Nuclear Power: Global Trend and Outlook

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1 Introduction

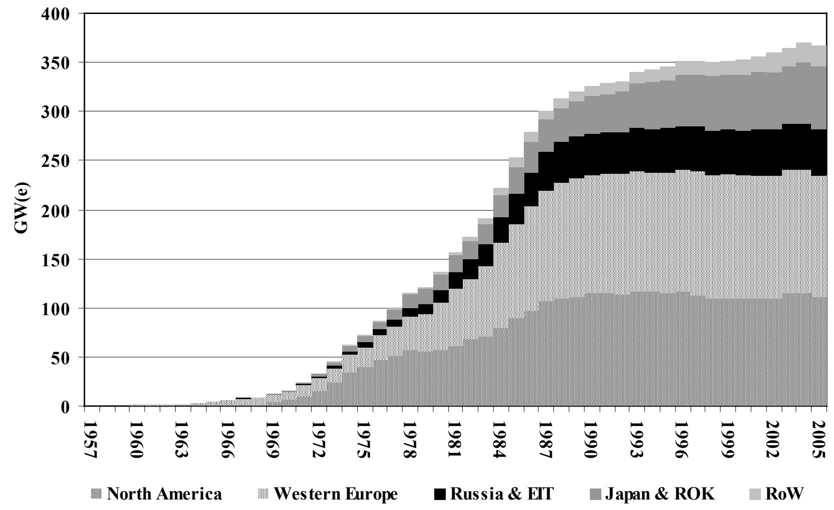
Nuclear power plays a significant role in the global supply of electricity. It provides substantial quantities of electricity in developed countries and is becoming increasingly important in some developing nations. However, countries and regions differ profoundly with regard to their existing energy infrastructures, economic capacities, energy demand and supply patterns (current and projected), degree of market liberalization, environmental policies, as well as their socio-political attitudes towards meeting energy supply challenges. Governments therefore pursue different strategies in meeting their national objectives - improving social welfare, economic efficiency, environmental protection, energy diversity and security - and the prospects for further nuclear power development vary.

Nonetheless, there are rising expectations about the future of nuclear power development. There is a good and growing track record of the safe operation of nuclear power plants which have now surpassed a cumulative 12,000 years of operation. Nuclear power provides for growing energy needs, while simultaneously avoiding greenhouse gas (GHG) emissions and other pollutants. In many countries it also contributes to the security of national energy supplies. These comparative advantages of nuclear power are increasingly being recognized by policy makers and investors as new environmental constraints take effect. This and appreciably higher fossil fuel market prices have led to regularly upwardly revised medium-term projections for global nuclear power development over the last 5 years. However, although nuclear power has provided around 16% of global electricity supply since 1986, medium-term projections indicate that without a tide change ("rising expectations") planned capacity additions are insufficient to maintain nuclear power's present market share.

2 Nuclear Power Status

By January 2006 443 nuclear power plants (NPPs) operated in 30 countries worldwide, with a total installed capacity of nearly 370 GWe. The joint electrical output was recorded at 2600 terawatt hours (TWh), which is equivalent to supplying 16% of global electricity demand.

Seventeen countries depend on nuclear power for at least a quarter of their electricity. France (78%) and Lithuania (72%) get around three quarters of their power from nuclear energy, while Belgium (55%), Slovakia (55%), Sweden (52%), Ukraine (51%), Bulgaria (41%), Switzerland (40%), Slovenia (39%), Armenia, (38%), South Korea (38%) and Hungary (33%), get one third or more. Germany (32%), Czech Republic (31%), Japan (29%) and Finland (26%) get more than a quarter of their power from nuclear energy, while Spain (22%), the USA (20%), and the UK (19%) get one fifth.



RoW = Rest of the World, EIT = Economies in transition, RoK = Republic of Korea

Figure 1: Development of global nuclear generating capacity: 1957 - 2005. Source: IAEA, 2005a.

In the past nuclear power deployment was dominated by the industrialized countries of North America and Europe. However, since the 1990s the growth of global nuclear power generation has begun to shift towards Asia and developing countries (see Figure 1) and it is expected that this trend will continue. Nuclear power is typically more attractive where energy demand is growing rapidly, where alternatives are scarce or expensive, where energy supply security is a concern, where reducing air pollution and greenhouse gases is a priority, where financing can look longer-term, or where high-technology development is a priority. One or more of these features provided the rationale for the adoption of nuclear power in the past and continues to shape nuclear investment decision in China, India, Japan, and the Republic of Korea, where most current construction is either taking place or planned in the near-term future.

Since the mid 1980s, the share of nuclear power in global electricity generation has stagnated at 16%, i.e., nuclear power just kept pace with overall electricity growth. Market liberalization and short-term maximization of shareholder value, low fossil fuel prices, lower than expected electricity demand in the OECD countries, technology advances in gas turbine technology and diminished public acceptance in the wake of the Chernobyl accident have been chiefly responsible for the slowdown in nuclear power construction (see Figure 1) and consequently in the market penetration of nuclear power.

Between 1990-2004 world nuclear capacity rose by approximately 12% or 39 GWe (equivalent to 270 TWh/p.a.) while total electricity generation grew by 718 TWh (38% increase). The apparent paradox between the small capacity increase and the three times larger growth in generation (see Figure 2) is the result of (a) substantial improvements in overall plant performance and plant availability since the early 1990s (see Figure 3) and (b) capacity increases by way of up-rating existing plants. The relative contributions to the global increase in nuclear electricity generation have been: new construction 36%, uprating 7% and improved plant performance 57%.

