Nuclear energy risks and benefits in perspective

S. Gordelier*

Energy demand, rising prices, security of supply, climate change... these are major issues facing today's energy policy makers. In response, the NEA has recently published a study on *Risks and Benefits of Nuclear Energy* in order to provide these policy makers with authoritative information in support of their decision making. The study has also provided much of the basis for this article.

Energy demand and efficiency

World energy demand continues to increase in an apparently inexorable manner. According to the International Energy Agency (IEA),[1] demand has more than doubled from around 5 500 Mtoe (million tons of oil equivalent) in 1970 to around 11 200 Mtoe in 2005. It also predicts that, based on current government policies, it will continue to increase, reaching about 17 400 Mtoe by 2030, a further increase of 55% over 2005 levels and a factor of more than three above the 1970 levels. Of these increases, coal is expected to rise most in absolute terms.

Electricity demand, as a component of the overall demand, is continuing to grow at an even faster rate, as the world's economies continue to develop. The IEA predicts that electricity demand will have increased by 100% by 2030[1] and that it will have reached 260% of the 2005 value by 2050.[2]

Energy efficiency is important and it is worth making efforts to improve it. However, it is often presented as a solution to the problem. Unless one believes (and can prove!) that world energy demand will cap out, energy efficiency, worthwhile though it is, only buys time to find a real solution, almost certainly technological.

By way of example, assume that overnight one could make an energy efficiency saving of 10%. Total primary energy supply (TPES) is growing by around 1.9% per year. In less than six years one would be back to the same level. Be more ambitious and improve overnight by 20%; in less than 12 years one would again be back to the same level. This is not to say that energy efficiency improvements should not be sought. Rather the time gained should be used to seek the technology developments needed to provide the real answers.

Greenhouse gas emissions

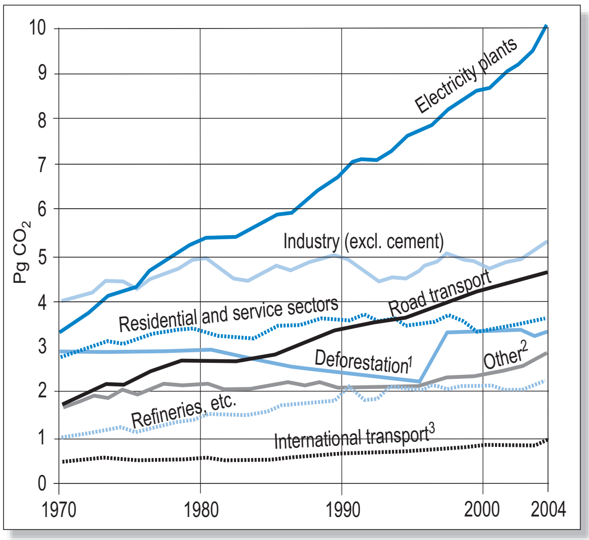
In terms of CO_2 emissions, while the carbon intensity of TPES has improved a little, and emission intensity of gross domestic product (GDP) has fallen more, CO_2 emissions have followed closely in line with population, GDP/capita and TPES. Figure 1 shows CO_2 emissions in terms of the various forms of energy use. For energy-related emissions, it is clear that electricity generating plants are by far the biggest culprit in terms of emissions growth. They are twice the next largest energy contributor, and are growing much faster. Road transport, which has attracted a great deal of media

* *Mr. Stan Gordelier (stan.gordelier@oecd.org) is Head of the NEA Nuclear Development Division.*

and political attention, is only half the size and is growing more slowly, although it is the second fastest growth area. International transport, including aviation, which has also attracted a great deal of attention, seems in reality to be one of the lesser concerns on a global scale.

