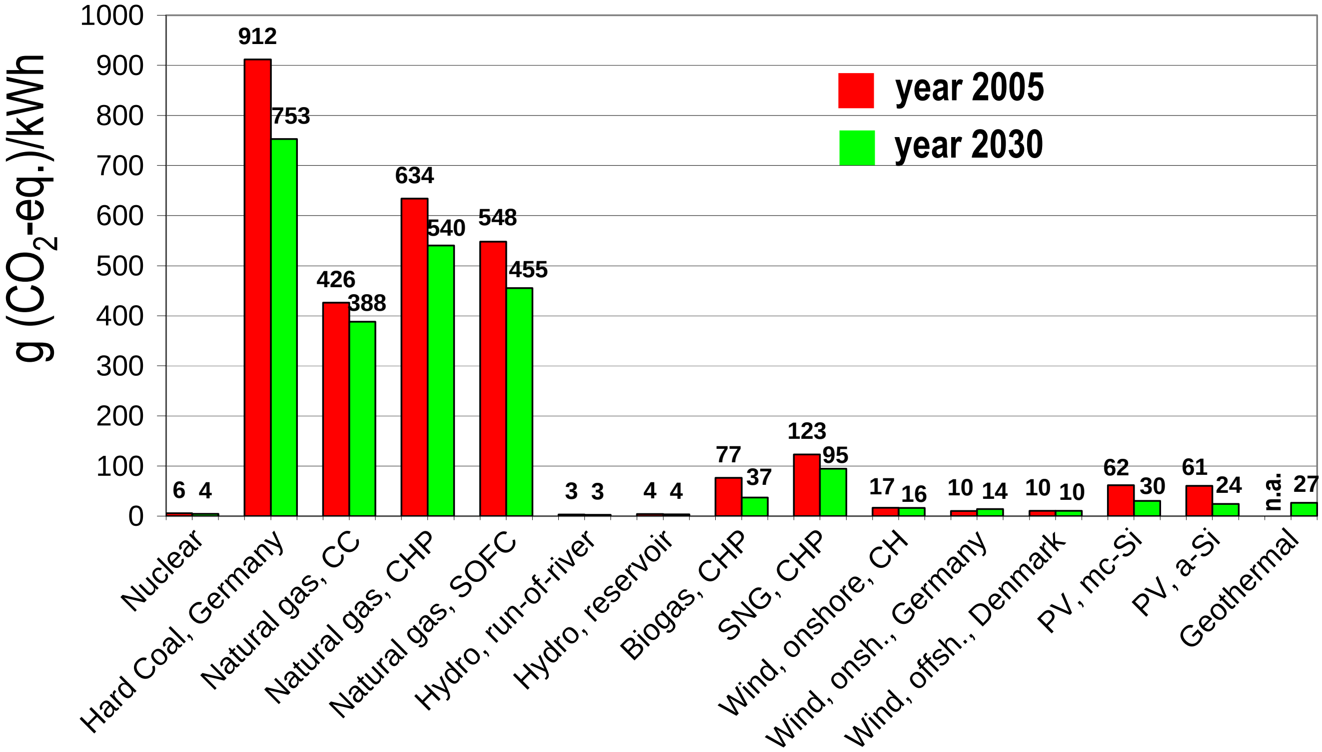
In conclusion, nuclear energy compares well with other sources of energy from a security of supply point of view, and is a major asset for the EU as a whole, as a region highly dependent of the outside for its fossil fuel supply.

4. Environmental Dimension

4.1. Global warming

This chapter deals with the impact of the use of different energy technologies across their respective lifecycles on the global warming, i.e. the amount of their respective GHG emissions per unit of energy generated.

<u>The 1st example</u> of this chapter is taken from work by PSI on the environmental profile of current and future electricity systems [Bauer et al., 2008]. The analyzed technology portfolio contains both large centralized power plants and smaller decentralized units in Switzerland and few other European countries. Small combined heat and power units burning natural gas or gasified biomass were assessed along with base- and mid-load large power plants. Evolutionary technology development was assumed to take place between today and 2030 for all reference power plants.



Source: Paul Scherrer Institute, [Bauer et al., 2008].

As can be seen from the figure, in terms of CO_2-equivalents, fossil systems generate by far the highest burdens for global warming. GHG emissions from nuclear, hydro and wind systems remain about two orders of magnitude below GHG emissions of fossil systems. Net GHG from PV and wood and biogas cogeneration are about one order of magnitude lower than fossil. However, for these technologies substantial reductions are envisioned until 2030. Although quite substantial reductions of GHG emissions from fossil power generation can be foreseen, natural gas and especially coal systems will remain the most emitting technologies by far in 2030 (unless Carbon Capture and Storage (CCS) systems will be implemented).

<u>The 2nd example</u> is taken from IAEA (2000) study on GHG of electricity chains [15]:

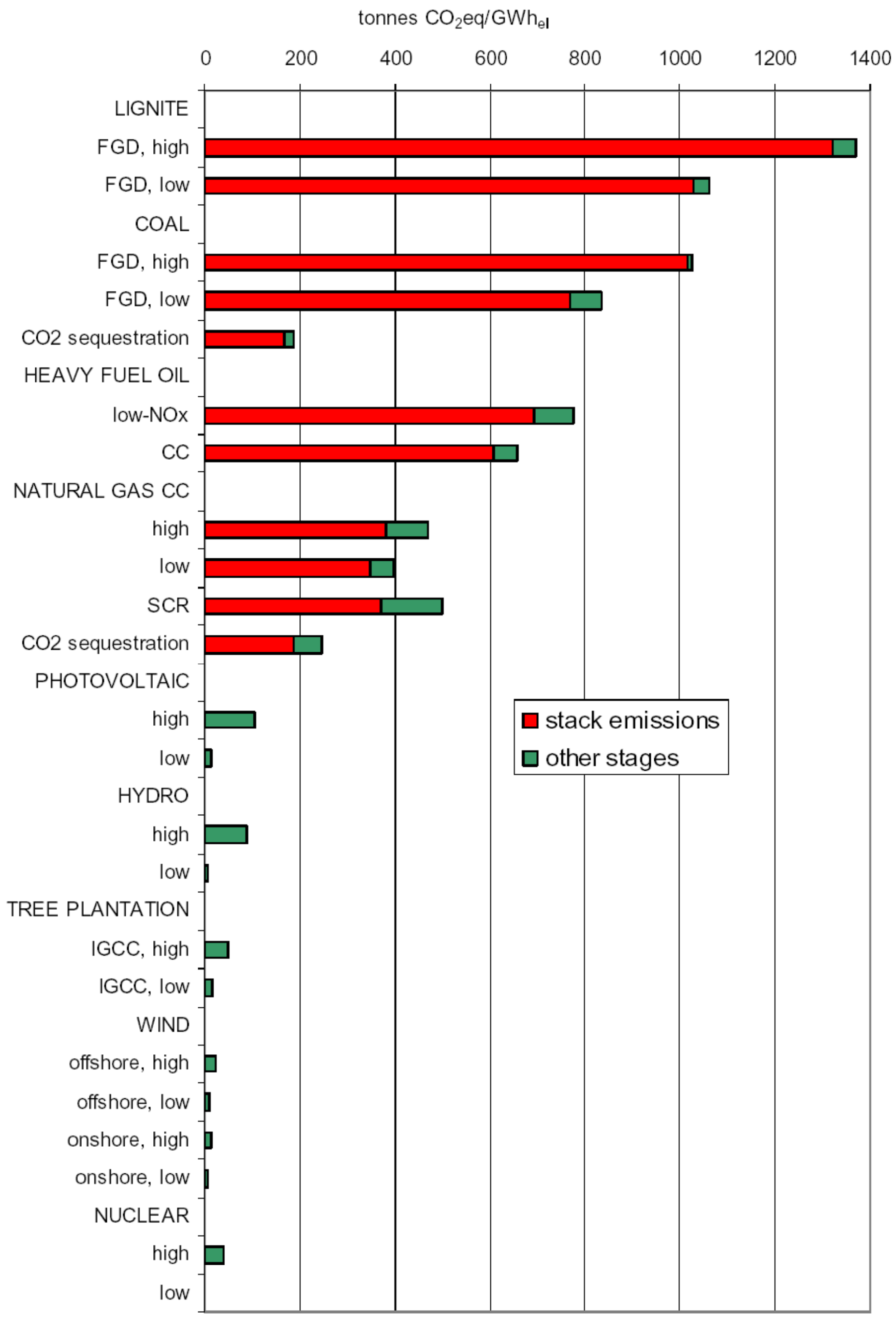
Range of Total GHG Emissions from Electricity Production Chains in gCeq/kWh: (to be multiplied by 44/12 to get gCO2eq/kWh)

Energy/Technology	Plant emissions	Other Chain Steps	Total
LIGNITE			
1990s Technology (high)	359	7	366
1990s Technology (low)	247	14	261
2005-2020 Technology	217	11	228
COAL			
1990s Technology (high)	278	79	357
1990s Technology (low)	216	48	264
2005-2020 Technology	181	25	206
OIL			
1990s Technology (high)	215	31	246
1990s Technology (low)	195	24	219
2005-2020 Technology	121	28	149
NATURAL GAS			
1990s Technology (high)	157	31	188
1990s Technology (low)	99	21	120
2005-2020 Technology	90	16	105
SOLAR PV			
1990s Technology (high)	0	76.4	76.4
1990s Technology (low)	0	27.3	27.3
2005-2020 Technology	0	8.2	8.2
HYDROELECTRIC			
Reservoir (Brazil, theoretical)	0	64.6	64.6
Reservoir (Germany, high value)	0	6.3	6.3
Reservoir (Canada)	0	4.4	4.4
Run-of-river reservoir (Swiss)	0	1.1	1.1
BIOMASS			
high	0	16.6	16.6
Low	0	8.4	8.4
WIND			
25% capacity (Japan)	0	13.1	13.1
<10% capacity, inland (Swiss)	0	9.8	9.8
10% capacity, inland (Belgium)	0	7.6	7.6
35% capacity, coastal (Belgium)	0	2.2	2.2
30% capacity, coastal (UK)	0	2.5	2.5
NUCLEAR[6]			
High	0	5.7	5.7
Low	0	2.5	2.5

[6] Factors Influencing GHG emission rates from LWR nuclear power [15]:
- Energy use for fuel extraction, conversion, enrichment, construction and decommissioning (plus materials);
- Fuel enrichment by gas diffusion, which is an energy intensive process that can increase GHG releases by an order of magnitude when compared to enrichment by centrifuge;
- Emissions from the enrichment step, which are highly country-specific since they depend on the local fuel mix; and
- Fuel reprocessing (uranium oxide or mixed oxide), which can account for 10% to 15% of the total nuclear GHG burden.

<u>The 3rd example</u> is taken from a World Energy Council study [30]:

Greenhouse gases emissions from alternative electricity production systems (tones of CO^2 equivalent per GWh of electricity generated)



Source: World Energy Council, 2004 [30].

The main relative contribution to the – very small – GHG emissions from the use of nuclear power originates from the upstream phase, followed by the construction/operation/decommissioning phase and the waste management phase, as demonstrated in the following **4th example** of this chapter, provided by the Ecoinvent Database, [31].

Greenhouse Gas Emissions from the Nuclear Fuel Cycle

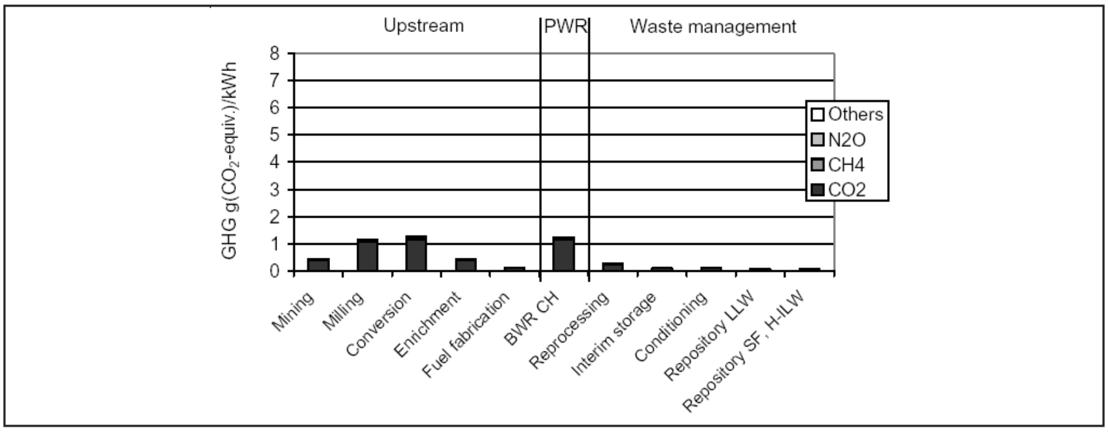


Fig. 3: Contributions of single species to total GHG emission per kWh from single steps in the nuclear fuel cycle of the Swiss PWR

Source: The ecoinvent database, 2004, [31].