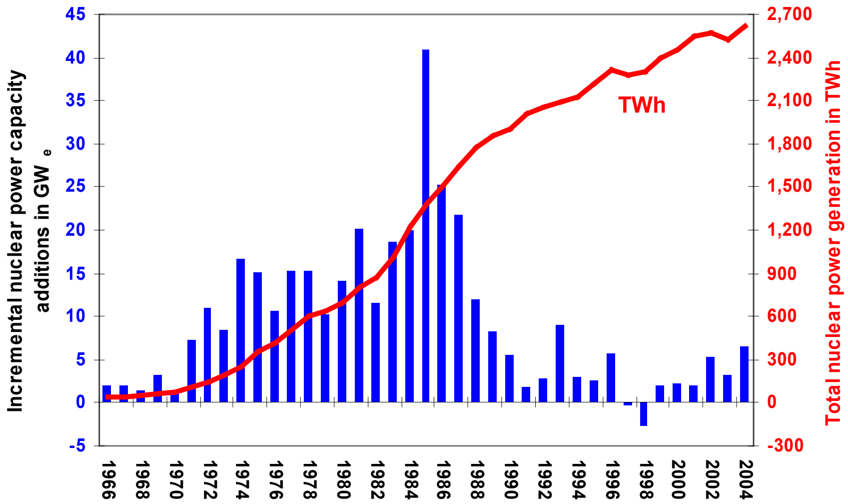


Figure 2: New annual nuclear capacity additions and nuclear electricity generation

Market liberalization was viewed by many as the demise of nuclear power. The "swan song" predicted for nuclear power was never sung. Because the old cost-plus price setting of regulated markets allowed utilities to pass on inefficiencies to ratepayers, many analysts expected that liberalization would make nuclear power uncompetitive. But nuclear power utilities rose to the challenge and turned their industry into a highly profitable sector. Innovation and streamlining in operations, management, training, procurement, and maintenance, plus a strict adherence to a safety culture and some industry consolidation (so more plants are being run by those who run them best) all resulted in continuous improvements in the average load factor for the global fleet of reactors thus reducing generating costs substantially and effectively adding capacity equivalent to more than 34 new

1000 MWe plants between 1990 and 2004. One quarter of the world's reactors have now load factors of more than 90%, and almost two thirds do better than 75%, compared with about a quarter of them in 1990. In 2004 ten countries had average load factors better than 80%. French reactors averaged 76% because they are dispatched in a load-following mode rather than being used only for base-load operation.

In addition, most plants are already fully depreciated and now benefit from the true virtue of nuclear power - low operating costs. The competitive generation costs and excellent safety performance have prompted capacity upratings and lifetime extensions.

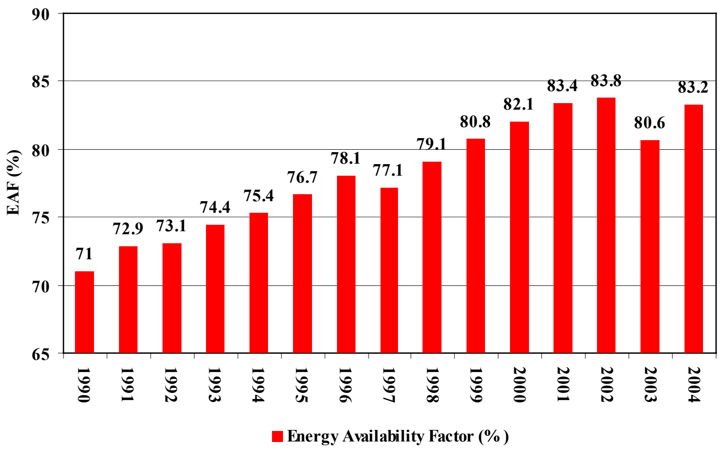


Figure 3: Energy Availability Factor (EAF) - 1990-2004. Source: IAEA, 2006.

2.1 Capacity Uprates

The replacement of aged equipment, such as steam generators or turbines in existing nuclear plants, usually results in additional generating capacity beyond the original name plate capacity. This is a highly cost-effective way of bringing on additional capacity and is often undertaken in combination with license renewals. For example:

- In Switzerland the capacity of its five reactors has been increased by 12.3%.
- In the USA the Nuclear Regulatory Commission has approved 96 uprates since 1977, a few with “extended uprates” of up to 20%.
- Spain, despite phase-out plans, has a program to add 810 MWe (11%) to its nuclear capacity through upgrading its nine reactors.
- In Finland the capacity of the Olkiluoto plants were boosted by 23%, while the Loviisa plant with two VVER-440 reactors has been uprated by almost 100 MWe (11%).
- Electricite de France has announced that it will increase the capacity of five of its 900

MWe nuclear units at three sites over the years 2008-10 by replacing turbine rotors, thereby adding about 30 MWe to each.

- Recently, Swedish regulators have approved a 250 MWe uprate of the 1200 MWe Oskarshamn-3 reactor, and government approval of other lesser uprates is pending at Forsmark and Ringhals. Forsmark-1 has been uprated by 47 MWe to 1015 MWe.

2.2 License Extension

Most nuclear power plants originally had a nominal design lifetime of up to 40 years, but safety engineering assessments of many plants over the last decade have established that many can operate longer. Especially since depreciated plants generate electricity at very low cost, operating companies seek extensions to maximize the profitable life-time of these plants. In the USA, 39 reactors have been granted license renewals, which extend their operating lives from the original 40 years to 60 years, and operators of most other reactors are expected to apply for similar extensions. In Japan, plant lifetimes up to 70 years are envisaged. In the UK, two units at Dungeness B in Kent have been granted a ten-year life extension. The Russian government in 2000 extended the operating licenses of 12 reactors from their original 30 to 45 years. Most recently, the Netherlands extended the license for the country's only nuclear plant to 2033, giving it a 60-year operating life.

2.3 New Nuclear Plant Plants

In short, the situation since the 1990s can best be described as: existing plants in deregulated markets thrive, but new plants wait. The reasons are that:

- utilities in deregulated markets no longer have a full supply obligation,
- governments have largely withdrawn from financing nuclear power,
- the front-loaded cost structure of new NPPs is a disadvantage in deregulated markets,
- regulatory and political uncertainty persist, and
- the general preference of private investors is for short amortization periods and low financial risks.

However, economic attractiveness differs for different countries, investors and markets. NPPs are more attractive to government investors responsible for energy security, GHG emissions, and long term development than for private investors who need rapid returns and receive no financial benefit from nuclear power's low GHG emissions or contribution to energy security.