Figure 1 – **Sources of global CO_2 emissions, 1974-2004**

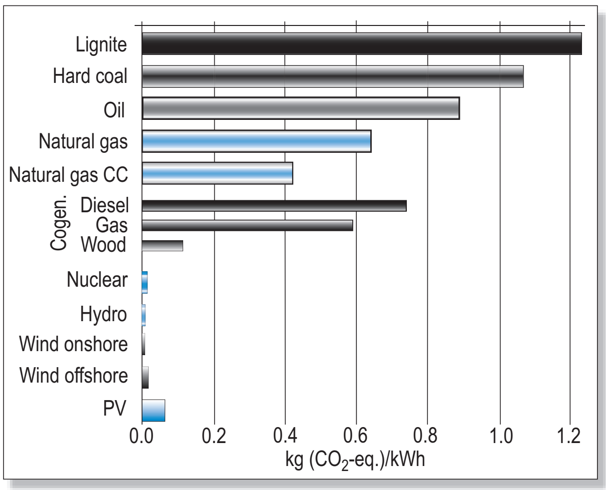
(only direct emissions by sector)



1. Including fuel wood at 10% net contribution. For large-scale biomass burning, averaged data for 1997-2002 are based on Global Fire Emissions Database satellite data (van der Werf et al, 2003). Including decomposition and peat fires (Hooijer et al, 2006). Excluding fossil fuel fires.
2. Other domestic surface transport, non-energetic use of fuels, cement production, and venting/flaring of gas from oil production.
3. Including aviation and marine transport.

Source: IPCC (2007), *Climate Change 2007: Mitigation of Climate Change*, Working Group III Report, Cambridge University Press, Cambridge.

Figure 2 – **Greenhouse gas emissions of selected energy chains**



Source: NEA (2007), *Risks and Benefits of Nuclear Energy*, OECD, Paris.

Hence, power plants are clearly **THE** big issue. This is not to say that the other sectors do not merit attention, but it would seem that unless the emissions from power plants are addressed one cannot really hope to make a significant impact on emissions reduction. Nuclear power can clearly play a role, but it remains a relatively minor player at present, contributing 16% (25% in the more developed economies of the OECD) of world electricity production and only 6% of TPES. Its growth has been curtailed by its contentious nature with politicians and their publics.

Figure 2 shows an analysis for full life cycle emissions from various means of generating electricity. The horizontal axis is expressed in normalised kilograms of CO_2 equivalent, taking into account the warming potential of each gas. All figures shown refer to the UCTE* member countries in the year 2000. Greenhouse gas (GHG) emissions of nuclear and renewable energy are between one and two orders of magnitude below emissions from fossil generation chains. UCTE averages are about 5g CO_2 eq/kWh for hydro and 8g for nuclear, 11g for onshore wind, 14g for offshore, 60g for photovoltaics and 100g for wood co-generation.

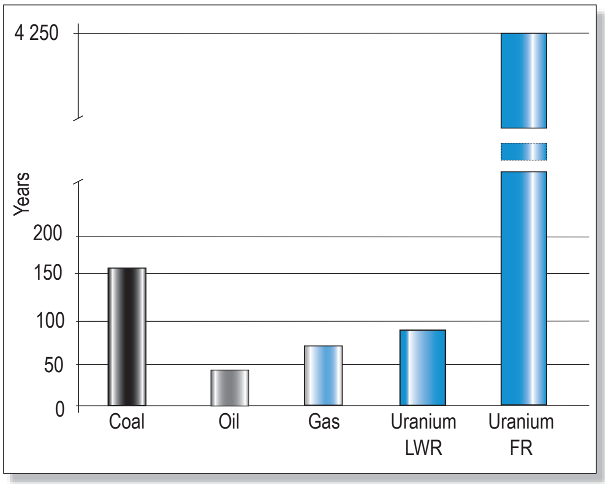
Security of uranium supply

Some suggest that high-grade uranium ores will soon run out and that the life cycle emissions advantages of nuclear will then disappear as uranium extraction becomes much more energy intensive. Official data show otherwise. According to *Uranium 2005: Resources, Production and Demand*[3], the reserves to production ratio for uranium is significantly larger than for oil or gas (see Figure 3). Industry does not dissipate significant exploration expenditures too far in advance of need, whatever the energy source.

Further, in the event of a significant expansion of nuclear power, Table 1 shows that progressive introduction of fast breeder reactors (FBRs), multiplying the energy extractable from a given quantity of uranium by a factor of 50 or more, expands the energy availability dramatically. Given that nuclear

*The Union for the Co-ordination of Transmission of Electricity (UCTE) included, in 2000, Austria, Belgium, Bosnia-Herzegovina, Croatia, Denmark (associate member), France, Germany, Greece, Italy, Luxembourg, the Former Yugoslav Republic of Macedonia, the Netherlands, Portugal, Slovenia, Spain, Switzerland, and Serbia and Montenegro. (The Czech Republic, Hungary, Poland and the Slovak Republic officially joined the UCTE in 2001.)