Sortir du Nucléaire proposes alternative studies, e.g. from Öko-Institut Freiburg, which mention CO2 emissions up to one order of magnitude higher than the one from the Ecoinvent database: 30-60 g CO2 per kWh. Due to seasonal peak demands “which nuclear power cannot meet, being restricted to baseload electricity supply…”, the electricity needed for backup is then coming “mostly from old coal-fired plant(s) with a catastrophic greenhouse gas balance”. The general issue of adjustment between generation means and load variations will be reexamined in the second part “Opportunities and Threats” since it is related to possible future evolutions of electricity supply systems.

The **5th example** of this chapter is taken from a report on the economic, environmental and security of supply impact of a project of adding up to 11,000 MWe from NPPs to the Spanish electricity market, so as to keep at 30% the rate of electricity production from nuclear in the period 2019-2030 [40]: The report identifies the savings in CO_2 emissions due to the new nuclear capacity added to the system and calculates the real CO_2 emission cost for different prices of CO_2 emission rights and in two different scenarios: replacement of coal plants or replacement of CCGT plants. The total savings over the period range from 3,400 million € to 21,000 million € depending on CO2 emission rights (25, 50, or 75 Euro/t).

CO_2 Emissions Costs avoided by the Use of Nuclear Power in Spain, considered as replacing CCGT gas plants or coal plants (Million Euros per year)

Coste evitado (millones euros/año)	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Suma del periodo	Valor en euros 2008 del flujo de ahorros
Sustituyendo Ciclo combinado de gas Precios del derecho														
25 euros	146,30	292,60	292,60	292,60	292,60	292,60	585,20	585,20	585,20	585,20	585,20	804,65	5.339,95	3.446,34
50 euros	292,60	585,20	585,20	585,20	585,20	585,20	1.170,40	1.170,40	1.170,4	1.170,40	1.170,40	1.609,30	10.679,90	6.892,68
75 euros	438,90	877,80	877,80	877,80	877,80	877,80	1.755,60	1.755,60	1.755,60	1.755,60	1.755,60	2.413,95	16.019,85	10.339,02
Sustituyendo Carbón Precios del derecho														
25 euros	298,30	596,60	596,60	596,60	596,60	596,60	1.193,20	1.193,20	1.193,20	1.193,20	1.193,20	1.640,65	10.887,95	7.026,96
50 euros	596,60	1.193,20	1.193,20	1.193,20	1.193,20	1.193,20	2.386,40	2.386,40	2.386,40	2.386,40	2.386,40	3.281,30	21.775,90	14053,91
75 euros	894,90	1.789,80	1.789,80	1.789,80	1.789,80	1.789,80	3.579,60	3.579,60	3.579,60	3.579,60	3.579,60	4.921,95	32.663,85	21.080,87

Tasa de descuento 2,5% anual
Fuente: elaboración propia.

Source: FORO NUCLEAR – SEOPAN – TECNIBERIA, 2007, [40].

The examples shown demonstrate that there is some variation in the LCA-based GHG emissions obtained for nuclear energy as well as for other energy technologies. The results are dependent on the definition of reference technologies in terms of their performance, on the associated fuel cycles, on background processes, on climatic conditions, and of course on the quality and level of detail of the analysis. For comparative results and their background we refer to (Dones et al., 2005).

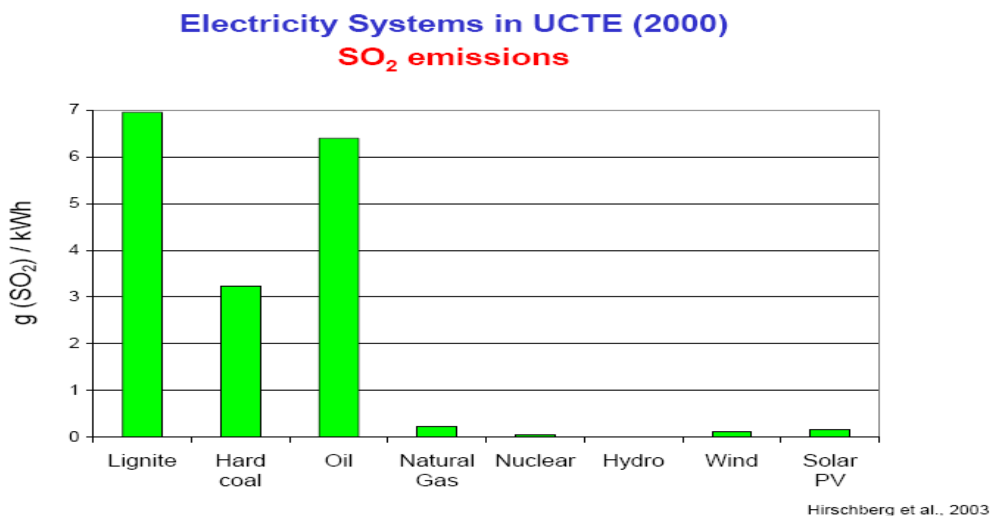
For example, as elaborated in:
(http://gabe.web.psi.ch/pdfs/Beitrag_zur_CH_Energiedebatte.pdf)
"a decisive factor for the total emissions from the nuclear energy chain is how the uranium enrichment process is implemented. In the case of most West European countries the enrichment either takes place using centrifuges that are characterized of low energy intensity and/or the diffusion process in the French facility Eurodif where the electric input originates from the nuclear power plant Tricastin. Other emission values may reflect various conditions resulting in a relatively large interval. Under quite extreme conditions the GHG emissions for nuclear can reach values of the order of 5% of emissions from the coal chain and thus reach a level similar to modern solar PV operating in countries in central Europe. This may be the case for example when diffusion is exclusively used for enrichment and the energy input is provided fully by coal power plants as in the old US enrichment facility Paducah, Uranium extraction gives today small contributions to GHG emissions but its impact can possibly increase in the future if the concentrations would decrease by orders of magnitude".

In summary, most of the available examples suggest a totally superior GHG emissions performance of nuclear, hydro and to a slightly lesser extent - wind power plants as compared to fossil energy technologies, and substantially better than biomass and solar photovoltaics.

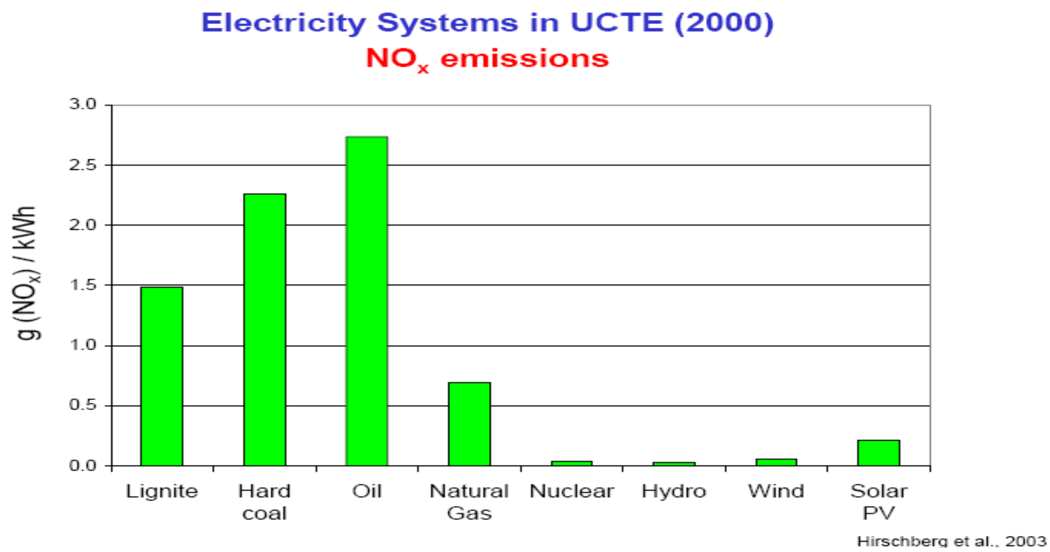
The numbers given for nuclear at a level of about 5 to 10 tons of CO_2 eg, per GWh are varying due to key factors such as reference plant technology, front end – in particular – enrichment, and fuel reprocessing: the spread of values given by IAEA (2000) are taken for illustration. The high numbers given by “sortir du nucléaire” (30-60) can be explained by the assumption that old coal-fired stations serve as back-ups for peak demand. The numbers given for coal are higher by about two orders of magnitude and vary from more than 750 to 1000; compared to coal the numbers for gas are less by a factor of at least 2. Both fossil energy technologies show a high reduction potential, if carbon capture & storage (CCS) were implemented. The numbers for hydro and wind are as favourable as for nuclear, if major advancements in wind technology are assumed. PV emissions exceed nuclear by about a factor of ten, also subject for reduction due to technology developments/economic breakthrough.

4.2. Regional environmental impact

Regional environmental impact from the use of different power generation technologies is mainly connected to emissions harmful to the environment in addition to GHG emissions. For example, the two charts hereafter show the emissions of SO_2 and NOX to the atmosphere generated by different power generation technologies in 2000 in Europe. They are extracted from a study of Paul Scherrer Institut (PSI, Hirschberg et al., 2004) for UCTE (Union for the Coordination of Transmission of Electricity) gathering continental European transmission system operators).



Source:[72].



Source:[72].

More widely, the regional environmental impacts induced by released pollutants include:

- Acidification – pollution cause by airborne deposition of sulphur
- Eutrophication – pollution of ecosystems caused by nitrogen compounds
- Ecotoxicity – impact of chemicals on environment and living organisms
- Ionising radiation - naturally (e.g. from decay of natural radioactive substances such as radon gas and its decay products) and artificially (nuclear power).

More comprehensive data can be found in the publications by PSI (see references to reports in http://gabe.web.psi.ch/research/lca/).

4.3. Non-pollutant effects (land use)

Land use (in m^2/GWh) refers to surfaces transformed from the original into different state as a result of human activities in the energy chains.

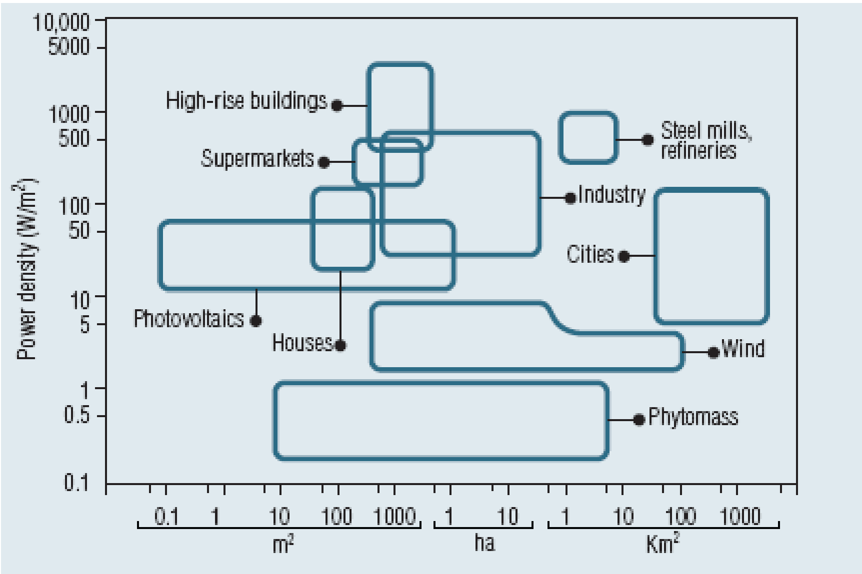
The extent of land covered by the power plant and the infrastructure necessary to sustain its operation across lifecycle is an important indicator for the "consumption of the environment" by a certain energy technology.

In contrast to pre-industrialisation's agricultural societies, land requirements as factors of production and thus as critical natural resources have been ignored for a long time in the energy intensive societies of the mid and late 20th century.