However, public policy may transfer parts or all of 'government responsibility', e.g., for supply security or protection of the environment, to the private sector by providing economic incentives (GHG emission taxes or production tax credits, etc.).

The 2004 decision of Teollisuuden Voima Oy (TVO) in Finland to build Olkiluoto-3 demonstrates that long-term thinking and nuclear power do not have to be inconsistent with liberalized energy markets. TVO's situation has some special features that favor longer term thinking, and longer term thinking (low discount rates) tends to favor nuclear power, with its relatively high initial investment costs but low long-term operating costs. First, TVO is owned by major long-term electricity consumers. It therefore effectively starts with long-term contracts that assure the sale of all its electricity and reduce financial risks. Second, natural gas was the closest contender to nuclear energy, and 100% of Finland's natural gas imports come from Russia. Although there was no explicit policy constraint from the Finnish government to promote national energy security, additional dependence on Russian gas would have diminished the diversity of TVO's generating mix, and thus the reliability of its supply. From a purely corporate perspective, diminished reliability translates into diminished potential revenues and a cost on the bottom line. Third, Finland has been a leader in actual, as opposed to rhetorical, carbon taxes, which means that TVO must hedge against future carbon costs, and that hedge also has an impact on the bottom line. Finally, TVO already had two sites with operating NPPs, which helps bring down cost estimates for new NPPs.

2.4 New Grid Connections

In 2005 six new NPPs began commercial operation:

- Higashidori 1, a Boiling Water Reactor (BWR) with a generating capacity of 1067 MWe, and Hamaoka 5, an Advanced Boiling Water Reactor (ABWR) with an output of 1325 MWe started operating in Japan.
- Commercial operation commenced for two Pressurized Water Reactors (PWR), Kalinin-3 in Russia and Khmelnitski-2 in the Ukraine with an electrical output of 950 MWe each.
- In South Korea, the Ulchin-6, a 960 MWe PWR, began operation.
- Tarapur-4 in India, a 490 MWe Pressurized Heavy Water Reactor (PHWR) was connected to the grid in June 2005 and now operates commercially.

In addition, Shika 2 (1304 MWe, ABWR) in Japan was connected to the grid and is scheduled for operation in March 2006. Pickering-1 in Canada (515 MWe, PHWR) was reconnected in

September after a long-term shutdown. While new construction was initiated for three NPPs, Chasnupp-2 (300 MWe, PWR) in Pakistan, Olkiluoto-3 (1600 MWe, PWR) in Finland and Lingao-3 in China (1000 MWe, PWR), final shutdown affected Barsebaeck-2 (600 MWe, BWR) in Sweden, and Obrigheim (340 MWe, PWR) in Germany.

2.5 Plants under Construction and Expansion Plans

Most of current new construction takes place in the fast growing developing countries. Table 1 shows that sixteen of the 25 new reactors currently under construction, or 11 GWe (56%) out of 20 GWe, are located in developing countries.

Table 1: Nuclear Power Plants under construction in 2005. Source: IAEA, 2006

	No. of NPPs under construction	Capacity under construction (MWe)
India	8	3,638
Russia	4	3,600
Taiwan	2	2,600
China	2	1,900
Ukraine	2	1,900
Finland	1	1,600
Iran	1	950
Japan	1	866
Argentina	1	692
Romania	1	655
Pakistan	1	300
Total	24	18,701

Ambitious plans for nuclear expansion exist in China and India. China, with three NPPs under construction and nine plants authorized by the government, plans to expand nuclear capacity from 6.6 GWe today to between 32 GWe and 40 GWe by 2020.

India, which possesses the youngest fleet of nuclear reactors of any country in the world (nine plants in operation and eight under construction), plans a 100-fold increase in nuclear capacity by mid-century, and an increase from 3% of nuclear electricity generation to more than 25%. A 100-fold increase sounds enormous, but works out to an average of 9.2% per year. This is well below the pace of global nuclear capacity growth in the 1970s of 21%, but above the 1980s' average of 8.7%. It is equal to the 34-year global average growth rate of 9.2% during 1970 to 2004.

Pakistan, with 425 MWe and one plant under construction, plans to add approximately 8 GWe by 2030. Significant short-term additions have also been planned by Japan (14.7 GWe) and the Republic of Korea (9.2 GWe) (WNA, 2006). If sustained, this shift of nuclear power development towards developing countries will affect the geographical distribution and operating experience of nuclear power plants in the future.

Prospects for nuclear expansion also appear to be gaining momentum in other parts of the world, although less dramatically than in China and India. Russia has two more plants under construction and plans to more than double capacity from today's 22 GWe to 53 GWe in 2020. The new EU accession countries and other Eastern European countries with nuclear power have expressed a clear determination to retain and expand the nuclear option. In Poland, where nuclear development was halted by a Parliamentary decision in 1990, the Council of Ministers approved a draft energy policy in early 2005 that explicitly includes nuclear power.

Finally, in Western Europe excavation work began in 2004 for Olkiluoto-3 in Finland, a European pressurized water reactor (EPR) that will be the first construction start in the region since 1991. In France Electricité de France selected a site for a demonstration EPR, with construction expected to begin in 2007.