Figure 3 – **Lifetime of fuel resources* (years)**



* Identified resources, i.e. those resources for which there is already confidence that they are exploitable at reasonable price.

Source: Data taken from NEA (2007), *Risks and Benefits of Nuclear Energy*, OECD, Paris.

Table 1 – **Lifetime of uranium resources (years)**

Technology	Identified ** resources ~4.7MtU	Total** conventional resources ~14.8 MtU	Total conventional resources plus phosphates ~36.8 MtU
LWRs once through	85	270	675
Progressive introduction of FBRs*	4 250	13 500	33 750

* Here it is assumed that the progressive introduction of fast breeder reactors (FBRs) multiplies by 50 the amount of electricity generated by 1 tonne of uranium.

** See reference 3 at the end of this article for an explanation of identified resources and total conventional resources.

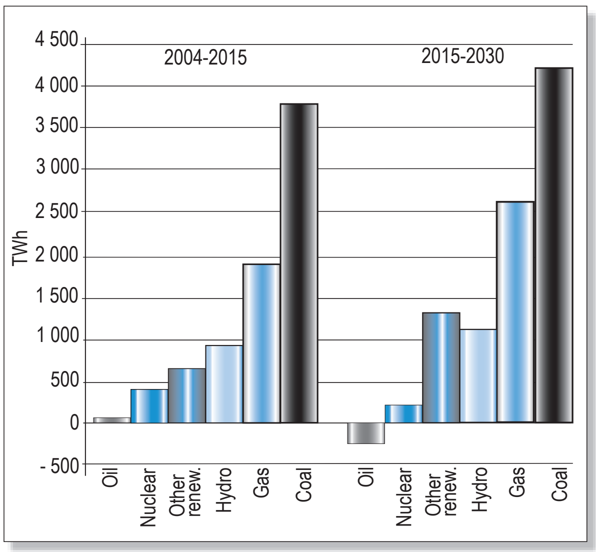
power currently contributes 6% of TPES, the uranium already known to exist in conventional and phosphate resources can quickly be shown to have the energy equivalent of 2000 years of current TPES, largely CO_2-free.

The spot price of uranium has risen from the historic lows of the last two decades to a point where commercial extraction of the very small amounts of uranium residing in some coal ash is under serious consideration. If the extracted uranium were to be used in fast reactors, it would produce more energy than the coal from which it was derived. A thorium fuel cycle is also possible, but has not been commercially developed thus far. Thorium is some three times more abundant in the earth's crust. Hence, there does not appear to be any shortage of largely CO_2-free energy, should one choose to use it.

The need for new power plants – an opportunity and a threat

According to the *World Energy Outlook*[1], some USD 5 trillion will need to be invested in power plants between now and 2030. Given that such investments have typical economic lives of 40 years or so, their normal turnover rate is very low. This represents a major opportunity to invest in low emissions plants for the future. Alternatively, if fossil fuel plants are constructed, they will lock the regions concerned into their continuing emissions up to 2050 and possibly well beyond (it is possible that carbon capture and storage, CCS, could alleviate this if the technology is developed and demonstrated at commercial scale and fossil plants are built as "CCS ready" for future backfitting). Based on current government policies, Figure 4 shows that the vast majority of new power plants will rely on fossil fuel and that most of the additional demand for electricity is expected to be met by coal, which remains the world's largest source of electricity to 2030. Clearly, this will not help achieve climate change objectives, and government policies will need to change quickly in order to do so.