4.3.1. Power Densities in Generation

A revealing way to illustrate land requirements of modern energy generation and use is to compare the power densities of energy conversion that rely on *renewables* and those that rely on *fossil fuels*: As can be seen from the following figure, in no case do average power generation densities of *renewable* conversions (examples: photovoltaics, phytomass, wind) surpass 10^2 W/m^2 (solar heat collectors come close to that value in sunny locations).

Comparison of power densities of energy consumption and energy generation by renewables



Source: OECD, 2006, [54]

In contrast, thanks to the lengthy periods of their formation, fossil fuel deposits are an extraordinarily concentrated source of high-quality energy. Extraction of fossil fuels produces coals, crude oils and natural gases with power densities ranging mostly between 103-104 W/m^2. Thus, comparatively small land areas are needed to supply huge energy flows.

Nuclear is even several orders of magnitude more "compact" in its power density: PWRs fission in their reactor core the enriched uranium with densities of ~100 MW/m^2 (108 W/m^2).

4.3.2. Power Densities in Consumption

With today's conversion and efficiency technologies, the electricity supply chain works by producing (fossil fired) power with densities that are 1-3 orders of magnitude higher than the common power densities with which houses, industrial installations, energy intensive industries and entire cities use energies. Typical consumption power densities range mostly between 20 and 100 W/m^2 for houses and low energy intensity manufacturing industries (see above figure).

In a fully solar-based society based upon today's civil and industrial infrastructures, we would harness various renewable energies with at best the same power densities with which they would be used in our buildings and factories. Consequently, in order to supply a house with electricity, PV cells would have to cover the entire roof. A supermarket would require a PV field roughly 10 times larger than its own roof, or 1000 times larger in the case of a high-rise building. In other words, a transition to renewable energy would greatly increase the fixed land requirements of energy production and would also necessitate more extensive rights-of-way for transmission.

Sortir du Nucléaire contests "the argument that a huge PV surface would be necessary to supply a house with energy … (as) the idea is not to meet energy demand with one source, but to provide energy services with the help of relevant technologies including energy efficiency."

4.3.3. Land Requirements for Different Generation Technologies

The mentioned high power densities of fossil and nuclear fuels enable relatively small power plant areas of some several km^2. In contrast, the low energy densities of renewables, measured by land requirements per unit of electricity produced, is demonstrated by the resulting large land areas required for, say, a 1000 MWe generation technology with values determined by local requirements and climate conditions (solar and wind availability factors ranging from 20-40%), [55]:

- Fossil and nuclear sites: 1-4 km^2 (corresponding to: 250-1000 W/m^2)
- Solar thermal or PV parks: 20-50 km^2 (= a small city) (corresponding to: 20-50 W/m^2)
- Wind fields: 50-150 km^2 (corresponding to: 7-20 W/m^2)
- Biomass plantations: 4000-6000 km^2 (= a province) (corresponding to: 0,2-0,25 W/m^2)

For solar, wind and biomass, the corresponding power density values as estimated by the IAEA in 1997 (i.e. the values put in the above brackets) correspond to the 2006 OECD values in the above figure.

For nuclear, the power density value of ~108 W/m^2 mentioned before would – for a 1000 MWe NPP – translate into an area of 10 m^2 for "the core". Together with nuclear and conventional islands, on-site storage of spent fuel and radioactive wastes, and the entire fenced plant sites, this could typically add up to the 1-4 km^2 mentioned by the IAEA in 1997.

However, it is necessary to consider also the requirement of low population zones around a NPP, i.e. risk and emergency type of zones. Here, differences in national legislation, can result in relevant differences in estimates on required land: A 2001 comparison between energy, material and land requirements between a nuclear fission and fusion plant [56] results in a value of ~200 m^2/MW (or: 0,0002 km^2/MW) for a "typical" European fission plant7, as compared to the 1997 IAEA values of 1-4 km^2 per 1000 MWe, or 1000-4000 m^2/MW.

Additional uncertainty is introduced as regards the ultimate claim of land for long-term depositories of radioactive wastes. Although final depositories will mostly be located in uninhabited and difficult-to-access regions, even in such cases there may be land use conflicts. The World Nuclear Association estimated in 2002 that the total land requirement for 1000 MW nuclear capacity is 1-10 km2 across the entire lifecycle, i.e. including mining and the fuel cycle [57] (corresponding to 100-1000 W/m^2 i.e. in very good correspondence to the 1997 IAEA values).

Sortir du Nucléaire adds that "in case of an accident in a NPP entire regions could be contaminated and wasted … what would not happen with sun or wind energy".

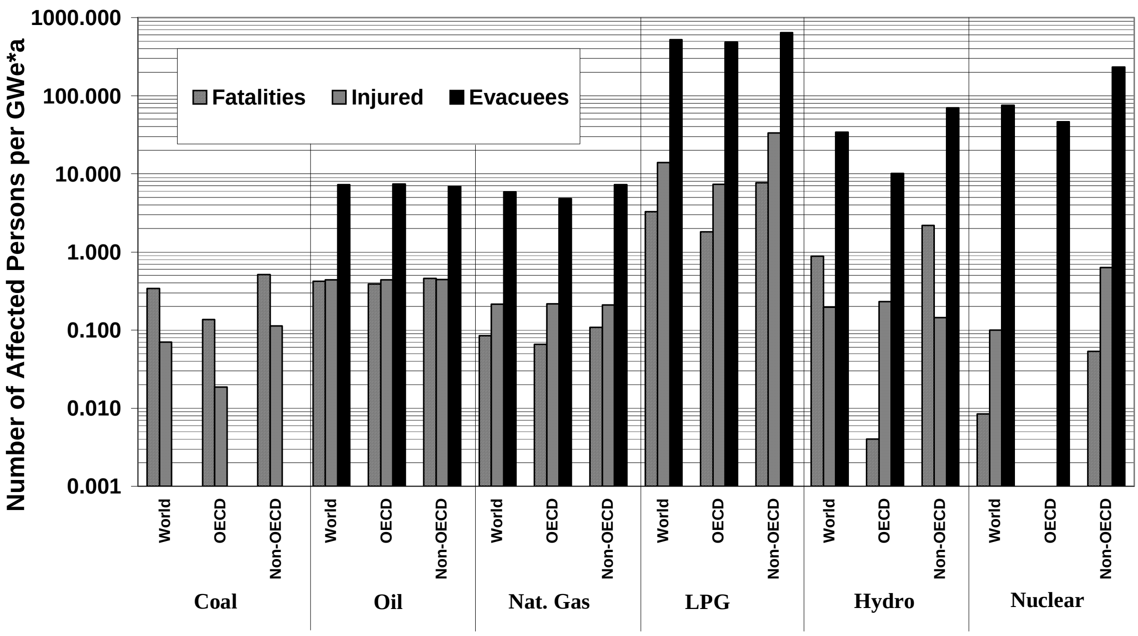
New infrastructures for power production should fit as much as possible within the footprint of the old infrastructures, where they exist, leaving land as much as possible for nature. The consumption of land for the development of new generation capacities is an important criterion to judge the environmental dimension of the sustainability of a particular energy technology. As an example, replacing a typical 1000 MWe nuclear power plant with renewables would require more than 2500 km^2 of prime land for the biomass option and 770 km^2 for the wind farm option [33].

[7] The fusion plant would have a land requirement of ~300 m^2/MW.

4.4. Severe accidents

The “classical” indicator regarding actual or potential damage from technologies is their fatal impact on human beings (measured in fatalities/GWh) the following figure shows the set of results obtained from the PSI’s GaBE project in terms of severe accident indicators (immediate fatalities, injured and evacuated persons) for different energy sources covering full energy chains (i.e. across lifecycle) [34]. These fatality rates summarise accidents data from the period 1969-96 and distinguish between the results obtained for OECD and non-OECD countries. For the normalisation of the results, the total energy produced by each energy source is used together with an allocation procedure considering trade-based flows of energy sources between non-OECD and OECD countries[8]:

Comparison of energy-related human impact damage rates covering full energy chains



Source: Paul Scherrer Institute, 2004 [34].

As can be seen from this figure on the world-wide basis as well as for OECD countries only, immediate fatality rates are much higher for the fossil fuels than what one would expect if only operation of power plants were considered. For OECD countries, the highest rates apply to liquefied petroleum gas (LPG), followed by oil, hydro, natural gas, coal and nuclear. In the case of nuclear, the estimated delayed (normalised) fatality rate solely associated with the only severe nuclear accident (Chernobyl, i.e. in a non-OECD country), clearly exceeds all the above mentioned immediate fatality rates.

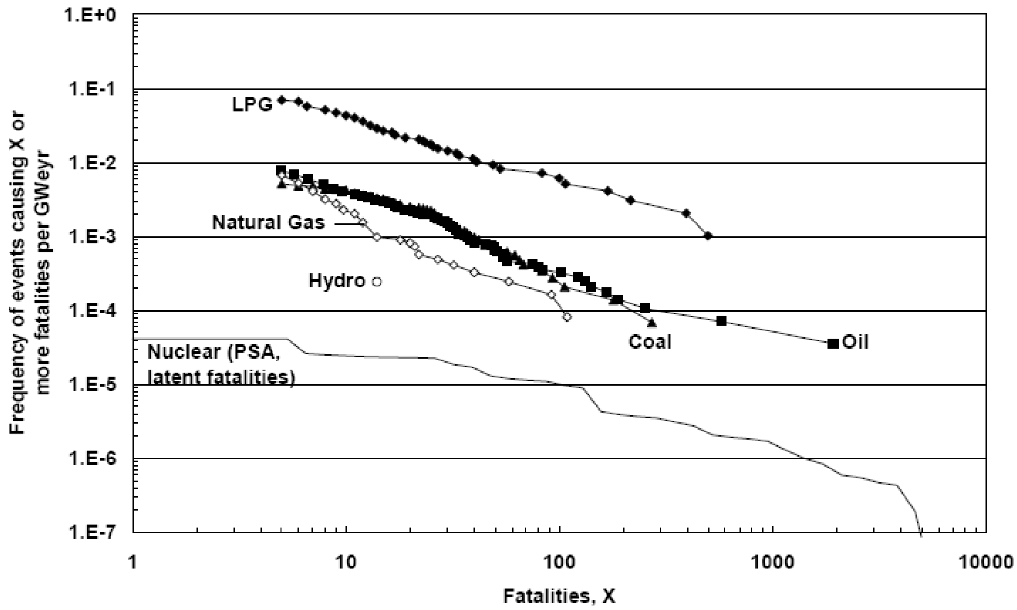
[8] OECD countries are net importers of some of these energy sources and the majority of accidents occur within the upstream stages of these chains. The reallocation to OECD countries of the appropriate shares of accidents that physically occurred in non-OECD countries leads to smaller differences between the corresponding damage rates for these two groups of countries as compared to straight-forward evaluation. The effect is of course particularly significant in the case of oil.

Generally, the immediate fatality rates are for all considered energy sources significantly higher for non-OECD than for OECD countries. In the case of hydro (mostly China), coal (mostly China) and nuclear (Soviet Union) the difference is dramatic. The recent experience with hydro in OECD countries points to very low fatality rates, comparable to the typical Probabilistic Safety Assessment (PSA) results obtained for a Western nuclear power plant [34].

Accounting for delayed fatalities along with the immediate ones preserves this ranking when OECD countries are considered but - as mentioned - due to the Chernobyl accident nuclear compares unfavourably to the other chains when the experience base is considered for non-OECD countries only.

To describe the societal aspect of risk related to the use of the different energy sources in OECD countries only, the next figure shows the overall frequency-consequence curves for full energy chains with partial reallocation for the period 1969-2000, as resulting from the EU-funded ExternE project [35]. The curves for coal, oil, natural gas, LPG and hydro are based on historical accidents and show immediate fatalities. Among the fossil chains natural gas has the lowest frequency of severe accidents involving fatalities. Apart from LPG, coal and oil exhibit the highest frequencies of accidents up to the level of several hundred or, in the case of oil, even more than thousand fatalities, while hydro has the lowest. For the nuclear chain, due – fortunately – to the lack of historical severe accidents in OECD countries, the result derived from the plant-specific probabilistic safety assessment (PSA) for a Swiss nuclear power plant is used here as a representative example for a “Western nuclear power plant” in a conservative way (i.e. latent fatalities):

Frequency-consequence curves for severe accidents in various energy chains in OECD countries (immediate fatalities for non-nuclear, latent fatalities for nuclear)



Source: ExternE [35].