3 Global and Regional Nuclear Power Projections

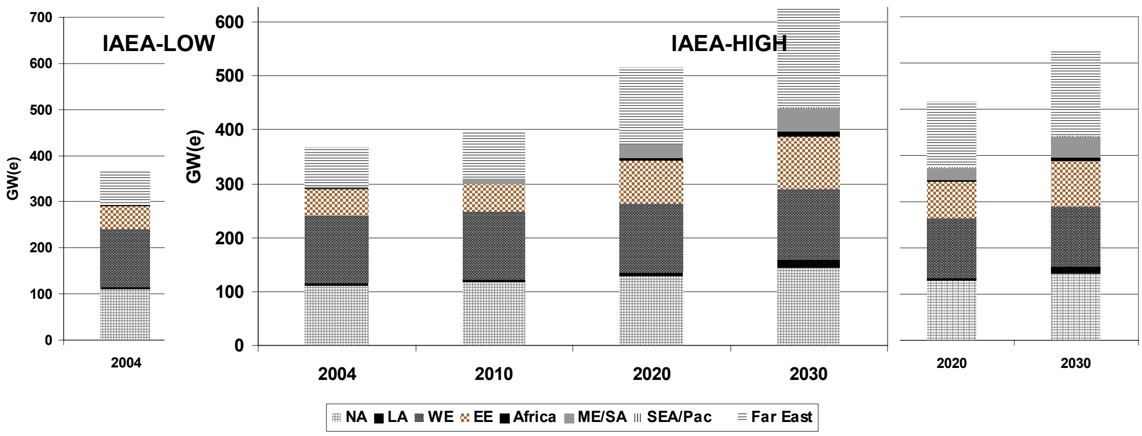
Projecting nuclear power development in the medium and long term is a difficult exercise, because a large number of driving factors cannot be assessed with any high degree of certainty. The projections developed by the IAEA are not meant to be predictions of the likely evolution of nuclear power generation but rather are intended to illustrate some plausible future possibilities. The medium term scenarios, up to 2030, are derived from a bottom-up approach based upon a review of nuclear power programmes and plans in Member States of the IAEA. The LOW and HIGH projections of nuclear capacity (Table 2) correspond to a set of contrasting but not extreme assumptions with regard to the parameters which will influence the implementation of national nuclear programmes.

Table 2. Nuclear Power Projections. Source: IAEA (2005a)

Country Group	2004			2010 (a)			2020 (a)			2030 (a)		
	Total Elect. GW(e)	Nuclear GW(e)	Nuclear %	Total Elect. GW(e)	Nuclear GW(e)	Nuclear %	Total Elect. GW(e)	Nuclear GW(e)	Nuclear %	Total Elect. GW(e)	Nuclear GW(e)	Nuclear %
North America	1055	111.3	10.6	1099 1155	116 117	11 10	1194 1279	118 128	10 10	1318 1422	115 145	8.7 10
Latin America	264	4.1	1.6	303 350	4.1 4.1	1.4 1.2	383 543	6.1 6.1	1.6 1.1	483 828	5.8 15	1.2 1.8
Western Europe	724	125.1	17.3	762 816	119 125	16 15	842 951	97 130	11 14	940 1118	79 145	8.5 13
Eastern Europe	466	49.4	10.6	469 496	48 51	10 10	505 605	64 78	13 13	543 736	66 97	12 13
Africa	105	1.8	1.7	115 135	1.8 1.8	1.6 1.3	143 207	2.1 4.1	1.5 2.0	181 316	2.1 9.3	1.2 3.0
Middle East and South Asia	284	3.0	1.0	331 370	9 10	2.8 2.8	430 555	15 27	3.6 4.9	556 811	18 43	3.2 5.3
South East Asia and the Pacific	143			169 184			213 270	0.9 0.9	0.4 0.3	264 391	0.9 3.0	0.3 0.8
Far East	651	72.8	11.2	685 840	82 85	12 10	804 1167	113 142	14 12	937 1589	131 183	14 11
World Total Low Estimate	3693	367.5	10.0	3934	380	10	4515	416	9.2	5223	418	8.0
World Total High Estimate				4347	395	9.1	5576	516	9.3	7210	640	8.9

The LOW projection is based on assumptions that reflect a continuation of present trends: public opposition in some countries, low economic growth in industrialized countries, institutional and sociopolitical uncertainties in economies in transition and a lack of funding in developing countries. In this case, the nuclear units under construction will be completed but only those countries where nuclear programmes are already firmly committed will continue to order new units. In some countries, nuclear units will not be replaced at the end of their lifetimes and the total installed nuclear capacity in these countries will remain quasi constant after 2020. The projected nuclear capacity is about 418 GWe in 2030 (LOW case) with a nuclear power share of 13% in total global electricity generation.

On a regional basis, the LOW projection shows a contraction of nuclear capacities in Western Europe and an expansion in the Far East (Figure 4). Considerable growth by a factor of six between 2004 and 2030 occurs also in the Middle East and South Asia region, though from a small base. There is some small net growth in Eastern Europe and basically no change in North America.



NA = North America; LA = Latin America; WE = Western Europe; EE = Eastern Europe; ME/SA = Middle East & South Asia; SEA/PAC = South-East Asia & Pacific

Figure 4: Regional Distribution of World Nuclear Capacity – IAEA LOW and HIGH projections.

The HIGH projection foresees a moderate revival of nuclear power development that could occur in light of a more comprehensive assessment of the macro-economic and environmental aspects of the different options available for electricity generation. This revival is expected to occur mainly in Western Europe and to a lesser extent in North America. In Eastern Europe, nuclear power programmes will be implemented according to the present plans. In the Far East, nuclear power will be developed in line with rapid growth in electricity demand. In the HIGH case, total nuclear capacity is projected to reach about 640 GWe in 2030, which will allow the share of nuclear power in electricity generation to reach just 12% (due to the considerably higher growth in total electricity demand underlying the HIGH projection).

There is capacity growth projected for all regions (Figure 4), but the Far East still leads the way with 100 GWe of new net capacity by 2030 ("net" means capacity additions beyond replacement of retired capacity). By 2030, 45% of the world's additional capacity will be in the Far East. While the Far East leads in net capacity additions, the Middle East and South Asia region have the most impressive growth rate, adding 31 GWe to increase capacity by a factor of ten, equal to average growth of 9% per year. Eastern Europe adds 40 GWe net.

