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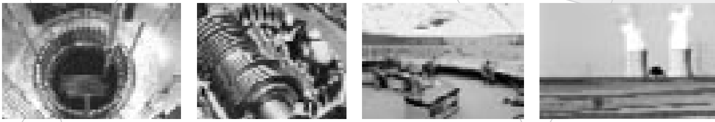

ILK Statement

on Sustainability Evaluation of Nuclear Energy and other Electricity Supply Technologies

Für deutsche Fassung bitte umdrehen!

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Foreword

The International Committee on Nuclear Technology (Internationale Länderkommission Kerntechnik, ILK) was established by the three German states of Baden-Württemberg, Bavaria and Hesse in October 1999. It is currently composed of 12 scientists and experts from Germany, France, Sweden, Switzerland and USA. The ILK acts as an independent and objective advisory body to the German states on issues related to the safety of nuclear facilities, radioactive waste management and the risk assessment of the use of nuclear power. In this capacity, the Committee's main goal is to contribute to the maintenance and further development of the high, internationally recognised level of safety of nuclear power plants in the southern part of Germany.

Over the last few years the question of a sustainable energy supply for the future has repeatedly been raised and has been discussed under widely varying framework conditions. These include for example, issues related to global warming or limited energy resources. The ILK attaches great significance to these topics and has thus, with the support of a third party expertise, dealt extensively with the sustainability evaluation of nuclear energy and other electricity supply technologies. The present ILK statement was adopted at the 27th ILK meeting on January 23rd, 2004 in Munich. In the ILK´s view, the evaluation process must be transparent and should also consider societal issues next to economic and environmental ones. This statement outlines an example of an evaluation method. Using this methodological example as a basis, a debate on the sustainability of energy supply technologies involving all major stakeholders is proposed. This statement is therefore not only directed at the regulatory authorities, but at politics and the general public as well.

The Chairman

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1 Introduction

The electric utility sector is of central importance for economic growth and societal development. While numerous societal and economic benefits arise from electricity consumption, its production can also have impacts which may not be fully and unanimously reconciled with the concept of sustainability. Consideration of sustainability issues plays an increasingly important role in decisions affecting the current and future energy supply. Judgements on the sustainability of specific electricity supply options are, however, mostly made in an ad hoc manner, and are susceptible to bias and arbitrariness. The German Federal Government singles out nuclear energy in particular as not sustainable for the future and considers it in a fundamentally critical manner separately from the other options. The ILK's opinion is that all options of interest, including nuclear, need to be evaluated in a comparative perspective based on a systematic and comprehensive approach. Therefore, the ILK considered it worthwhile to investigate this matter in more detail and express its views in the form of the present statement.

The ILK statement on sustainability takes into consideration the most relevant international and national developments. These form the background and input for the establishment of ILK's position. A limited scope comparative study on the sustainability of different electricity supply technologies under German conditions was carried out [1] by the Paul Scherrer Institut (PSI) in order to demonstrate the applicability of a systematic approach and generate reasonably consistent results from which robust conclusions can be derived.

2 Sustainability Concept and its Operationalisation

The concept of sustainable development first emerged or rather was reborn in 1987 with the publication of the report "Our Common Future" by the World Commission on Environment and Development (the so-called Brundtland Commission). Sustainable Development, as defined in this report, is the capability to "meet the needs of the present without compromising the ability of future generations to meet their own needs" [2]. *In a broad sense, sustainable development incorporates the aim of equity within and across countries as well as generations, and integrates economic growth, environmental protection and societal welfare.* A key challenge of sustainable development policies is to address those three dimensions in a balanced way, considering their interactions and making relevant trade-offs whenever necessary.

In the meantime a wide spectrum of definitions of sustainable development has been proposed, with varying emphasis on the major attributes of sustainability[1]. The ILK supports the basic ideas expressed by the definition in the report by the Brundtland Commission. At the same time this definition is subject to various interpretations, which are highly essential for the implementation and practical applications. On the conceptual level there is a quite distinct dividing line between those advocating "strong" sustainability versus proponents of "weak" sustainability. The differences between these basic concepts stem from different assumptions about substitutability between natural and man-made resources ("capital"), about compensating damage, and about discounting future events. "Weak" sustainability demands that the present generations have an obligation to leave future generations a capital stock which remains undiminished overall while simultaneously allowing that man-made capital can in principle be substituted for natural capital.

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1 The ILK statement focuses on the degree of sustainability of specific energy carriers and current technologies, i.e. the scope of assessment is more limited than when addressing sustainable development in general.