In summary, the results of the 2nd figure reflect pretty much the ranking from the 1st figure, but provide also additional information such as the observed or predicted chain-specific maximum extents of damages. This perspective on severe accidents may lead to different rankings of energy options when developing sustainable energy mixes, depending on the individual (subjective) risk aversion.

Although there are significant differences between the aggregated, normalised damage rates assessed for the various energy sources, one should keep in mind that from the absolute point of view severe accident fatality rates for fossil sources are small when compared to fatality rates for fossil sources associated with the health impacts of normal operation (see Chapter 5.3).

It should be noted that avoiding accidents and promoting the higher level of safety culture is an absolute priority of the EU and for the nuclear industry. The recently adopted nuclear safety directive requires that all member states have a legislative regime on nuclear safety in place and that the national nuclear safety authority is independent and has sufficiently resources to perform its duties.

Nuclear safety is based on more than 11000 reactor-years of globally accumulated operating experience (over 4600 reactor-years in Europe). Long-term experience and extensive research and development programmes have had a significant impact, improving plant performance and availability and enhancing safety. Nuclear power plants in Europe have achieved excellent operational records.

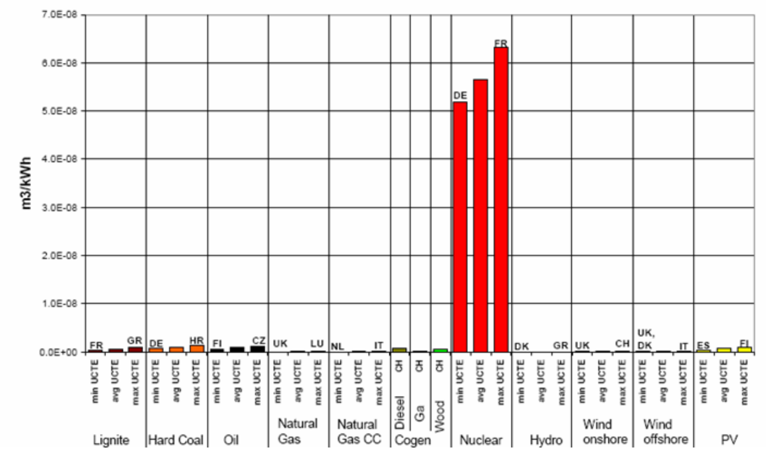
The specific nature of nuclear risk (very low probability and very high potential consequences) has made it imperative to find another system than classical assurances to cover the liability. International Conventions (Vienna, Paris) have been set up and adopted to define responsibilities and ways of recourse in a coordinated fashion among the nuclear countries.

4.5. Total waste

This chapter deals with the production of non-radioactive and radioactive waste tons/GWh by each of the different power generation technologies.

The 1st example of this chapter is taken from PSI's LCA work and shows the total amount of radioactive waste in m^3/kWh produced across lifecycle by nuclear, fossil and renewables:

Radioactive waste produced by nuclear, fossil and renewables

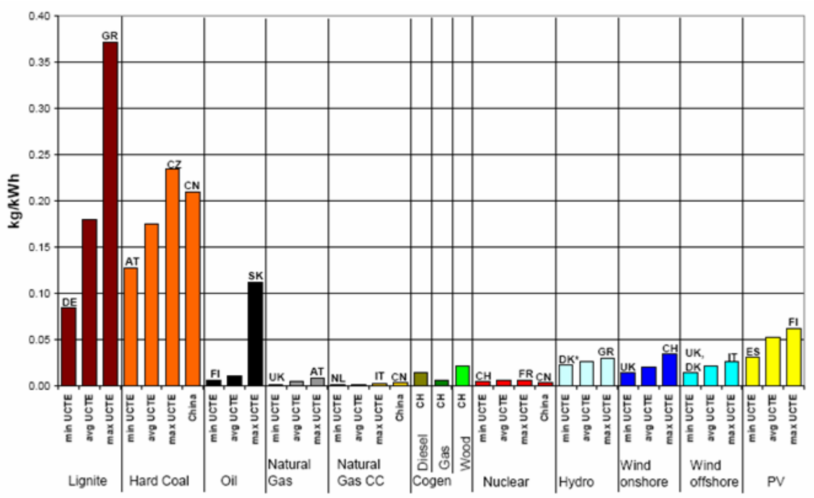


Source: Paul Scherrer Institut, [16; see also 13].

Of course, the nuclear contribution is by far dominating, but the radioactive waste produced by hard coal, lignite, oil and photovoltaics cannot be ignored.

The 2nd example is from the same source as the 1st one and concerns non-radioactive toxic waste:

Non-radioactive toxic waste produced by nuclear, fossil and renewables



Source: Paul Scherrer Institute, [16; see also 13].

As can be seen from the figure, for non-radioactive toxic waste, nuclear performs best together with natural gas. Particularly the fossil technologies, but also the renewables show worse performance.

However, as Sortir du Nucléaire points out, it is not sufficient to compare radioactive and non-radioactive waste in terms of volume: what matters is also their lifetime and their level of radiotoxicity. These aspects will be addressed in Chapter 5.4 and in much more detail in ENEF WG Risks.

The 3rd example originates from a 2001 Eurelectric report on “Nuclear Power Plants' Radwaste in Perspective” which stated that according to a survey made by the European Commission the annual production of all conditioned radioactive waste in the EU is ~50,000 m^3. This represents an annual amount <200 ml (or 0.0002 m^3) per inhabitant or ~15 l for one person's average lifetime. This includes all types and levels of radioactive waste (of which high level waste is <1%). These quantities should be kept in perspective. It is estimated that approximately 2,700 million m^3 (2,000 million tones) of other wastes are produced in the EU every year, close to 5.3 m^3 (4 tones) per inhabitant. Around 46 million m^3 (35 million tones) of this is hazardous waste - 0.056 m^3 (80 kg) per inhabitant. These include pesticide residues, heavy metals, asbestos and contaminated hospital wastes.

The 4th example is a comparison between the annual volume of waste generated from operating a coal fired plant and a Light Water Reactor plant, 1000 MW each:

- the NPP generates ~60 m^3 /year high-level radioactive waste which has to be stored underground for indefinite time;
- The coal-fired plant generates ~5.700.000 m^3 /year liquefied CO_2 which – via CCS – has to be stored underground for indefinite time (i.e. almost 100.000 times the volume from the NPP). Further, to illustrate the potential adverse effects of massive CO_2 leakages and related risk management needs, a corresponding volcano-induced event in Cameroon in 1986 shall be recalled, killing more than 1500 people in the surroundings [39].

In summary, although the volume of wastes is an important indicator for sustainability, it only covers one dimension of the problem, i.e. an indication how waste-intensive the different energy chains are.

For a fuller picture of the sustainability of energy technologies, the waste influence on ecosystems can be addressed through other indicators such as toxicity (over time) (see Chapter 5.4) and land use (see Chapter 4.3). The results of such analyses show very low impacts of radioactive wastes based on the assumption that the waste management concept with its barriers works as intended over a very long period of time. Similarly strict safety requirements for waste disposal barriers need to be implemented for CCS from the use of fossil fired plants.

To also address the social dimension of sustainability and avoid highly subjective indicators such as “social acceptance”, a complementary indicator on "the necessary confinement time for critical waste" can be used (see Chapter 5.4).

4.6. Aggregation of environmental effects

Environmental impacts involve different factors:

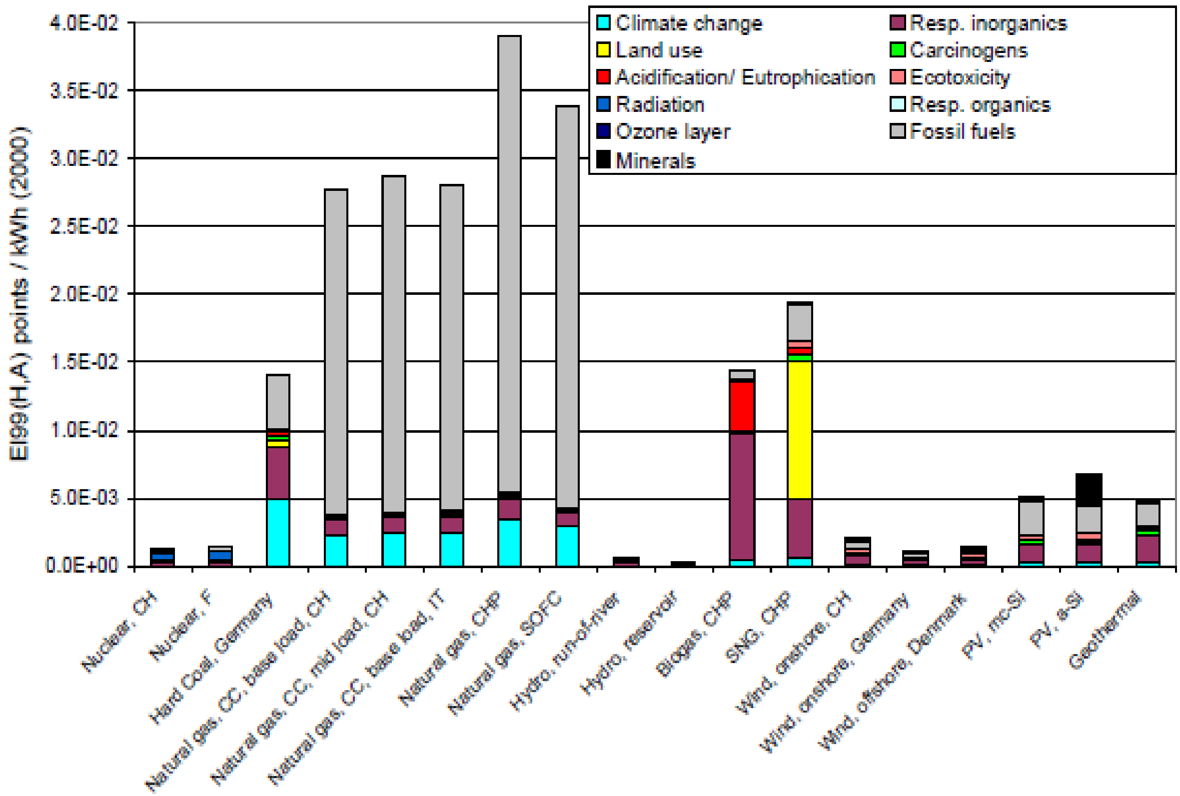
- resources consumption and releases to the environment;
- quite different damaging effects of the released pollutants on the ecosystems and population health.

An overall performance assessment of a power supply chain is difficult to derive, since it will depend on the weight attributed to each factor of environmental impact. However, some attempts have been made with aggregated eco-indicators.

The following example from a PSI study [Bauer et al., 2007] compares current electricity systems across their respective lifecycles in terms of environmental impact with the method of “Ecoindicator 99” which covers the following aspects:

- resources consumption (land use, but also fossil fuels and minerals consumption such as mentioned in chapter 3.2.4 of this report)
- human health (radiation, ozone layer, respiratory organics, carcinogens)
- ecosystem quality (climate change, acidification/eutrophication, ecotoxicity

Life Cycle Impact Assessment results for reference technologies in year 2000, using Ecoindicator 99 (H,A)



Source: Paul Scherrer Institute, [Bauer et al., 2007].

Nuclear follows hydro as top performer based on Eco-indicator 99 (H, A). Fossil systems score worst and biomass shows worse performance than other renewables.

Sortir du Nucléaire “contests the impact assessment given in the SWOT report” and states that “some independent studies stressed the contamination of water and soils in the neighbourhood of nuclear power plant(s), uranium mining districts and reprocessing plants”.

Further, according to Sortir du Nucléaire, “operators define legal radiation level themselves and therefore allow themselves to pollute as much as needed, with no regards to environmental impacts … Nuclear industry also involves other effects which ought to be taken into account better, like for example rejects of warmer water in the rivers. This has very important impact on aquatic fauna, particularly on fishes.”

It should be noted that the Euratom treaty gives Basic Safety Standards for nuclear facilities and for the radiation protection. The nuclear industry is one of the strictly regulated and controlled industries, with regulatory bodies operating nationally and enforcing regulations that follow internationally agreed IAEA standards. International co-operation has played a major role in setting these standards. National radiation protection legislations give radiation limits, and the operators are voluntarily committed to go much below the legal limits. Also the radiation levels are continuously monitored both among the operational personnel and the surrounding environment.