The IAEA projections are, to different degrees, consistent with "rising expectations". First, the past couple of years have already shown several encouraging signs, including upward revisions in specific expansion plans and actions in a number of countries, consequently higher medium-term nuclear projections, increased media attention on the potential benefits of nuclear power including its very low GHG emissions, and more favourable ratings for nuclear power in a number of public opinion polls. While the entry-into-force of the Kyoto Protocol could stimulate the future development of nuclear power, the Protocol's immediate impacts on nuclear power during the first commitment window 2008-2012 are indirect (making nuclear's GHG benefits visible to current plant operators in countries with emission reduction obligations) and thus limited. Potentially significant impacts will depend on the specificities of yet to be negotiated post-Kyoto emission reduction schemes for the post 2012 time frame.

Second, what may be more telling are the consecutive upward revisions of mid-term nuclear power projections over the past four years. As shown in Figure 5 the LOW projection was adjusted upwards substantially between 2001 and 2004, reflecting an increasingly bullish outlook for nuclear (even despite a small downward adjustment in 2005). It now projects 416 GWe of nuclear capacity in 2020, the equivalent of 116 more 1000 MWe nuclear plants than projected just four years earlier. In the HIGH projection there has been less change, and a less consistent pattern of change, from year to year. But the overall pattern is consistent with an industry with good prospects. The list of reasonable medium-term projects at the high end is fairly stable, and each year more of them get promoted from promising prospects to actual projects in the pipeline. Figure 5 shows historical nuclear capacity growth together with the evolution of the IAEA projections in the last four years. The IAEA's latest HIGH projection shows an 82% increase in nuclear electricity production between 2004 and 2030.

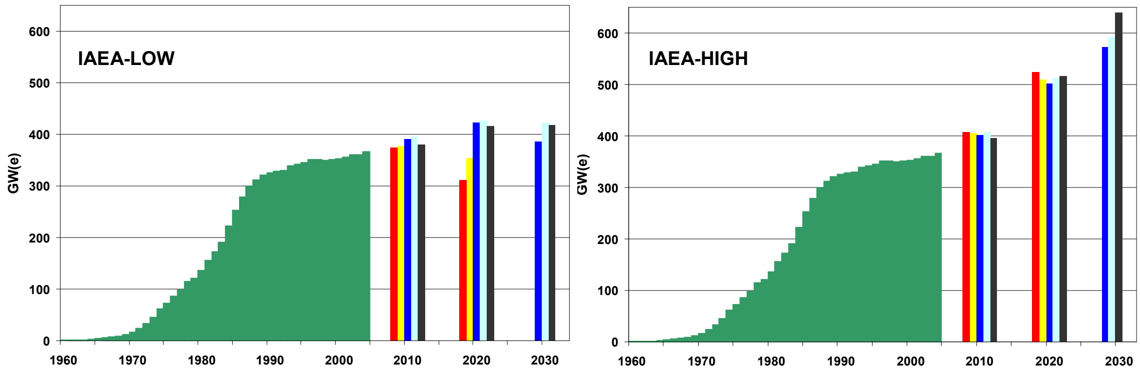


Figure 5: Historical Growth in World Nuclear Capacity and IAEA's LOW and HIGH Projections of the Years 2001, 2002, 2003, 2004 and 2005 (bars from left to right)

4 Driving Forces behind Rising Expectations

4.1 Economics

Economic performance will always remain the single most important decision criterion for investments in electricity generating facilities. A study by the OECD Nuclear Energy Agency (NEA) and the International Energy Agency (IEA) reports that the general competitiveness of new nuclear build has improved since the last study seven years ago (NEA/IEA, 2005). The principal changes are higher nuclear plant capacity factors and rising market prices for natural gas. The study analyzed over one hundred power plants (including 13 nuclear plants) available for grid connection in the 2010-2015 timeframe. Overnight construction costs for nuclear power range from $1000/kWe[1] to $2500/kWe (average around $1500/kWe) depending on technology, unit size and location. Coal plants are costed at $1000-1500/kWe, gas plants at $500-1000/kWe and wind turbines at $1000-1500/kWe.

One critical parameter in the cost assessments of different electricity generating options is the discount rate. At an annual discount rate of 10% per annum nuclear generating costs range between 30-55 $/MWh (except Japan where they are closer to 70 $/MWh). Capital costs account for 70% of the generating costs. Nuclear power is cheaper than coal in seven out of ten countries and cheaper than gas in all but two.

At a 5% discount rate nuclear generating costs are 20-40 $/MWh depending on the country; coal is at 20-50 $/MWh, and gas is at 40-55 $/MWh (see Figure 6). Nuclear costs were lowest in the Republic of Korea, the Czech Republic, Canada and France and highest in Japan. Nuclear power is comfortably cheaper than coal in seven out of ten countries and cheaper than

[1] All dollars are US$.

gas in all but one.

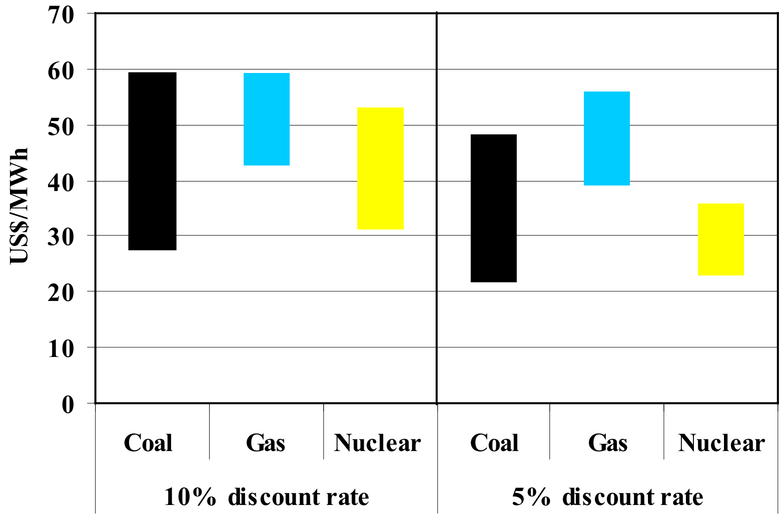


Figure 6: Spread of levelised generating cost[2]. Source: NEA/IEA, 2005

According to the NEA/IEA study, nuclear power on a levelised-cost basis can be quite competitive. However, the large spread of generating costs for all technologies indicates the importance of local conditions and circumstances.