The ILK subscribes to the view that:

- The use of renewable resources should not exceed their regeneration rate.
- Non-renewable energy carriers and raw materials should be consumed at most at a rate which corresponds to physically and functionally equivalent substitution by economically useful renewable resources, increased efficiency in utilizing the available resources or discovery of new reserves.
- Pollution and waste flows into the environment should not exceed the absorption capacity of the natural environment.
- Technologies incorporating risk should only be adopted if they produce sufficient benefit to society. Risks to human health should be kept as low as reasonably achievable.

Thus, with regard to resource consumption "weak" sustainability is adopted by the ILK. This position is realistic, considering that the (human) "development component" is a mandatory part of the overall concept.

The above discussion on sustainable development constitutes an essential background. However, the definitions and principles as such do not allow for a straightforward operationalisation of the sustainability concept if the objective is to differentiate between the performances of various energy technologies of interest. Independently of the chosen sustainability concept there seems to be a general consensus that promotion of sustainable development within the electricity sector calls for the integration of economic, ecological and societal dimensions in the decision-making process. The ILK's opinion is that the evaluation of alternatives can (and should) be done on the basis of an explicitly stated set of criteria and indicators covering these three dimensions, which should be agreed upon for specific applications, i.e. in this case for electricity supply technologies.

There are many examples of criteria and indicators relevant for the sustainable development and established by international and national organizations. Examples include proposals by: United Nations (UN) special Commission on Sustainable Development [3], OECD [4, 5], IAEA [6], German Enquête Commission [7] and PSI [8, 9]. The initiatives have been driven by global concerns about "the planet earth" and by demands of decision makers responsible for the promotion and attainment of sustainable development mainly on the national level. At the same time there have been very few attempts of consistent implementation of the proposed sets.

The state of the art can be summarized as follows:

1. The indicators have different scope and focus: sustainable development in general, sustainable development of the energy sector, sustainable development of specific energy carriers.
2. The sets of indicators originating from international organizations are not sufficient for comparing sustainability attributes of major energy carriers, with appropriate differentiation between technologies.
3. Economic and environmental criteria/indicators are relatively well developed; societal indicators are poorly developed and highly subjective (in relevant cases).
4. Most of the sets are primarily based on directly available, simplistic indicators. There are major problems with consistency.
5. Few efforts have been made towards aggregation of indicators to support decisions.
6. The sets of indicators originating from the Enquête Commission and PSI exhibit a number of similarities. The Enquête Commission does not consider specific accident and waste indicators that are highly relevant for the societal dimension. PSI's set employed in aggregation avoids use of overlapping indicators, which is not the case with most other sets.
7. A set of widely accepted, technology- and application-specific, harmonized numerical indicators is not available from earlier studies. A broad knowledge base is a prerequisite for the establishment of such indicators. The analytical framework that can serve as a basis for analyses leading to generating a relevant set of indicators has been employed in the PSI study [1] which provides the basis for this statement.

Based on survey results, experiences by PSI from sustainability assessments under radically different conditions encountered in Switzerland and in China, and basic requirements on indicators, the ILK follows the recommendations in [1] on an appropriate criteria and indicator set. Three dimensions of sustainability, i.e. Economy, Environment, and Society (including health) were considered. The table below provides the indicators selected for the evaluation of alternative electricity generation technologies and proposed as a basis for further discussion.

Dimension	Impact Area	Indicator	Unit
Economy	Financial Requirements	Production cost	*€ cent/kWh*
		Fuel price increase sensitivity	*Factor*
	Resources	Availability (load factor)	*%*
		Geo-political factors	*Relative scale*
		Long-term sustainability: Energetic	*Years*
		Long-term sustainability: Non-energetic	*kg (Cu)/GWh*
		Load following	*Relative scale*
Environment	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	Collective risk	*Fatalities/GWh*
	Total Waste	Weight	*tons/GWh*
Societal	Employment	Technology-specific job opportunities	*Person-years/ GWh*
	Proliferation	Potential	*Relative scale*
	Human Health Impacts (normal operation)	Mortality (reduced life-expectany)	*Years of Life Lost/GWh*
	Local Disturbances	Noise, visual amenity	*Relative scale*
	Critical Waste Confinement	“Necessary” confinement time	*Thousand years*
	Risk Aversion	Maximum damage of potential accident	*fatalities/ credible accident*

These indicators are taken from the PSI report [1] with a few changes in wording to facilitate comprehensibility within this ILK statement. As outlined before, sustainability addresses the needs of both, the future and the current generation, which is, among others, reflected in indicators like “Land use” or “Local disturbance”. The aspect of efficiency is not taken as a separate indicator but rather implicitly incorporated within the set of indicators used. In accordance with the Enquête Commission [7] health is considered a part of the societal dimension rather than of the environment dimension. In general it is assumed that these indicators are sufficiently independent of each other.

