COMPARATIVE RISK ASSESSMENTS OF ENERGY OPTIONS
THE MEANING OF RESULTS

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Significant progress has been made in both the development of the techniques of comparative risk assessment, and in the use and interpretation of their results. This is particularly so for the assessment of options for electricity generation and transport. The results have become a useful aid to decision-making, though they often need to be integrated with other social, political, and economic issues before any decision may be made.

Seven studies have been published since 1990 that analyze "complete" fuel chains. *(See box and tables, pages 15 and 16.)* In all of them, the risks were converted to a monetary cost, although some discussion of non-monetary values is included.

A review of their results shows that:

- There is a range of damage estimates due to different assumptions and methodologies. The differences also show the development of a methodological approach which is more complete in recent studies, such as the European Commission's (EC) ExternE project.
- Large differences in assumptions and methodologies make direct comparisons difficult; and
- None of the assessments was able to include all of the possible impacts (e.g. global warming except to a limited extent, or the possible diversion of fissile material).

These limitations have to be brought to the attention of decision-makers so that they can be factored into any decision.

The main controversies for comparative risk assessment concern global warming for fossil fuels; catastrophic accidents, particularly for nuclear and large hydropower plants; and high-level radioactive waste disposal. These issues involve technical and complex social and political questions. However, comparative risk assessment should provide information in a transparent manner so the limitations and strengths of results are correctly understood.

Some specific issues and impacts that must be assessed in comparisons of energy systems include:

Fossil Fuels. For fossil fuels the dominant impacts are global warming and mortality from air pollution (particles, NO_x and SO_2). Natural gas is cleaner and therefore has lower impacts than coal, with the impacts being about two to four times smaller for plants meeting current emission standards within the European Union (EU). The monetary values of the impacts from the use of fossil fuels are relatively large, especially for coal-fired electricity generation (ranging from 10% to 100% of the market price of electricity for plants operating at the present time in the EU).

Global warming is generally accepted as an important risk resulting from fossil fuel combustion. But more studies are needed on its possible impacts. The report of the EC ExternE Project published in 1999 investigates the influence of some of the most sensitive parameters in the analysis of global warming. Although the report does not narrow the broad range of results already reported for global warming effects, it clarifies which uncertainties are likely to be most significant. It seems likely that as fossil fuels continue to be used in the future, greenhouse gas levels will increase and regulations to control emissions will have to be tightened.

Nuclear Power. For nuclear energy generation, the dominant impacts are possible cancers and hereditary effects resulting from exposure to increased levels of radioactivity in the environment.