In spite of competitive levelised generating costs, the front-loaded cost structure of new NPPs remains a disadvantage in deregulated markets. The nuclear industry is working to reduce these costs to $1200 to $1500 per kWe over the next decade through standardization, series construction, streamlining of the licensing and regulatory processes, innovation and technology learning. Still even if these cost reductions can be accomplished by 2015, a 1000 MWe nuclear power plant would have investment costs of $1.2 billion to $1.5 billion. For comparison, natural gas combined cycle (CCGT) power plants in a similar capacity range would cost about $350-800 million. Moreover, CCGT plants are available in smaller units than nuclear power and are faster to build. Thus the investment requirement for a complete CCGT project could be as small as $40 to $60 million for a 100 MW unit.

In liberalized markets investors need to internalize risks into their investment decisions (see Table 1) that in previous natural monopolistic settings could be passed on to consumers (cost plus approach) or balanced through public sector funds. As with any technology with high up-front costs, economic risks include cost overruns and delays during construction, unsatisfactory technical operating performance, lower-than-projected demand for electricity in the market place, declining product prices due to low-cost competition, and unexpected changes in regulations and relevant government policies.

[2] Excluding the 5% highest and 5% lowest values

Table 2: Technology-risk matrix. Source: NEA/IEA, 2005

Technology	Unit size	Lead time	Capital cost	O&M cost	Fuel prices	CO_2 emissions	Regulatory risk
CCGT	Medium	Short	Low	Low	High	Medium	Low
Coal	Large	Long	High	Medium	Medium	High	High
Nuclear	Very large	Long	High	Medium	Low	Very low	High
Hydro	Large	Long	Very high	Very low	Nil	Very low	High
Wind	Small	Short	High	Very low	Nil	Very low	Medium
Recip. engines	Small	Very short	Low	Low	High	Medium	Medium
Fuel Cells	Small	Very short	Very high	Medium	High	Medium	Low
PV	Very small	Very short	Very high	Very low	Nil	Low	Low

The required rate of return on investment increases commensurately with higher financial risks, while the time frame for capital recovery decreases. Consequently investors tend to favour less capital intensive and more flexible technologies that can be deployed with minimum lead times and adapt easily to changing market conditions. The dash-for-gas in the UK is a prominent example illustrating private sector preference for investment in low-cost, highly efficient, short lead-time combined-cycle gas technology (CCGT) over other energy technologies.

In contrast to liberalized markets, public sector spending does not require the same rapid return on investments as do private investors, and Governments can directly incorporate beneficial externalities that are effectively invisible to private investors, such as national energy supply security, the development of an advanced high technology industrial base and environmental protection. In the Republic of Korea, for example, high first-of-a-kind nuclear power costs were accepted as part of a long-term national energy strategy that anticipated (and subsequently realized) both eventual cost reductions from 'technology learning' and economic spin-off benefits from developing the country's high technology sector. A recent study estimated these economic spin-off benefits from nuclear power at about 2% of the country's GDP (KAERI, 2004).

In the US the Energy Policy Act 2005 includes incentives including a production tax credit of 1.8 c/kWh for the first 6000 MWe of new nuclear build during the first eight years of their operation (the same as for wind power although there is no time limit associated with wind), federal risk insurance of $2 billion to cover regulatory delays in reaching full-power operation for the first six advanced new plants, a rationalized tax on decommissioning funds (some reduced), federal loan guarantees for advanced nuclear reactors or other emission-free technologies up to 80% of the project cost, and R&D support for advanced nuclear technology.

The finance barrier of nuclear power can further be mitigated, in part, by making its environmental benefits visible for investors and thus reducing exposure to economic risk. Climate change policies can directly affect the revenue stream of a utility through imposing directly or indirectly a penalty on GHG emissions thereby affecting the investment risk, which can tilt the balance in favour or against certain technologies.

Placing a cost on carbon emissions alters the merit order of existing power plants (see Figure 7) to the advantage of low-carbon technologies (i.e. a shift from coal to gas), but only if long-term incentives or carbon markets are created (Reinaud, 2003). Therefore, an incentive system that operates on short time scales, such as the Kyoto Protocol, is unlikely to provide the long-term investment security needed by investors to invest in plant technologies that have long lead-times and/or high-capital requirements, such as nuclear power plants.

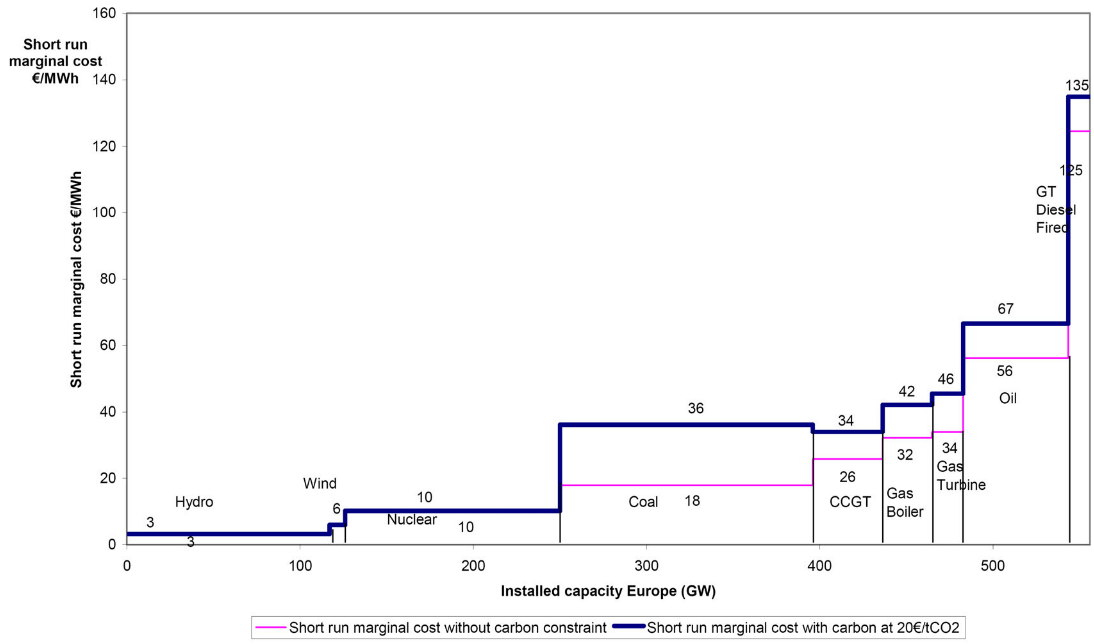


Figure 7: European Merit Order and Impact of a 20/t CO2 Carbon Price. Source: Reinaud, 2003