In summary, integrating aspects of emissions to the atmosphere, land use and waste generation, nuclear energy compares very well with other sources of energy in normal operation. That has to be related to the characteristics of nuclear fuel and fission reaction: high energy density, no generation of SOX and NOX in the effluents. Probabilistic Safety Assessments show lower level of risks of fatalities due to nuclear power compared to historical figures for other sources of energy. In addition, new built Generation III plants, will, by design, ensure that there will be no radioactive release outside the plant fence, would a highly improbable core melt occur.

5. Social dimension

The social dimension of sustainability performance involves probably the highest degree of complexity. At least three aspects should be considered.

- Measurable social impacts of power generation facilities and related fuel cycle facilities, at local, national and regional scales. In this work, some information could be collected on employment, health impacts, local benefits and disturbances, waste confinement requirements in repository. Equity issues are raised since benefits and risks are not the same for different groups of population. The issue holds both as intragenerational (e.g. local population versus all country population) and intergenerational (long term impacts of climate change and waste repositories). Another issue is the reliability of impact assessment when measurement is not feasible.

- The end appraisal of the risks and benefits belongs to the concerned groups of population. Their perception of risks and benefits is influenced by many individual and social factors. In particular, the valuation (in monetized terms) of potential damages, named “external costs”, often depends on the observer. Risk aversion is known to vary from one individual to another, from one country to another. More widely, overall public acceptance of a technology varies according to a complex bunch of influencing factors.

- The policy making process is another important aspect in energy policy choices. Processes are more or less centralized or decentralized according to the country structure and habits, but in all cases they will determine the acceptability and effectiveness of policy choices. National authorities have to deal with different kinds of questions, such as national regulation, social equity, international treaties, etc.

In this work, it has been possible to document the first two aspects partially. To go further, contributions from the ENEF Working Groups Risks and Transparency will be helpful.

5.1. Employment (technology-specific job opportunities)

In addition to direct employment, nuclear energy has other benefits in dimensions where its direct impact is difficult to quantify, but is significant (e.g. construction sector, supply industries, mining, research, academia, medical applications). Further, nuclear power plants produce electricity at stable and predictable costs which is crucial for the economy in a general sense.

The example of a 2007 Spanish study [40] shows aggregated economic effects of the use of nuclear in Spain (>23,000 million €), which is more than 3% of the Spanish GDP at 2004 levels. 54% correspond to direct effects whereas 46% correspond to multiplying effects or interactions between the different sectors. In terms of impact on employment, the study concludes that the generated yearly employment flow over the period of concern is 145,000 employments (direct and indirect effects). When considering also the induced effects, the result is 172,000 employments.

Beneficial effects with regard to employment are of course also true for non-nuclear energy technologies, such as coal, gas and renewables. According to Sortir du Nucléaire, “a change in energy efficiency policy involving a strong development of end-use energy savings and renewables generates far more jobs.” Sortir du Nucléaire supports this argument on the basis of a 2007 publication by the German Environment Ministry which says that more than 230.000 persons are working in the field of renewable energies in Germany [62].

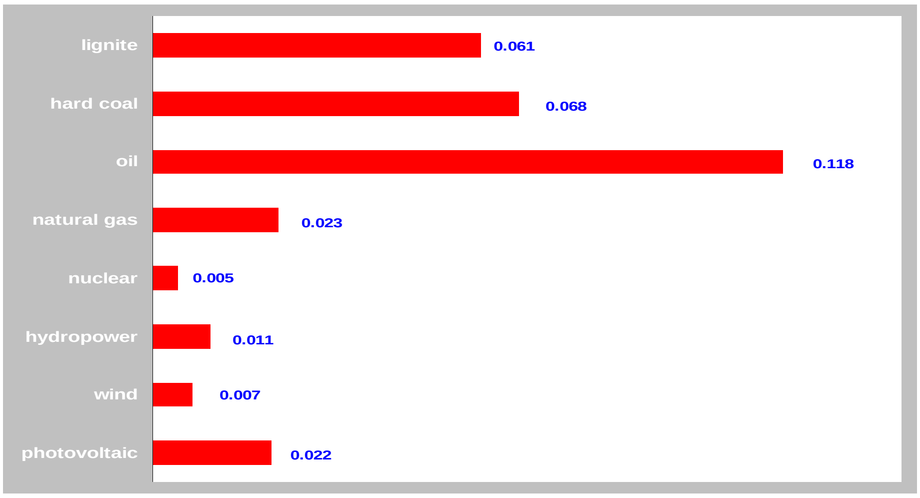
In summary, from the information provided to the Commission, no overall comparative assessment of employment effects among the different energy technologies was possible.

5.2. Human health impacts

Power generation by fossil fuels, nuclear and renewable energy technologies causes direct or indirect emissions of polluting gases and other environmental pressures across all lifecycle stages which might have important impacts on human health. Effects can occur due to operation of power plant, a statement on nuclear energy is missing and should – regarding potential health effects due to release of radioactive substances – point to the linear dose-sigh-relationship and due to up- and downstream processes such as, the production and transport of the fuels, the mining and processing of the materials to build and construct the power plant or the handling and disposal of waste products. Whereas in the case of photovoltaic, wind and hydro power effects can be attributed mainly to the installations’ construction stage, in the case of combustion processes (coal, gas, oil, wood) the health risks are resulting mainly from power plant operation (mainly SO_2 , NO_x and primary particle emissions). Health effects might impact the mortality as well as the morbidity.

The 1st example shows the loss of life expectancy due to operation for German energy chains in 2000 in terms of Years of Lost Life (YOLL) per GWh. The YOLL indicator is more accurate than simple numbers of induced premature deaths since it accounts for the age dependent life shortening induced by pollution: it will vary with the age distribution of the impacted population.

Loss of Life Expectancy due to normal operation for German energy chains in 2000 as Years of Lost Life per GWh produced

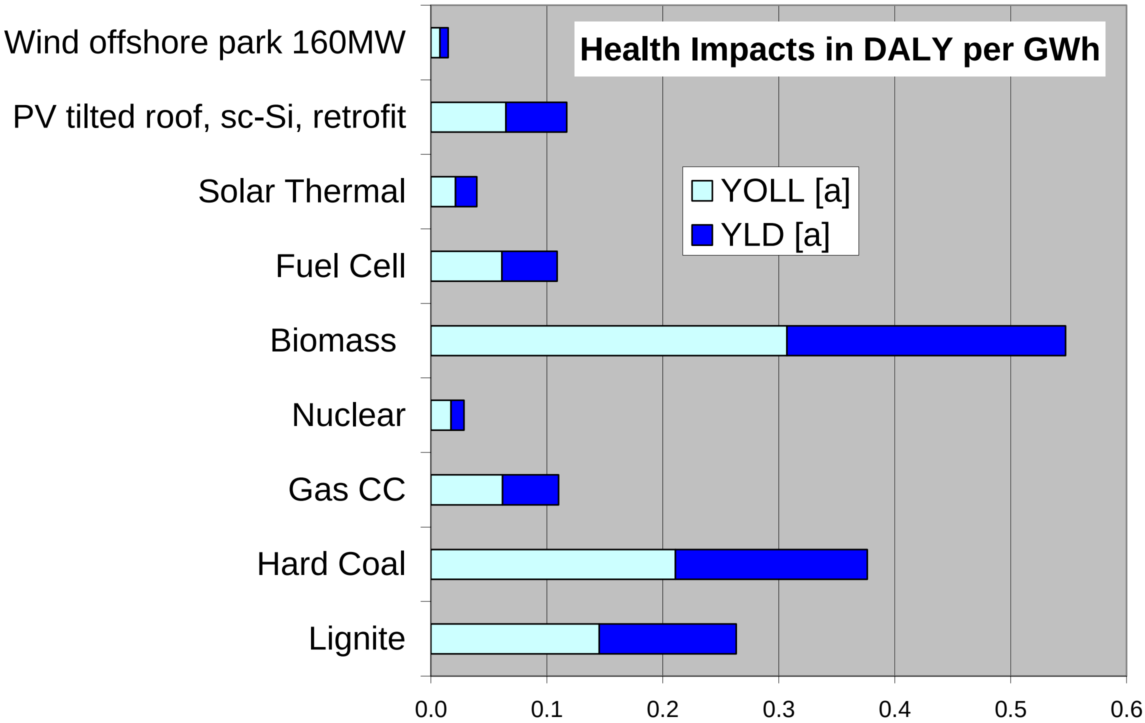


Source: OECD NEA, 2007, [13].

As can be seen from this figure, nuclear performs best, clearly vis-à-vis the fossil energy technologies, but also vis-à-vis the renewable ones.

<u>The 2nd example</u> shows the LCA-based health impacts (mortality and morbidity risks) estimated within the NEEDS project [64]. The concept of "Disability Adjusted Life Years" (DALY) is used to assess both the health impacts with regard to mortality and morbidity. The DALYs, which are expressed in "years", are the sum of years of lifetime lost (YOLL) and the years lived with disabilities (YLD). YLD is the product of duration of a disability and a corresponding disability weight (DW) [65, 66].
The electricity generation technologies represent the present state of the art. The power plants are assumed to be sited in Central Europe. However, the operation of the solar thermal plant is located in Southern Spain.

Morbidity and mortality health impacts caused by operation und up- and downstream processes of different electricity generation technologies



Source: NEEDS, 2009 [64].

The health impacts of wind (offshore), solar thermal and nuclear are on the low side, whereas the health effects of lignite, coal and biomass are on the high side. The biomass power plant (here a 30 MW plant using straw) has relatively high emissions, especially regarding NO_x, SO_2 and particulate matters during operation.

With regard to the health impacts of severe accidents and related frequencies see Chapter 4.4 of this report.

Sortir du Nucléaire has some general reservations in relation to how human health impacts during normal operation are treated in this report: “The consequences of radiation exposure mostly reveal themselves in the mid-term. It is therefore very difficult to evaluate the number of deaths related to contamination. Morbidity would be a slightly better criterion to evaluate human health impacts.” Also, Sortir du Nucléaire observes from a 2005 UK and a 2007 German study “…a strong correlation between cancer rate and the proximity of nuclear facilities.” Finally, Sortir du Nucléaire proposes that “we cannot just focus on « normal operations », given the high number of incidents and the restricted, but existing probability of a major accident. Consequences are just too enormous not to be taken into account.”

It has to be noted that the statistical significance of the correlation between cancer rate and the proximity of nuclear facilities has not been proved.

5.3. Local disturbances (noise, visual amenity)

The Subgroup has not found reliable data which would allow quantifying the local disturbance effects of different energy installations.

Conversely, local benefits are related to economic and social development (taxes e.g.) induced by the large (nuclear) facilities. No data was found to measure differential impacts between nuclear power and alternative energies.

5.4. ”Necessary” waste confinement time

The highly radioactive and toxic composition of nuclear high level waste makes it compulsory to isolate them as long as necessary from the biosphere, until the decay of radioactivity has reached a sufficient by low level. Similarly, in other industrial sectors, hazardous chemical waste has to be isolated, however for ever in theory since chemical toxicity will not decrease with time. The time length of the required confinement is part of the relevant criteria to be used in the evaluation of different energy options, since risk management over very long periods implies significant consequences in the social process to be set up. Namely, future human generations should not be exposed to unacceptable risks that would be caused by the present generation energy consumption. The safety principle is that any eventual release of radioactivity back to the environment will be at such a low level insignificant in terms of health impact compared to other radiation doses.

The evolution of radioactive content and resulting radiotoxicity along long periods can be computed from radioactivity decay laws, starting from the waste initial content. It has been done by several institutes, generally considering two cases:

- The whole spent-fuel (SNF), when direct disposal is the selected option; it contains unspent uranium, plutonium and other transuranics (“minor actinides”), fission products and activation products in the fuel metallic structure.
- The high level active waste, containing only fission products, minor actinides and activation products, when the option of spent-fuel treatment and recycling of uranium and plutonium has been preferred prior to disposal.