Figure 4 – **World incremental electricity generation by fuel**

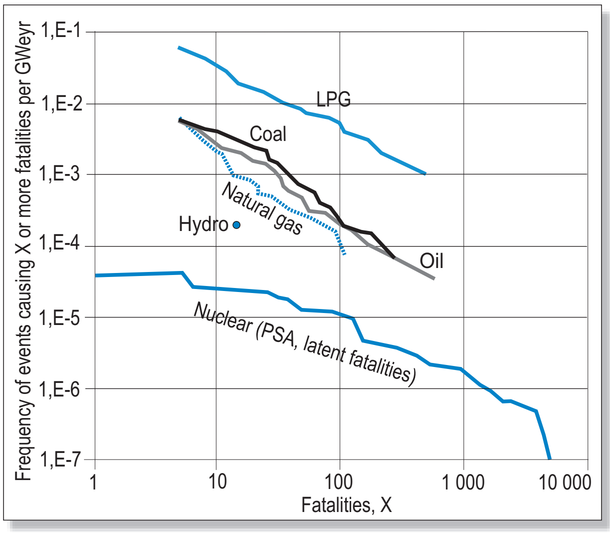


Source: IEA (2006), *World Energy Outlook*, The Reference Scenario, OECD/IEA, Paris.

Risks and benefits study

The recent NEA publication on *Risks and Benefits of Nuclear Energy*[4] covers quantitative and qualitative aspects of these risks and benefits encompassing economic, social and environmental dimensions. It provides numerous comparisons of nuclear and other options for electricity generation and examines techniques by which a wide range of factors can be weighed and balanced in an overall assessment. A small selection will be presented here. The benefits in terms of GHG emissions reduction have already been explored above. In economic terms, nuclear is cost-competitive in many countries that do not charge for carbon releases, and is therefore even more so when and where a carbon charge is levied. For a full description of cost issues and comparisons between energy sources, see the NEA/IEA publication on *Projected Costs of Generating Electricity*[5].

Figure 5 – **Comparison of frequency-consequence curves for full energy chains in OECD countries for the period 1969-2000**



Source: NEA (2007), *Risks and Benefits of Nuclear Energy*, OECD, Paris.

Accident risks

A continuing concern for the public and politicians is the safety of nuclear power. ENSAD, the Energy-related Severe Accident Database established by the Paul Scherrer Institute in Switzerland, contains data on over 18 400 accidents, mainly between 1969 and 2000, of which 35% are energy-related, and 3 117 of which are rated as severe (with five or more prompt fatalities). Figure 5 shows frequency/consequences curves for this data, for OECD countries. The data for LPG, coal, oil and natural gas are data from real accidents. During this period there has only been one severe hydro power accident in OECD countries, resulting in 14 prompt fatalities. There have been no OECD nuclear accidents in this "severe" classification.

To enable some comparison, Figure 5 also shows the probabilistic safety analysis (psa) for a Swiss nuclear power plant. Note that this line is not directly comparable, in that it is for the latent deaths (in contrast with prompt deaths for other data) from theoretically possible releases (not actual releases or accidents). From this figure, one may nevertheless conclude that nuclear energy is much safer, in comparison with other energy sources, than the general public would believe. In OECD countries, both hydro and nuclear are much safer than other sources.

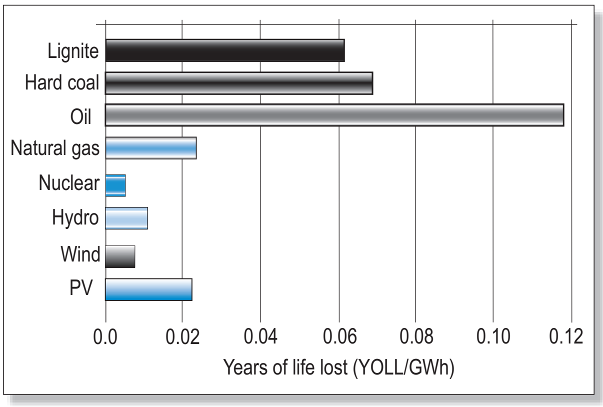
This particular plot could be subject to criticism from a number of positions. In choosing OECD countries, it ignores Chernobyl, but the Chernobyl plant also used a design not licensed in OECD countries and severe as it was, the accident only caused about 40 prompt deaths. It could also be criticised for ignoring the latent death estimates from Chernobyl; but in that case it should also include latent deaths from both operation and accidents, and fossil technologies come out quite badly (see Figure 6). The biggest energy-related accidents outside the OECD area were caused by oil (3 000 fatalities in the Philippines in 1987; 2 700 fatalities in Afghanistan in 1982), hydro (1 000 fatalities in India in 1980) and LPG (600 fatalities in Russia in 1989).