Still, the Kyoto Protocol is a first and modest step towards climate protection and signals that future GHG emission constraints may become increasingly stringent. Rational market agents tend to hedge against such regulatory risk by investing parts of their portfolios in low or no GHG emitting technologies. A charge on GHG emissions of €20 per tonne of carbon (tC) would improve a nuclear plant's generating costs relative to a modern coal-fired plant by 10%-20%. Nuclear power would be competitive with CCGT at €26 per tonne of CO_2 (including decommissioning), while renewables require CO_2 permits prices between €30-200 depending on the specific technology and base line (Reinaud, 2003). Presently, in Europe a tonne of carbon dioxide trades at around €25. Yet any measurable impact of these effects on nuclear power will only become visible sometime after the first commitment period and only if the carbon constraint is sufficient and permanent.

4.2 Fuel prices

Current high prices for fossil fuels are also likely to be more permanent than were those of the 1970s because they are driven largely by demand increases, although they presently contain a 'speculative' component estimated at 20-30% which leaves some room for price reductions. Nonetheless, energy demand growth driven by continuing economic development is expected to persist - hence the pressure on prices is likely to last.

Since the competitiveness of nuclear power depends also on the economics of alternatives such as coal, oil and natural gas, which dominate current and projected electricity generation, rising fossil fuel prices ultimately improve nuclear power's standing.

4.3 Environment

Environmental considerations may also weigh increasingly in favour of nuclear power. Nuclear power at the point of electricity generation does not produce any emissions that damage local air quality, cause regional acidification or contribute to climate change, especially in countries with obligatory GHG reduction requirements under the Kyoto Protocol. Along the full source-to-electricity chain including indirect emissions, nuclear power generates two orders of magnitude less CO_2 than fossil fuel power plants (see Figure

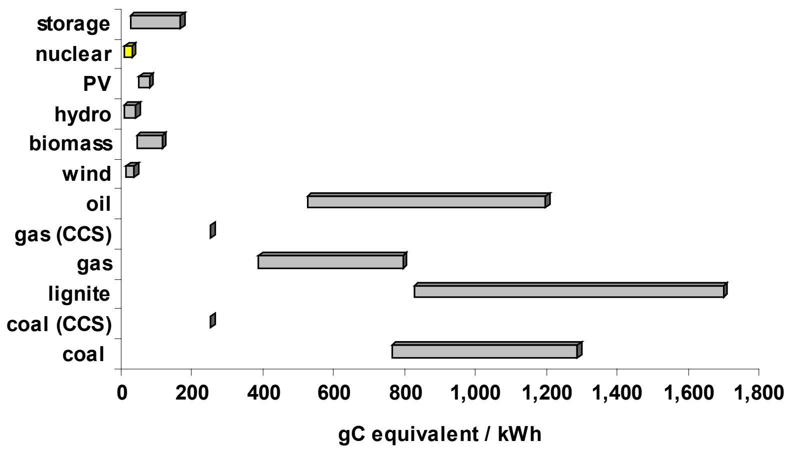


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Figure 8: Life-cycle GHG emissions from energy technologies[3]. Source: Weisser, 2006.

In addition, nuclear power also produces virtually no air pollutants responsible for local and regional environmental degradation. At present nuclear power helps to avoid some 8% of CO_2 emissions globally each year.

4.4 Internalising Externalities

The full life-cycle of electricity generation has detrimental effects on the natural and built environment, as well as society in the form of creating, for example, acidification, eutrophication, photochemical smog, terrestrial toxicity, aquatic toxicity, human health risks, resource depletion, and anthropogenic global warming. With increasing concerns about environmental degradation and human health risks, externalities need to be internalized, i.e., included in the market price of electricity. Research shows that electricity generated from NPPs has an advantage over fossil fuel generated electricity (Figure 9).

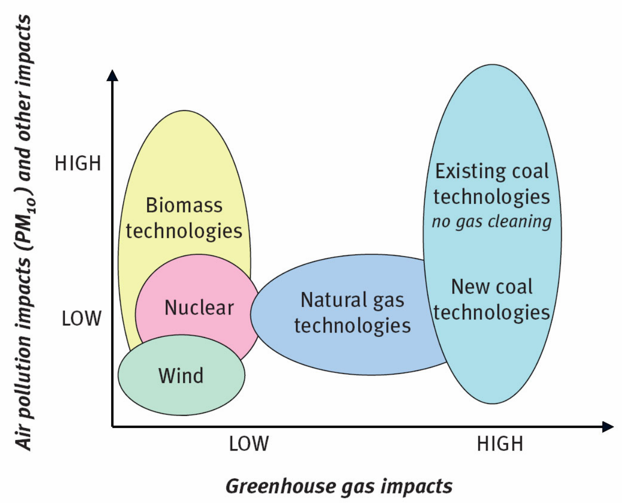

Figure 9: External impacts of electricity generating technologies. Source: EC, 2003.

4.5 Supply Security

Because of long intervals between refueling and nuclear power's low volume fuel requirements per unit of electricity a strategic inventory of low enriched uranium for nuclear fuel can be more readily established in a country. This minimizes the exposure to fuel market price volatility and sudden changes in the terms of trade or supply disruptions. Nuclear power thus offers a definite level of energy security, which may be especially important in countries with high degrees of energy import dependence.