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COMPARATIVE RISK ASSESSMENTS OF ENERGY FUEL CHAINS IN THE 1990s

YEAR/STUDY	KEY ATTRIBUTES
1991: *Environmental Costs of Electricity*, R.L.Ottinger et al, Oceana Publications, New York (1991)	***Scope:*** United States. Assessed nuclear, coal, oil, gas, hydropower, solar, wind, energy from waste. Impacts analyzed: health, crops, forests, fisheries, materials, visibility. Global warming assessed by abatement cost, not damage cost.
1992: "*The Social Costs of Fuel Cycles*" D.W. Pearce, C. Bann, and S. Georgiou, report for the UK Department of Trade and Industry, CSERGE, University College of London (1992); and "*Development of Externality Adders in the UK*", D.W. Pearce, presentation at workshop organized by the European Commission, International Energy Agency, and the Organization for Economic Cooperation and Development, (30-31 January 1995).	***Scope:*** United Kingdom and European Union. Thirteen fuel chains/technologies assessed. Impacts analyzed: health, crops, forests, biodiversity, materials, visibility.
1993:"*External Costs of Electricity Generatio*", R. Friedrich and A. Voss, Energy Policy (February 1993).	***Scope:*** Germany. Assessed nuclear, coal, wind, photovoltaics. Impacts analyzed: forests, agriculture, fauna, materials, health.
1994:"*An Analysis of Electricity Generation Health Risks: A United Kingdom Perspective*", D.J. Ball, L.E.J. Roberts, and A.C.D. Simpson, Centre for Environmental and Risk Management, School of Environmental Sciences, University of East Anglia, Norwich, UK (1994).	***Scope:*** United Kingdom. Assessed nuclear, coal, oil, gas, wind, tidal. Focus on risks to human health. Transboundary air pollution and global warming are not taken into account. No monetary valuation.
1994: *External Costs and Benefits of Fuel Cycles*, Russell Lee, editor, Oak Ridge National Laboratory and Resources for the Future, Oak Ridge, Tennessee, USA (1994).	***Scope:*** Two sites southeast and southwest of United States. Assessed nuclear, coal, oil, gas, hydropower, biomass incineration. Local and regional impacts.
1995: *The New York City Electricity Externality Study*, R.D. Rowe, C.M. Lang, L.G. Chestnut, D. Latimer, D.Rae, S.M. Bernow, and D. White, Ocean Publications, New York (1995).	***Scope:*** Two sites in New York State, USA. Assessed nuclear, coal, oil, gas, biomass incineration, wind. Local and regional impacts.
1995: *ExternE: Externalities of Energy*, European Commission, Directorate General XII, Luxembourg (1995).	***Scope:*** European Union, numerous sites (United Kingdom, Germany, France, Norway). Assessed nuclear, coal, lignite, oil, gas, hydro, wind. Local, regional, and global impacts. Literature survey for global warming.
1996: *Environmental Impacts and Costs: The Nuclear and Fossil Fuel Cycles*, A. Rabl, P.S. Curtiss, J.V. Spadaro, B. Hernandez, and A. Pons, European Commission, Luxembourg (1996).	***Scope***: Application of 1995 ExternE to France. Assessed nuclear, coal, oil, gas. First systematic study of site dependence.
1996: *Counting the Social Costs: Electricity and Externalities in South Africa,* C. van Horen, Elan Press and UCT Press, University of Cape Town (1996).	***Scope:*** Application of ExternE/Rowe et al. to South Africa. Assessed nuclear, coal.
1999: *ExternE: Externalities of Energy*, European Commission, Directorate General XII, Science, Research, & Development, Luxembourg (1999). Three volumes on national implementation, methodology update, and global warming effects.	***Scope:*** Fourteen European Union countries and Norway. Many technologies. Assessed local, regional, and global impacts. New analysis for global warming. Chronic mortality applied to primary and secondary particles. Valuation of mortality using years of life lost (YOLL).

SUMMARY OF IMPACTS AND DAMAGE COSTS FOR COAL FUEL CHAIN

Study	Impacts (deaths per TWh)	Damage Costs (in milli-Euro per kWh)				
	Occupational Fatalties	Public Health	Occupational Health	Environment	Global Warming	Study Total
Ottinger et al 1991						22-55
Pearce et al 1992		0.05		0.005	0.04	0.14
Pearce et al 1995						0.11
Friedrich & Voss 1993		0.01-0.07		0.013-0.015		0.02-0.09
Ball 1994	0.04-0.14					
ORNL/RFF 1994		0.01-0.64	0.08	0-0.1	nq	0.7-1.4
Rowe et al. 1996		3 to 5		0.1	nq	3 to 5
ExternE 1995	0.13-0.23	4 to 13	1 to 2	0.2 to 0.8	10 to 18 (at 0% discount rate)	16 to 34
Rabl et al 1996		5 to 14	nq	0.02	15	20 to 29
ExternE 1999		10 to 50		0.5 to 2	10 to 50	20 to 100

Notes: Numbers have been rounded. For study totals, refer to other columns to see what is included.
nq = not quantified

SUMMARY OF IMPACTS AND DAMAGE COSTS FOR A NUCLEAR FUEL CHAIN

Study	Impacts (deaths per TWh)		Damage Costs (in milli-Euro per kWh)					
	Public Fatalties	Occupational Fatalties	Public Health	Occupational	Environment Health	Global Warming	Major Accident	Study Total
Ottinger et al 1991			4.9				18.5	23
Pearce et al 1992			0.003-0.009			0.0012	0.002-0.006	0.007-0.017
Pearce et al 1995						0.0012	0.006-0.044	0.006 -0.044
Friedrich & Voss 1993			0.001 -0.005		0 -0.002		0.0005-0.004	0.002 -0.01
Ball 1994	0.01-1.23	0.02-0.09						
ORNL/RFF 1994			0.012	0.08-0.09				0.09 -0.1
Rowe et al. 1996								0.09
ExternE 1995	0.65	0.04	2.4	0.15				2.6
Dreicer et al. 1995	0.62	0.02	2.4	0.14			0.0005-0.023	2.5