The unit (“factor”) for the indicator “Fuel price increase sensitivity” reflects the increase of production costs due to the doubling of fuel costs. The indicator “Geopolitical factors” is related to the security of energy carrier supply in view of the stability of the country of origin (based on judgment). Copper (Cu) was selected as a representative measure for non-energetic aspects (resources) of “Long-term sustainability” since it is a relatively expensive, broadly used raw material which cannot be fully recycled. The “Collective risk” is defined as consequences of severe accidents related to the amount of electricity generated by this technology per year. The number of fatalities serves as a surrogate for the corresponding environmental effects and is either based on historical data or theoretical analyses (probabilistic safety assessment, PSA). “Employment” is an important societal issue for current and future generations; possible detrimental effects of labor intensive energy production are reflected in “Production cost”. “Fatalities per credible accident” is used as a surrogate for “Risk aversion” reflecting the maximum damage that may be caused by potential accidents, without taking their frequency into account and thus differs from “Severe accidents” and “Collective risk”, respectively.

3 Implementation – Reference Set of Indicators

3.1 Methodology for Indicator Assessment and Aggregation

The quantitative indicators used in the PSI study are based on a systematic, multidisciplinary, bottom-up methodology for the assessment of energy systems [1]. The overall approach is process-oriented, i.e. the technologies of interest and their features are explicitly represented. The implementation and applications of the various assessment methods is inspired by principles adopted from Life Cycle Assessment (LCA) [1]. The methods briefly described here focus on disaggregated environmental and related societal indicators; most economic and societal indicators are either directly available, or may be based on straight-forward assessment and use of expert judgment.

Detailed *environmental inventories* (i.e. burdens such as emissions or wastes) for current and future energy systems during normal operation have been established for UCTE (European "Union for the Coordination of Transmission of Electricity") countries, with the highest level of detail for Switzerland (see [1]). Full energy chains are covered, including fuel extraction and conversion, energy production and waste management. All systems are described on a "cradle to grave" basis, with each step in the chain being decomposed into construction, operation and dismantling phases. Material inputs and transportation needs are accounted for in connection with all energy chain stages. The approach allows the coverage of: (a) the direct emissions and other burdens from the entire lifetime of power plants as well as all relevant processes upstream and downstream within each energy chain; and (b) the indirect emissions and other burdens associated with material and energy inputs.

The *environmental impact* analysis allows the estimation of pollutant concentrations and depositions resulting from emissions of the major pollutants. The estimation of *environmental external costs*, i.e. health and environmental damages currently not included in energy prices, is based on the "impact pathway" approach [9, 10]. The steps involved in this approach are: technology and site characterization, including the burdens they impose, description of the receiving environment, quantification of impacts (using dispersion models for atmospheric pollutants and dose-risk relationship whenever applicable), and economic valuation.

Severe accident risks are addressed based on the examination of historical experience world-wide and by employing Probabilistic Safety Assessment (PSA) techniques, i. e. for nuclear energy. In this context a highly comprehensive database

ENSAD (Energy-related Severe Accident Database) was established (see [1]), which covers the full energy chains. In the evaluations particular attention is being paid to the applicability of historical data to the cases being analyzed. A broad spectrum of damage categories is addressed including fatalities, serious injuries, evacuations, land or water contamination, and economic losses (see also [11] for a discussion of severe accident risks in the field of nuclear energy).

External costs estimates represent a highly aggregated indicator of environmental performance. The *total ("true") costs* of electricity production by different means are established by combining internal costs with the external ones. It has been proposed by some authors, e. g. [12], that the total system-specific cost of energy production could serve as an integrated relative indicator of sustainability since it reflects the economic and environmental efficiency of energy systems. It should be pointed out that these total costs comprise only the costs directly attributable to the specific energy carriers. There are other costs which result from the specific mix of energy carriers in the overall energy supply system. For example different energy mixes and different regional distributions may entail varying costs for the grid and for reserve capacities. These aspects penalize energy carriers with stochastic availability or a strong regional concentration.