Moreover, fuel price volatility is not a concern for nuclear power because of its typically low fuel costs. A doubling of international fuel prices, for example, translates into generation cost

[3] Storage: A range of energy storage technologies, e.g., compressed air, pumped hydro, battery systems. CCS =

increases of about 35-45% for coal-fired electricity and 70-80% for natural gas. In contrast, a doubling of uranium prices increases nuclear generating costs by only 2-3%, since uranium costs as a share of generating cost are small.

4.6 Public Policy and Public Acceptance

Public policy and public opinion towards nuclear power development remain divided in Europe. While some countries vigorously support nuclear development others have either placed a total ban on atomic energy or have legislated nuclear phase-out policies. For example, in France approximately 78% of electricity consumption is provided by nuclear power, and in August 2005 Electricité de France (EDF) announced that it plans to replace its 59 present reactors beginning in 2020 at a rate of, on average, one 1600 MWe unit per year. EDF has already selected a site for a demonstration European Pressurized Reactor (EPR), with construction expected to begin in 2007. At the other end of the spectrum, nuclear phase out policies have been legislated by Sweden (1980), Belgium (1999) and Germany (2000), while nuclear power development is banned in Austria, Italy, Denmark and Ireland.

However, there seems to be a slow but steady change in the public's attitude towards the technology - for several years a more positive attitude towards nuclear power has generally been observed and existing public policies in some cases appear to no longer fully reflect the views of the public.

Positive signals started to spread across Europe from the Finnish parliamentary decision in 2002 to build a fifth nuclear power station - the first decision to build a new nuclear power plant in Western Europe for more than a decade.

A national referendum in Switzerland in 2003 rejected the renewal of a moratorium on the construction of nuclear power plants, which had been in place for 10 years. And while Sweden still upholds its nuclear phase-out policy, a public opinion poll in March 2005 showed 83% of the respondents in support of maintaining or increasing nuclear power.

The Netherlands reversed its previous policy of closing down the country's only remaining nuclear power reactor by 2013, and is looking at increasing nuclear power's contribution - for energy security reasons and to limit greenhouse gas emissions.

In Poland, where nuclear development was halted by a Parliamentary decision in 1990, the Council of Ministers approved a draft energy policy in early 2005 that explicitly includes

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carbon capture and storage

nuclear power.

In the United Kingdom positive nuclear power attitudes appear to have emerged at the end of 2005. The UK government has indicated that it may change policy to encourage new nuclear power plants. The majority of the public also supports this policy change. According to a Mori survey of 1 500 people conducted in early 2006, 54% of those polled would accept new nuclear power stations if they helped fight climate change. And 48% agreed that the nation needs nuclear power because renewables alone are not able to meet its electricity needs. Polls also found that pitting nuclear power against renewables lowers support for nuclear power while a combination of both appears often quite acceptable.

A cross-party group of 25 EU Members of Parliament endorsed the vital contribution of nuclear energy in combating climate change and called for more investment in all low- or zero-carbon power generation technologies to address climate change. In November 2005 a 453 to 204 vote in the European Parliament signaled an endorsement of the role of nuclear power in combating climate change.

In March 2005, high-level representatives of 74 governments from around the world gathered in Paris to consider the future role of nuclear power. The vast majority of participants affirmed that nuclear power could make a major contribution to meeting future energy needs and sustainable development objectives.

In the United States, public support for the continued use of nuclear energy now stands at a record high of 70% and shows a continued upwards trend, according to a new opinion poll conducted from 5th to 9th May 2005 for the US Nuclear Energy Institute (NEI).

An 18-country opinion survey sponsored by the IAEA (IAEA, 2005b) found in 2005 that "while majorities of citizens generally support the continued use of existing nuclear reactors, most people do not favor the building of new nuclear plants". Indeed, the findings of the survey show that "six in ten citizens (62%) overall believe that existing nuclear reactors should continue to be used, yet six in ten (59%) do not favor new nuclear plants being built".

In general, it appears that objections to the use of nuclear power based on fears about operating safety can only be addressed by positive experience. The accidents of Three Mile Island in 1979 and Chernobyl in 1986 triggered extensive safety reviews and implementation of additional safety measures. The results of these measures are significantly improved production figures for nuclear power plants around the world with lower radiation doses to plant personnel and fewer unplanned outages. Because safety is a dynamic concept involving continuous improvements, new reactor designs feature further improved safety characteristics.

5 Concluding remarks

The last five years have witnessed a notable change in the perception of nuclear power. Current high fossil fuel prices with no immediate end in sight, fears over energy supply security such as the gas dispute between Russia and the Ukraine earlier this year, entry into force of the Kyoto protocol and a more factual treatment of the technology by the media result in cautious optimism for a brighter future for nuclear power, or “rising expectations”. Evidence of ambitious nuclear power development plans in countries, such as China and India, and positive statements by private and public sector decision makers around the world further nurture these expectations. After a decade of policy support for renewables and clean fossil energy conversion, it is becoming more and more evident that renewables alone can not meet projected energy demand and that fossil fuel based energy services will become even more expensive, especially if used in an environmentally benign fashion. As a result, nuclear power reemerges as an attractive component of a broad energy mix, together with renewables and clean fossil energy conversion. However, one size does not fit all. Countries with untapped wind or hydropower resources, for example, have more possibilities than those with none, and countries that are heavy coal users can consider carbon capture and storage for extended fossil fuel use. It depends on specific energy needs and how fast a country is growing. And it depends on national preferences and priorities. How countries trade off environmental quality, jobs, occupational hazards, energy security and energy costs is at least partly a matter of national preference, and thus an area of legitimate disagreement even where there is agreement on relevant facts. A country sufficiently averse to nuclear risks might rationally prefer a non-nuclear route to GHG emission reductions, even if it were more expensive.

Put succinctly, all countries will need a mix of energy sources, each country's mix will be different, and, globally, all options will need to be included in the energy mix to provide the energy needed to meet global development aspirations while protecting our shared environment.

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