Hereafter are shown two examples of evolution, computed respectively by NAGRA [2004] and by CEA [2009]. The index of radiotoxicity used in each study is not exactly the same but in both cases related to the hypothetical ingestion of 100% of the inventory of contained radionuclides, e.g. following intrusion. The evolutions computed SNF are quite similar: a reduction by a factor about 80 after 10,000 years, then again by a factor 10 between 10,000 and 100,000 years. As concerns HLW, separated by spent fuel reprocessing, the main difference from SNF content is the quasi - absence of uranium and plutonium. CEA diagram shows the separate contribution of each radionuclide category in SNF. It shows that beyond 1000 years the contribution of fission products is negligible as compared to that of minor actinides. Also noteworthy is the time in the future when the radiotoxicity gets as low as that of a natural uranium ore. Recycling makes it shorter by a factor about 100.

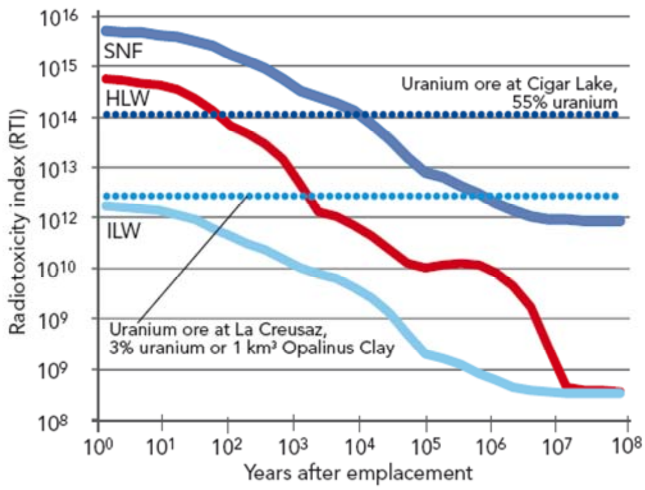
For the safety analysis of a nuclear waste repository, the additional parameter of "long term dose to the biosphere" is introduced. The purpose then is to compute the rate of release of radionuclides from the repository to the biosphere and to derive the radiological impact of such very low quantities to the neighbouring population. Several projects in several countries have been assessed, The resulting doses have been computed up to 10 million years; thanks to the efficiency of the technical (waste encapsulation, casks, repository engineering), and natural barriers (host rock), they remain very low, at most 0,1 per cent of exposure to background natural radioactivity.

Under normal evolution, no significant improvement on repository long term safety is expected from reprocessing and recycling. However, separating plutonium and minimising the radiotoxicity content would reduce the hypothetical impact in case of human intrusion into the repository. Moreover, the acceptability of waste disposal over such long periods is only partially based on scientific computations, while diverse risk perceptions and legitimate ethical concerns with respect to future generations play an important role. In that respect, the recycling option brings a long term benefit.

a) NAGRA/ Cited in NEA Nuclear Energy Outlook (2009) p249

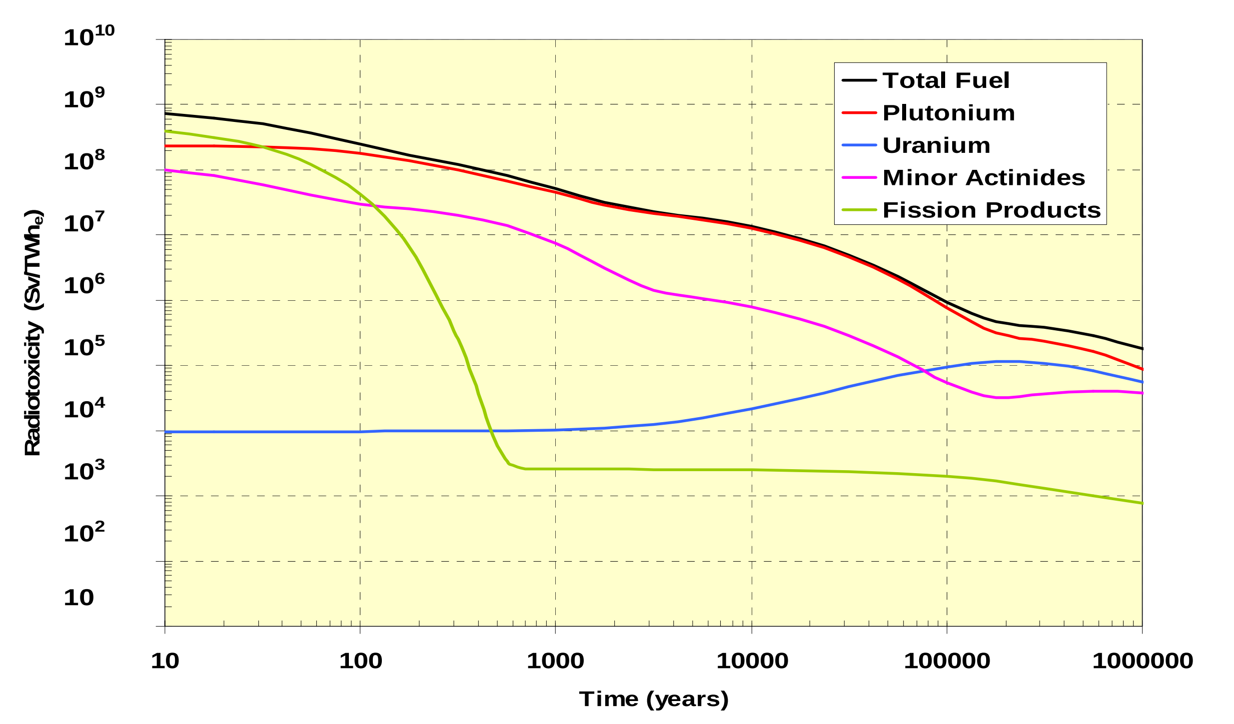
RTI: The radiotoxicity index is defined as the hypothetical dose resulting from the ingestion of radioactive material, made dimensionless by dividing it by a reference dose – in this case the 0.1 mSv derived from the annual dose limit given in the Swiss regulatory guideline.
Note: This figure shows the decrease of the radiotoxicity of typical spent nuclear fuel (SNF) and of high-level waste (HLW) and intermediate-level waste (ILW) from reprocessing, in a geological repository compared to natural uranium ore (highly concentrated and typical deposits).

Source: Nagra (2004).



Source: NEA [63].

b*) CEA Bernard Boullis, Budapest, March 18-19 (2009)*



(Ingestion Doses Coefficients from ICRP72)

Source: [75]

All EU MS generate radioactive wastes, whether or not they have a national nuclear power programme[9]. All MS therefore need to have a strategy for dealing with those wastes safely. It is then essential to take the necessary political and technical decisions and to develop a roadmap for the long term management of all types of radioactive waste, including specific routes, milestones and endpoints. The issue of public involvement deserves particular attention in this context.

While the situation for low and short-lived intermediate level waste has been industrially developed with operational repositories in 7 out of 16 MS, there is no repository for high level waste in operation. However, there is large technical agreement that deep geological disposal of high level waste is the best available solution from a safety point of view. Although there is a general “in principle” commitment by many MS to this option, probably only few member States will have deep repositories for high level waste operational by 2030 e.g. Finland, Sweden, France.

[9] Text in this subchapter taken from document “Developing a roadmap for comprehensive long term radioactive waste management in the EU”, produced by the ENEF WG Risks in 2008.

Sortir du Nucléaire states that in their view no solution to waste problems has been found.

The process of finding and/or implementing final solutions for the management and disposal of radioactive waste is very long, independently from the type of waste concerned. Geological repositories provide safe, long-term solutions and are a necessary element in the radioactive waste management programmes, irrespective of the fuel cycle solution applied. However, experience has shown that the implementation of geological repositories spans over decades.

Recent Eurobarometer surveys on radioactive waste revealed that the EU public wishes to see a solution for high level radioactive waste being implemented without further delays. On the basis of intergenerational equity, MS should take responsibilities now and not postpone decision on radioactive waste management.

There have indeed been several reasons to postpone the necessary decisions to develop and implement geological disposal, such as the possibility for multinational solutions and pending decisions regarding fuel cycle options. However, the possibility of multinational solutions, in particular for minimising waste management costs, should not be used as an argument to postpone a decision or to establish a wait-and-see approach. Instead, as already mentioned, each Member State should actively develop solutions on its own territory. Despite the choice of the fuel cycle (closed or open) and potential future development (e.g. partitioning and transmutation) there will always be waste that needs to be disposed of. Consequently, there is no reason for postponing the decision to develop geological disposal.

In summary, “necessary“ confinement times serve as a social indicator to address the burden placed on the current and future generations to carefully isolate hazardous (toxic, particularly radiotoxic) waste from the biosphere. Although not limited to the use of nuclear energy the requirements for nuclear radioactive waste are challenging given the high confinement times. It is noteworthy that these times relate to the inventory of radiotoxic material. It is noteworthy that these times relate to the inventory of radiotoxic material. The technical feasibility has been demonstrated by various national waste management research programmes and progress is being made towards deep geological repositories operational by 2030 in some Member States. The opponents state that the waste problems are still unresolved. Implementing effective solutions, as started in Finland, Sweden and France, is therefore important and will impact public acceptance for nuclear power, as showed by the Eurobarometer.

5.5. Proliferation

Proliferation concerns are a specific problematic characteristic for the nuclear fuel cycle. It is, however, important to note that proliferation resistance and physical protection of nuclear facilities and materials are key priorities for the nuclear industry and are subject to international scrutiny via International Atomic Energy Agency (IAEA) safeguards system and the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). This report does not analyse the proliferation risks, as this issue is within the mandate of the ENEF Working Group on Risks. Sortir du Nucléaire would, however, “like to emphasize how easy it is, in their view “ to make “weapon grade” materials out of «

reactor grade » fuel ; that only 5 kg plutonium are needed to make a bomb, and that France still keeps more than 5 tons of military plutonium in La Hague…"

Another issue is the risk that non-state actors use radioactive materials for a dirty bomb (classical explosive used to disperse radioactive material). This goes beyond the issue of nuclear material used in nuclear power plants and fuel cycle, since any radioactive material could be used for this purpose, in particular sources used in industry and the medical sector.

5.6. Risk aversion

As shown in chapter 4.4 on severe accidents, nuclear accidents are in the category of risks with extremely low frequency and very serious possible consequences[10].

In the field of risk assessment the product of accident probability by accident consequences is generally used as the key indicator to rank different sources of risk. But it has been observed that risk perception does not follow the same law: for the same product value, the category of extremely low probability with very serious consequences will be perceived and rated as "more dangerous". This raises the question of "risk aversion", which has to be quantified by specific enquiries.

For that reason, the latest designs of reactors include protections to minimise the consequences of worst accidents. Although developments in reactor technology have minimised the risk with the adoption of numerous control measures, in theory the risk of core melt can never entirely be excluded with Generation-II and -III reactors. Passive safety systems, such as core catchers, already used in the Gen-III EPRs currently being built in Finland and France, ensure that radioactive leakage from the core is contained even in the highly unlikely event of core melt. Future "inherently-safe" reactors of Generation-IV could eliminate this risk entirely. For example, the European VHTR Raphael Project would guarantee that even in the event of a blockage in the cooling system, there would be a gradual thermic progression towards a steady state in which heat dissipation would offset energy production, whereas with current reactors rapid intervention is needed to halt the increase in core temperature, [53].

5.7. Public acceptance

In most EU member states, the operation of nuclear facilities is controversial to varying degrees. However, with time, the public expectations for nuclear power change, as does the general industrial and social environment.

According to the 2008 *Eurobarometer* survey, there are now as many EU citizens (44%) in favour of nuclear as there are against it (45%) and public acceptance has improved in 18 out of 27 EU countries. Radioactive waste remains a major concern, but if those against nuclear felt the issue of radioactive waste management were solved, a majority of EU citizens would be favourable to nuclear (61%). That compares to 57% in the 2005 *Eurobarometer*

[10] Again, this aspect is also treated by the ENEF Working Group Risks.