Why then, does nuclear seem to provoke unique safety fears in the public mind? It could likely be some combination of the association with nuclear weapons, the fear of very low probability, but very large accidents, the fact that latent deaths are associated with cancer, a disease much feared in its own right (and cancer can affect "me", whereas oil and gas accidents generally impact those working with the industry, except for the huge accidents), and the publicity that nuclear attracts because of these factors. Almost everyone remembers Chernobyl and even Three Mile Island (no prompt fatalities). Who remembers (or ever heard of) the oil, hydro and LPG accidents listed above, which occurred around the same time and directly killed thousands?

Human health impacts from normal operation

Human health impacts due to normal operation may be represented by "mortality", defined by reduced life expectancy calculated in terms of years of lost life (YOLL). Figure 6 shows, by way of example, an analysis of mortality resulting from the emissions of major pollutants specific to German energy chains. Nuclear, wind and hydro have very low mortality rates associated with normal operation. Mortality for natural gas and solar PV are somewhat higher, and other fossil systems are significantly higher. It is worthwhile noting that, for all chains, mortality due to accidents (as discussed above) is practically negligible compared with the corresponding effects of normal operation. Again this does not seem to be widely known among the public and decision makers.

Figure 6 – **Mortality associated with normal operation of German energy chains in the year 2000**



Source: NEA (2007), *Risks and Benefits of Nuclear Energy*, OECD, Paris.

Decision-making aids

Two decision-aiding techniques are explored in *Risk and Benefits of Nuclear Energy:* internalisation of external costs and multi-attribute decision analysis. An externality exists when some negative or positive impact is generated by an economic activity and imposed on third parties without being priced by the market[6]. If the inventory of externalities could be exhaustive and if their value could be estimated in an accurate and reliable manner, the internalisation of external costs would lead to the best choice. Unfortunately, those two conditions can seldom be fully met. Nevertheless, the technique is of value if it can capture reasonably reliable key components.

Multi-criteria decision analysis can be used as a separate decision aid, or as a complementary technique. It enables a more extensive representation of social criteria, but these are the most difficult to define, select and measure, and are therefore the most controversial. Examples are discussed using three branches of impact factors (those factors which are evaluated and weighed against each other): economic, environmental and social. In general, only if very high weight is given to social factors (e.g. aversion towards hypothetical severe accidents) does the analysis show that nuclear power is not in the group of the most advantageous generating technologies. Many of these social issues remain controversial and, depending on the socio-political perspective of those involved, can be of paramount importance. Otherwise, with balanced weightings, nuclear power regularly ranks amongst the best generating technologies available.

Conclusions

The world's energy challenges are serious. Power plants are the biggest and fastest growing contributors to greenhouse gas (GHG) emissions. They are already twice the size of the next largest sector for energy consumption.

Due to the rapid growth in energy demand in developing countries, and the need to replace the ageing stock of power plants in developed economies, some USD 5 trillion will need to be spent over the coming two decades. This provides an excellent opportunity to invest in largely GHG-free generating capacity. Governments and industry must act decisively if this opportunity is not to be missed.

Nuclear electricity is virtually CO_2-free and, in principle at least, there are vast amounts of energy available for the countries that decide to use it. Known available uranium resources have a potential energy equivalent of 2000 years' worth of the current global total primary energy supply.

However, nuclear energy remains contentious in many countries. The OECD/NEA has published its study on *Risks and Benefits of Nuclear Energy* to provide policy makers with authoritative information in support of their decision making and public debate. ■

References

1. IEA (2006), *World Energy Outlook*, OECD/IEA, Paris.
2. IEA (2006), *Energy Technology Perspectives*, OECD/IEA, Paris.
3. NEA (2006), *Uranium 2005: Resources, Production and Demand*, OECD, Paris.
4. NEA (2007), *Risks and Benefits of Nuclear Energy*, OECD, Paris.
5. NEA and IEA (2005), *Projected Costs of Generating Electricity – 2005 Update*, OECD, Paris.
6. Pearce, D. (2002), *"Energy Policy and Externalities: An Overview"*, in the proceedings of the IEA/NEA workshop on *Externalities and Energy Policy: The Life Cycle Analysis Approach*, OECD, Paris.