***Notes**: Numbers have been rounded. For study totals, refer to other columns to see what is included.*

For the public, the individual risks from routine releases of the complete nuclear fuel cycle tend to be small if no accident occurs. But if integrated over long time periods for the entire global population, the collective risk appears significant under assumptions generally accepted by the radiological protection community.

Other issues concern assumptions about changes in the international political climate and governmental compliance with globally accepted standards and norms. Given the lessons of the last ten years, let alone events of the past few thousand years, political factors clearly should not be ignored.

If analysts assume governmental adherence to all safety regulations, and they exclude consideration of catastrophic accidents, the impacts of nuclear power are small (the monetary valuation or "cost" of these impacts are a few percent of the market price of electricity, much lower than those for fossil fuels).

Additional considerations include the social costs of other public concerns, such as the proliferation of fissile materials; these have not been included in most comparative risk assessments, though they were discussed in the latest ExternE report.

Renewable Energy Sources. A great variety of renewable energy technologies exist, but assessment of them is difficult because some of their impacts are extremely site specific. Their impacts during the stage of power generation are small, with the exception of biomass (where materials are burned on site) and some hydroelectric plants at certain sites (where water flow changes can seriously affect the environment).

Overall, however, the impacts of renewables can be significant at the stage of equipment production and plant construction. This is because the amount of materials used per unit of effective power generation is larger than for other energy systems. Some renewable technologies can have appreciable amenity impacts (such as noise). Reported experience with some hydropower plants in India has shown the importance of considering land use, and societal and cultural impacts, particularly where large populations are displaced.

INTERPRETING THE RESULTS

Methods of Comparison. Key questions in comparative risk assessment concern the methods of deriving a common denominator for comparing results. The questions have a direct bearing on the assessment methodology and are important for the interpretation of results. In all cases, the methods that are used will have an important influence on how the information can be used in decision-making.

Once the releases and/or impacts of different energy fuel chains have been estimated, many studies have quantified and converted them into monetary values, often called "external costs".This valuation remains controversial, particularly for human life or other impacts that are not driven by market forces equally among countries.

Methods have been developed that account for these type of "social costs" but they have not been accepted by all analysts.

Another method that can be used in certain situations is to base the interpretation of results on "exceedances" of environmental standards; in other words, on the extent to which they are exceeded. Many studies have compared risks in this way, and the approach is particularly appropriate where issues of biodiversity and ecological impact are to be considered and monetary valuation would be highly subjective.

When this approach is applied, it is vital to understand the basis and appropriateness of the standards being used. The selected standards must be relevant to the specific comparative risk assessment being done, since they are not generally transferable to other studies, and they will complicate the interpretation of results. International agreements, such as the Montreal Protocol and the 1997 Kyoto agreement, can be used as benchmarks against which results can be interpreted.

Another method of comparision is to rank risks through the use of techniques such as multi-criteria analysis and risk screening. These have some advantages compared to economic assessment, in that they are in theory at least able to ascribe weightings to all known impacts without requiring further experimental valuation work. The weightings assigned to each impact can effect the results, and sensitivity analysis is a useful aid for interpreting results in these circumstances.

Presently, the method of monetary valuation has a major advantage in that the metric used is familiar to virtually everyone around the world. Hence the results generated have a higher level of understanding than those arising from application of weightings based on multi-criteria analysis.

Time and Space Scales. The interpretation of results of comparative risk assessments further depends on the timescale over which the impacts occur and are assessed. If monetary valuation and discounting are used, the importance of using similar timescales when assessing different impacts becomes even more important. The choice of discount rates need to be accounted for in the interpretation of results. This is because the selected rate could serve to minimize long-term risks, which is not acceptable to everyone.