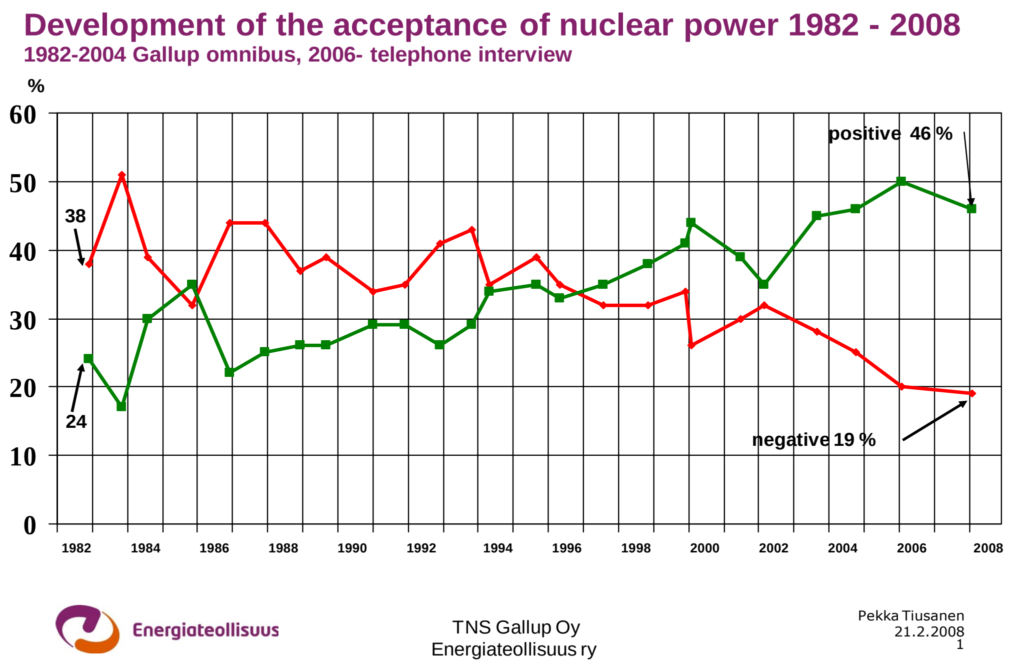
Several opinion polls carried out recently show that public support for nuclear energy is increasing worldwide. Over two third of the population worldwide is now supportive of the use of nuclear power in their own country according to a global survey conducted by the consulting company, Accenture in November 2008 and published on 20 March 2009. Some 29% of respondents in the poll said that they support the use or increased use of nuclear power, with a further 40% saying that they would support nuclear power if their concerns about it were overcome. The main hurdles to public acceptance are still the issues of waste management, safety and decommissioning. The main reason for supporting nuclear power is the fact that it contributes to the fight against climate change (41%), the second one is that it reduces energy dependency (9%). The lack of information is once again earmarked as the main reason why people oppose nuclear.

In Poland, the population is becoming more favourable to the construction of nuclear power plants. A 2009 opinion survey conducted in early March by GfK Polonia on behalf of the Rzeczpospolita shows that 40% of Poles back the idea, while 42% still oppose it. In January 2008, a similar poll found that only 33% supported the building of a plant, whereas 56% were against it. The Polish government has indeed announced plans to build one or two nuclear power plants by 2020.

According to a (recent) survey conducted by the Gallup polling organisation, public acceptance of nuclear energy in the USA has increased and is at the highest level ever registered by the organisation. Around 59% are in favour of its use, including 27% who strongly support it.

Attitudes towards nuclear power have been the most important stimulating and dividing factor in the Finnish energy debate for a long time. It is the clearest issue in the realignment of the front lines in energy policy and stands behind all opinions one way or another. In practice, the other energy options and their pros and cons, as well as the development of the entire electricity generation system, are always assessed in relation to the nuclear power alternative. This deliberation took the form of an open antithesis in the Finnish Parliament's decision on nuclear power in 2002, both in the debate leading up to the decision and in the final vote, which resulted in a narrow victory for the nuclear power supporters. After positive decision in principle the society became even more favourable towards nuclear energy, because the decision making process with wide consultations created confidence on democratic procedures (see figure). Other issues making the opinion so favourable were the concern on security of energy supply and on reducing CO_2 emissions. In parallel a program on promoting investments in different renewable energy source were established, and all stakeholders committed to implement that program.

Finland



In summary, the positive evolution of public opinion in favour of nuclear world-wide demonstrates that where there is a political will to promote nuclear power, there is no reason to believe that public opposition can prevent nuclear new build from going ahead. It also underlines the fact that information is the key to gaining public support. Informing the public and engaging them in debate remains, therefore, just as important as ever.

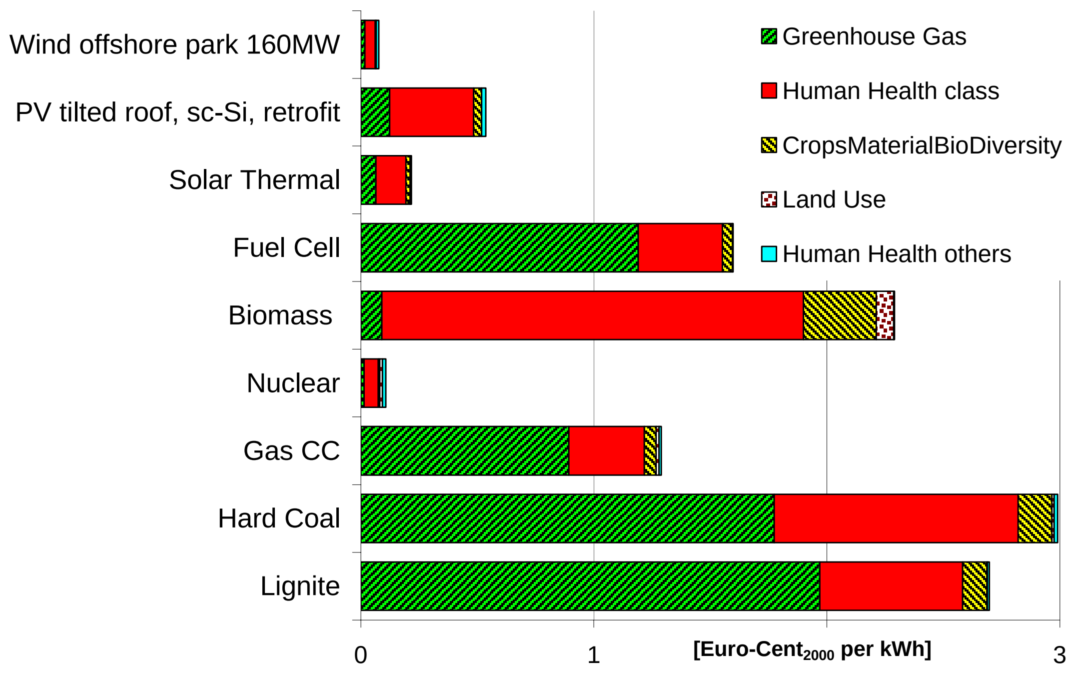
6. Aggregation

6.1. External and social costs

The provision of electricity by the various power plant technologies is associated with direct and indirect emissions and other burdens stemming from the various stages of the overall energy chain. These externalities might cause health and environmental damages currently not included in the private energy costs or energy prices. The concept of external costs is a way to estimate these externalities using monetary values as a common denominator for the damages. Current state-of-the-art external cost analysis is based on the "impact pathway approach" [67, 68].

The Figure displays the recent central estimates of external costs of various current electricity generation technologies for average central European conditions from the NEEDs-project. The climate damage costs are assumed to be 23.5 $Euro_{2005}$ per t $CO2_{eq}$. It appears that climate change external cost comes first, human health impacts second in value. The latter are derived from assessments such as shown in 5.3, multiplying them by estimated unit monetized values for YOLL and DALY.

External costs of current electricity generation technologies in Central Europe



Source: NEEDS, 2009 [64]

Notes:

- “Greenhouse Gas” cover additional health and other impacts caused by climate change
- “Human Health class” includes health impacts of the so called classical pollutants, i.e. SO2, NOx, NH3, NMVOC, and primary particulate matter (PM2.5 and PM10).
- “CropsMaterialBioDiversity” includes crop yield loss, damage to materials and loss of biodiversity due to acidification and eutrophication
- “Land Use” includes loss of biodiversity due to land use change
- “Human Health others” includes heavy metals and radio nuclides (e.g. radon from uranium mining).

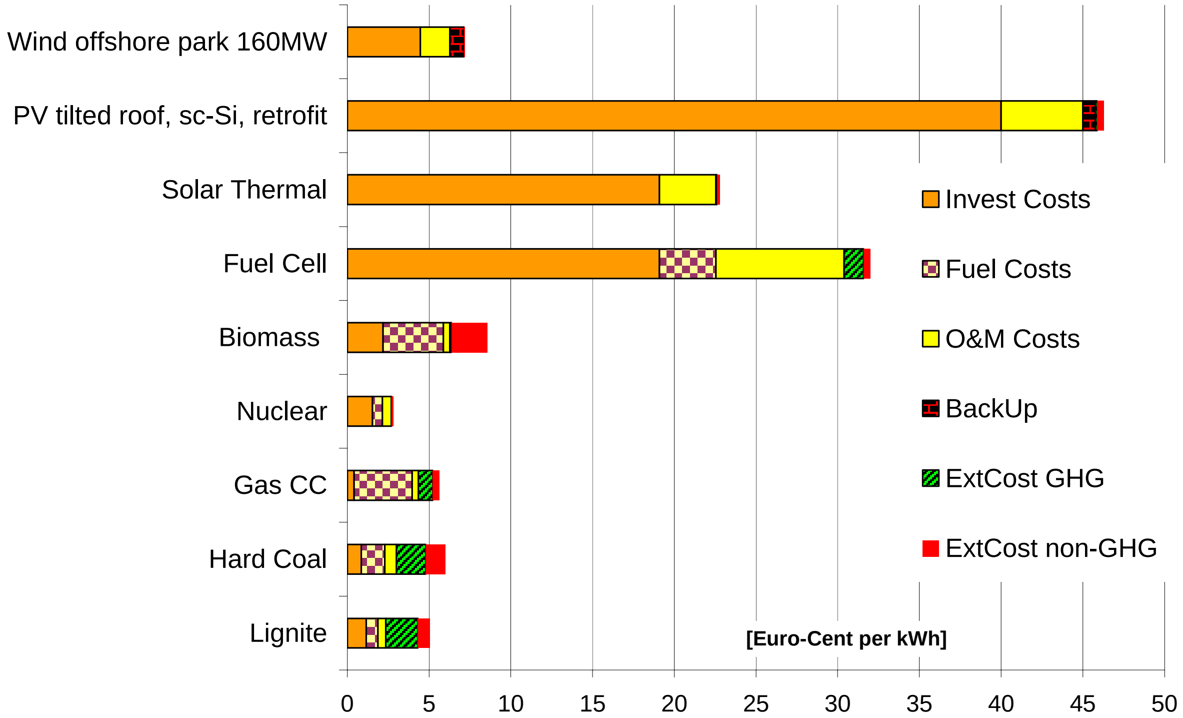
The figure shows that the external cost of wind (offshore), solar thermal and nuclear are low compared to the external costs of coal, lignite and biomass. The external costs of fossil fuels are dominated by greenhouse gases whereas the external cost of biomass is dominated by human health impacts due to NO_x, SO_2 and primary particulate matter.

Estimates of external costs also cover health impacts and damages from severe accidents within the various energy chains. Based on the definition of risk as the probability of accidents times the damage, the contribution of severe accidents to the external costs is practically negligible compared to the monetised health and environmental damages resulting from normal operation [68, 69, 70].

Social costs are the total costs of an economic activity and can be considered as the sum of the private and the external costs of that activity. Social costs are to be understood as measure of the overall resource consumption as well as the environmental and health impacts using a common denominator, namely monetary values. The assessment and aggregation of the consumption of the various resources is based on observed or empirically estimated preferences of the society at large.

The figure shows the social costs for current electricity generation technologies which are sited in Western Europe, except the solar thermal plant, located in Spain.

Social costs of current electricity generation technologies



O&M = operation and maintenance, GHG = greenhouse gases

Source: NEEDS, 2009 [71]

6.2. Multicriteria approach

The approach of external costs is still a subject of discussion mainly with respect to the monetary valuation of health and environmental impacts. For example, assessing the monetary value of future climate change consequences is a huge and difficult task, raising several questions. As a consequence, values of social costs such as the example above are fraught with large error margins, combining the uncertainties on both private and external costs. That does not mean they should not be considered: the broad differences shown by the chart are meaningful, but they are to be handled with caution.