Equally, time periods over 25 years will introduce issues of inter-generational equity which can greatly affect both the interpretation and subsequent use of the results. In the selection of discount rates for inter-generational costs, a crucial variable has usually been overlooked: the evolution of future technologies and costs.

For instance, if a simple and pain-free cure for cancer is found, most impacts and therefore the costs of the nuclear fuel chain can become negligible. Similarly, for global warming, a number of actions might mitigate impacts and the costs for fossil fuel chains. In light of these factors, the weighting of long-term impacts typically involves a choice of scenarios.

Apart from long-lived globally dispersed gases (greenhouse gases, carbon-14, iodine-129), most impacts are fairly local and site dependent.

For the gaseous air pollutants, NO_x and SO_2, the impacts can easily vary by an order of magnitude with conditions of site and stack height.

For example, a tall stack disperses the pollutants farther away from the site, making the electricity plant's location far less important in the assessment of long-term impacts of particulates. Site dependence is particularly strong for water pollution, solid wastes, and mining (including assessments of accidents).

Uncertainties. Uncertainty of data used for comparative risk assessments and interpreting the results is an issue that deserves special attention.

Four types of uncertainty should be considered:

- technical/scientific (models, input parameters, data, dose-response functions);
- policy/ethical choices (value of life in countries, inter-generational discount rate);
- scenarios for the future (lifestyles, population size and distribution, technological and medical advances);
- omission of some types of impacts.

The selection of technical/scientific methods, scenarios, and assessment of specific impacts are influenced by expert judgement. Because such opinions are by nature subjective, they should be clearly indicated so that decision-makers can take them into account when interpreting the results.

In this context, it is important to note that public perceptions of risks are important factors in energy policy- and decision-making. This is particularly the case for public concerns about environmental risks, where perceptions may not always square with expert opinions.

COMPARATIVE STUDIES OF ENERGY FUEL CHAINS: POSSIBLE APPLICATIONS

- ***Application*:** Choice and balance of technologies for strategic energy planning (e.g. coal vs. nuclear vs. renewables). ***Information Requirements:*** impacts and costs of fuel cycle (aggregation over all stages of the technologies under consideration).
- ***Application*:** Choice of a new power plant. ***Information Requirements:*** Impacts and costs of power plant (aggregation over the emissions for each of the technologies under consideration)
- ***Application*:** Optimal dispatching of existing plants. ***Information Requirements:*** Impacts and costs of each of the plants in electric grid (aggregation over all stages).
- ***Application*:** Optimization of regulations (emission limits, environmental quality objectives such as air quality limits, tradable permits, pollution taxes, etc.). ***Information Requirements:*** Impacts and costs, for each pollutant and each polluter (no aggregation).
- ***Application*:** Green accounting (correction of GNP for environmental damage). ***Information Requirements***: Costs (aggregation over all emission sources in a country).

APPLYING THE RESULTS

Results of comparative risk assessments can be used for a range of potential applications. How they are applied is important. *(See box.)*

Transferring the results of one scenario to another, or from one country to another, can be problematic. For example, at the present time, the results of an assessment of a major accident in Eastern European countries may not be applicable to an accident elsewhere because of differing economic conditions.

Other examples further underscore the difficulty of trying to apply the results from one assessment to another. Some of them concern the assessment of environmental costs that are based on studies estimating a particular society's "willingness to pay" them. Differences among countries in environmental laws, regulatory standards, and other factors all must be taken into account.

As is the case with all risk assessments, the final presentation of results directly influences how effectively the information can be used.

In the chemical industry, comparative risk assessments often present the risks using ranked lists or matrices. The European Commission's ExternE Project presented the results for all stages of the fuel chain and all output stages of the impact pathways (burden, impact, value). This was done so as to present results with maximum transparency.

For decision-making purposes, the presentation of results can be particularly important.

When reporting the results of comparative risk assessments, a number of factors should be made clear:

- the precise nature of the energy system being assessed;
- the impacts that have been quantified;
- what has been excluded from the analysis;
- sources of data used in the assessment;
- assumptions that have been made; and
- what the analysts and other experts have regarded as the key sensitivities in the analysis.

If all factors are addressed, the results of comparative risk assessment will prove to be an essential resource for making the best decisions about energy options and policies. ❐