Another approach to combine resource consumption and other impacts into an aggregate figure is multi-criteria decision analysis (MCDA) which is using individual preferences; that means each stakeholder chooses individual weights for each impact item to implement the aggregation into a unique value. This method does not need the introduction of monetized impacts; it has been developed notably by the Paul Scherrer Institute and applied to different contexts [73], [74]. Generally, the weights allocated to each item will vary with the stakeholder. If the preferred option remains the same through different weight combinations, then a “robust” decision can be taken, acceptable by all stakeholders. Even in other cases, the approach ensures transparent and traceable decisions, referring to clearly stated priorities as reflected by the allocated weights.

From the material collected here on measurable impacts, an overall positive picture is derived as to nuclear energy, compared with other options. Attempts to express the impacts with aggregated indicators, such as external costs, confirm this picture. However the overall balance between risks and benefits will be assessed differently by different stakeholders. Public acceptance has grown up to about 50% in many European countries and would be higher if solutions to manage nuclear waste are implemented. The material collected probably does not capture the whole complexity of the social dimension. Further investigation will call on the work from the other ENEF working groups dedicated to Risks and to Transparency.

7. Conclusions

7.1. General Conclusion

The following overall conclusions on the strengths and weaknesses of nuclear power in comparison to its competitors with regard to centralised generation of base-load electricity on European market can be drawn:

- Today, Nuclear Energy baseload electricity, emitting practically no greenhouse gases and thus combating climate change, contributes a third of electricity generation in the EU and to 2/3 of the low-carbon electricity generation, respectively.

- For all energy technologies, the different dimensions of sustainability – economical, environmental and social effects – should be taken into consideration, namely low emissions, security of supply, low costs and marks of public interest.

- There are neither “good” nor “bad” energy technologies as such, but only technologies with differing degrees of sustainability.

- Nuclear shows, when used for baseload electricity supply, the best relative economical performance; Its competitiveness vis-à-vis (largely imported) gas is strongly determined by prices of gas, Its competitiveness vis-à-vis (largely domestic) coal as well as gas is strongly determined by CO_2 prices and in the future by the cost of CCS. However, this is questioned by some NGO’s.

- In the longer run, the impact of the decentralised generation and smart grids on the competitiveness of nuclear generation and other forms of baseload generation should equally be examined.

7.2. Strengths

Regarding nuclear energy, on the basis of the examples compiled and evaluated in this report, <u>the following main strengths are stressed</u>:

11. ***In a wide range of scenarios, nuclear energy is currently recognised as the least cost option for base-load centralised generation, even in low CO_2 price scenarios.***
    This will be further analysed in the 2nd part of the SWOT analysis.

12. ***Decommissioning and waste management costs are internalised in the nuclear energy generation costs*** Cost assessments are available for both back-end options.
    The Commission is monitoring the adequacy of decommissioning and waste management funding and is reporting on a regular basis the results to the

European Parliament and the Council. A new Directive on the Management of Nuclear Waste will define a legally binding level playing field at EU level. .

13. ***Nuclear power plants do not emit CO_2, and the use of nuclear power across its lifecycle results in only very small amounts of greenhouse gas emissions***, which gives it a significant boost in competitiveness in a carbon constrained economy.
    The European energy policy recognizes equally the important contribution of energy savings and renewable energies for low carbon economy.

14. ***Nuclear power generation is much less sensitive to fuel price increase than fossil fuels.*** A 50% increase in uranium, coal and gas prices would make nuclear generating costs increase by 3%, coal generating costs by 20% and CCGT generating costs by 38%.
    The cost of uranium has a limited impact on the electricity price and thus, compared to gas and coal fired technologies, nuclear generation seems to show greatest resilience to upside fuel price risks.

15. ***Uranium security of supply is based on resources coming in a major part from politically stable countries. In addition, due to its high energy density, nuclear fuel may be easily stored in small volumes.*** This allows tackling any fuel supply interruption problems and therefore offers additional guarantees on availability of nuclear power plants.

16. ***The major part of the fuel supply chain is based in the EU.*** European companies are global leaders in nuclear fuel fabrication, enrichment, reprocessing and recycling activities which supports nuclear energy's high level of security of supply

17. ***High average capacity factors are shown by nuclear power plants in the EU***. These have encouraged plant operators to invest in life time extension and power up-rates which is a progressive and cost efficient way of adding generation capacity in response to increasing energy demands. The safe lifetime management and corresponding research for nuclear safety improvement are continuous priorities to the nuclear industry, in line with the European and international safety requirements.

18. ***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.

19. ***Waste from nuclear power generation is small in volume but challenging with regard to its long term confinement. It is controlled at all stages including collection, treatment, volume reduction, storage and transportation; the impact of radioactive waste management to the biosphere is insignificant to negligible in the short, medium and very long term.*** Progress is made for final disposal of radioactive waste. In 7 out of 16 Member States with NPPs final disposal facilities for LILW are in operation. The Commission is monitoring that each EU Member State establishes and keeps updated a national programme for the safe management of radioactive waste and spent fuel that includes all radioactive waste under its jurisdiction and covers all stages of management. Nevertheless, some groups regard waste management problem as still unresolved.

20. ***Social benefits of nuclear power include direct employment and positive impacts of stable and predictable cost of electricity on the economy.*** Nuclear energy also supports technological and scientific development in the EU and has lead to many spin-offs and applications with major social benefits, like nuclear medicine and other.

7.3. Weaknesses

Regarding nuclear, on the basis of the examples compiled and evaluated in this report, <u>the following main weaknesses are stressed:</u>

9. ***Nuclear power is capital intensive; therefore variations in construction costs have significant impact.*** Capital cannot be provided by state aid, which is subject to Community control. Construction delays in nuclear projects can result in substantially higher financing costs, causing cost overruns.

10. ***Public perception and acceptance is an element of volatility.*** This creates uncertainty in the licensing process of nuclear installation. Negative public opinion could in some cases delay, obstruct or stop nuclear energy projects.

11. ***Impact of low frequency accidents could be high***
    A single, rare accident in a nuclear facility could have potentially severe consequences on human health and the environment. To address the risk of accidents, plant safety is built on precautionary measures in design, construction and operation. The aim of these basic safety functions is to protect the plant in the event of incidents and failures, and to limit the consequences of severe accidents. New built Generation III plants will, by design, exclude any release outside the plant, would a highly improbable core melt occur.

12. ***The fact that there is no final repository for High Activity Waste (HAW) yet in operation creates the perception as if there would be no solution.*** In order to avoid any undue burden on future generations, it is an ethical obligation to proceed with the development of a radioactive waste management programme in each country using nuclear energy.

13. ***Uranium resources are limited as compared to unlimited availabilities of renewable energy resources***
    Uranium resources are finite. IAEA/OECD-NEA “Red Book” provides detailed quantitative assessment of uranium resources. Reasonable assured resources (RAR) correspond with a range of coverage of about 50 years: RAR together with “inferred” resources would cover about 80 years – “more realistic rates of consumption” would result in an additional 100 years. If all “undiscovered resources” would be considered, the range of coverage would be extended to another 300 years. Advanced reactor and fuel cycle technologies under development (fast breeder reactors and multiple recycling) could extend the ranges of coverage “from hundreds to thousands of years”.

14. ***Uranium mining & mill tailings need long-term stewardship***. However, good practices are available in the EU.

15. ***Proliferation concerns are a specific problematic characteristic of the nuclear fuel cycle.*** Therefore, proliferation resistance and physical protection of nuclear facilities and materials are key priorities for the nuclear industry and are subject to international scrutiny within the frame of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) via International Atomic Energy Agency (IAEA) safeguards system, supplemented by EURATOM Agency in the EU.

16. ***Sufficient Human Resources are critical to use of nuclear energy***
    Loss of retiring employees who hold knowledge that is critical either to operations or safety can pose a problem to operation of nuclear power plants. Preserving and transferring this knowledge to successors is a challenge for the nuclear industry. This has been fully recognised and countermeasures are taken or in preparation.

8. Outlook on Opportunities and Threats

"Opportunities" are understood here as evolutions that may, based upon the deliberations in this report, positively impact the relative competitiveness of nuclear in the future. The following initial list of opportunities has been identified:

1. ***Need of new power generation capacity due to increased electricity demand and necessary replacement of old carbon-emitting power plants***

2. ***Need of substantial growth in low-carbon energy production due to GHG emission targets***

3. ***High fossil fuel prices***

4. ***Impact of CO_2 prices and CCS implementation***

5. ***Cost reductions through reduction of project achievement duration by design standardisation, improved planning, harmonisation of safety criteria and licensing procedures***

6. ***Strong growth of nuclear energy capacities in the other regions of the world, fostering the development of European nuclear industry, bringing along technological progress and positive industrial scale effects***

7. ***Research on reduction of the volumes and the radiotoxicity of radioactive waste by closing the fuel cycle.***

8. ***Generation IV of nuclear reactors, promising better uranium resource utilization and waste minimization.***

9. ***New applications of nuclear energy (heat production, hydrogen production)***

10. ***Safety regulations moving from national towards harmonized European regulations***

11. ***The evolution of energy competitive markets design at the European Union level***

"Threats" are understood here as evolutions that may, based upon the deliberations in this report, negatively impact the relative competitiveness of nuclear in the future. The following initial list of threats has been identified:

1. ***Nuclear security / terrorist threats to nuclear infrastructures***

2. ***Risk of accident anywhere, and corresponding risk perception following bad accident management***

3. ***Changes in nuclear accident liabilities***

4. ***Bottlenecks in industrial capacity and skilled workforce for a massive expansion of nuclear***

5. ***Uncertainty on investments costs (increases in construction costs and raw materials, impact of turmoil on financial markets on project costs)***

6. ***Slowdown of waste management implementation programs and impact on potential investors***

7. ***Feedback of massive future expansion of renewables, CCS and distributed generation on nuclear energy***

8. ***Impact of major infrastructure investments (supergrids and smart grids) on nuclear energy***

9. ***Impact of water warming and water scarcity in some areas for operation of nuclear power plants***

10. ***The evolution of energy competitive markets design at the European Union level***

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APPENDIX

Interim Findings of the Subgroup Competitiveness

Statement of April 2009

The European Nuclear Energy Forum (ENEF) was launched by the European Commission on the basis of the March 2007 European Council Conclusions. The ENEF Subgroup (SG) on Competitiveness under the Working Group (WG) Opportunities was mandated to analyse more in detail, in comparison with other energy sources, the competitiveness of nuclear energy in a European low-carbon economy and a global energy security context.

From the information collected and evaluated so far in the course of the work of this SG, the following conclusions can be drawn:

There is widespread recognition among industry (both utilities and vendors), consumer and research organisations; currently working in the nuclear sector, that nuclear energy represents also in fully liberalised energy markets at least for the next few decades the least cost option for base-load centralised electricity generation in Europe, even in low CO_2 price scenarios.

Nevertheless, there are different views among NGO's:

- Greenpeace continues to question the competitiveness of nuclear power in liberalised markets;
- Sortir du Nucléaire considers that the centralised energy production can be a threat for energy security and that a small, decentralised production prevents loss of power and may prove more economically efficient.

As for any other technology, the use of nuclear energy has inherent Strengths and Weaknesses. Sustainability aspects of nuclear, fossil and renewable energy technologies can be evaluated on the basis of quantitative and qualitative indicators, addressing the three pillars of sustainability: the environment, economics and social aspects. Published assessments reviewed so far by the SG in the form of a SWOT[11]-type report cover the three pillars and support the overall argument that nuclear energy, like all of its competitors, displays both clear relative strengths and clear relative weaknesses:

Identified Strengths for nuclear energy are: Nuclear shows best economical performance vis-à-vis its competitors when used for baseload electricity supply. Further, the use of nuclear energy represents an important contributor to fighting climate change and increasing energy security.

Identified Weaknesses for nuclear energy are: Important long-term sustainability issues are not yet solved, such as implementation of waste management solutions[12], high capital cost and long term investment may create uncertainty in generation cost, risk of proliferation, possible lack of human resources.

The participants of the SG are aware that the findings of the SWOT analysis have to be used by keeping in mind the following facts and principles:

The new EU Energy Policy aims at balancing the triangle of the three sustainability objectives in energy policy in an integrated way. The relative ranking of strengths and weaknesses and the development of national energy policies can, however, be subject to specific circumstances.

[11] Strengths / Weaknesses / Opportunities / Threats (SWOT).
[12] Weaknesses are to be addressed more thoroughly by the ENEF WG Risks.

More information on European Nuclear Energy Forum is available on
http://ec.europa.eu/energy/nuclear/forum/forum_en.htm.