Another approach to aggregation is based on the application of *multi-criteria decision analysis* (MCDA). The use of the multi-criteria framework allows decision-makers to simultaneously address the often conflicting economic, ecological and societal criteria. In comparison to the total cost assessment, MCDA brings the societal dimension into the equation. The study commissioned by the ILK involves extensive use of the acquired detailed knowledge on systems performance in a process that is also able to account for values.

3.2 Reference Technologies

The evaluation covers fossil energy carriers (lignite, hard coal, oil, natural gas), nuclear and renewables (hydro, wind, solar (photovoltaic (PV))). Whenever feasible, electricity generation technologies currently operating in Germany were selected as the reference. The calculations carried out are representative for the average performance characteristics for these technologies. The same applies to the associated energy chains. Also, representative load factors were employed. The set of indicators chosen for the evaluation reflects the fact that only current technologies are considered. For example, expansion potential, a critical attribute when considering realistic options for future electricity supplies, has not been considered within the present evaluation that is centered on the current electricity supply in Germany.

3.3 Data Adjustments to German Conditions

Germany-specific data were used directly when available and considered consistent with the overall framework. In few cases use of the Swiss data was relevant as the possible differences were judged to be insignificant. Whenever necessary, suitable adjustments of mostly the Swiss or UCTE indicators to the German conditions were made. Due to resource constraints some of these adjustments were by necessity relatively rough, which is nevertheless adequate for the purpose of the current study.

In the particular case of accident indicators, the OECD-specific results for fossil and hydro chains (see [1]) were considered to be representative for Germany. For nuclear energy the risk measures obtained in Level 3 PSA for a Swiss nuclear power plant were employed as the starting point and then adjusted to reflect the higher power level and higher radioactive inventory that are more typical for the German plants.

The following tables show the complete set of indicators used in the present application. Some of the numbers provided in the tables originate from model-based assessments, some are based on judgment. The associated uncertainties may be substantial. For this reason the cited quantitative indicators are primarily suitable for comparisons aiming at establishing an internal technology ranking. They are adequate for the purpose of the present study, including MCDA-based aggregation. The numbers have been rounded where applicable. The attempt to establish quantitative values for all technologies and all indicators had to be restricted to point scores; although desirable the state-of-the-art does not allow a general quantification of ranges of uncertainties.

Some comments regarding the numbers for specific indicators might be helpful for a better understanding of the following tables: The indicator “Production cost” covers the costs for systems currently in operation, but not for new ones. The capital costs of the operating installations are included unless they have been amortized as for example in a lot of cases of nuclear energy. The quoted maximum numbers for “Risk aversion” were derived from experience for all technologies, except nuclear. For nuclear the figure is taken from theoretical analyses (PSA, level 3, see also [11]) that are dominated by long term effects from low doses taking a linear dose-risk relationship as a (conservative) basis. These analyses contain substantial uncertainties.

Economic Indicators*

Impact Area	Indicator	*Unit*	Lignite	Hard Coal	Oil	Natural Gas	Nuclear	Hydro	Wind	Solar (PV)
Financial Requirements	Production cost	*€ cent/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
	Geo-political factors	*Relative scale*	100	80	20	40	80	100	100	100
	Long-term sustainability: Energetic	*Years*	400	2 000	100	100	500	∞	∞	∞
	Long-term sustainability: Non-energetic	*kg (Cu) /GWh*	13	11	12	4	5	1	510	230
	Load following	*Relative scale*	20	50	100	100	10	30	0	0

Environmental Indicators*

Impact Area	**Indicator**	***Unit***	**Lignite**	**Hard Coal**	**Oil**	**Natural Gas**	**Nuclear**	**Hydro**	**Wind**	**Solar (PV)**
Global Warming	CO_2-equivalents	*tons/GWh*	1 220	1 080	884	531	10	4	14	86
Regional Environmental Impact	Change in unprotected ecosystem area	*km^2/GWh*	0.032	0.039	0.061	0.016	0.0017	0.0009	0.0029	0.011
Non-Pollutant Effects	Land use	*m^2/GWh*	52	198	335	47	7	92	29	65
Severe Accidents	Collective risk	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	93	66

Societal Indicators*

Impact Area	**Indicator**	***Unit***	**Lignite**	**Hard Coal**	**Oil**	**Natural Gas**	**Nuclear**	**Hydro**	**Wind**	**Solar (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-expectany)	*Years of Life Lost/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 damage of potential accident	*fatalities/ credible accident*	10	500	4 500	100	50 000	2 000	5	100

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* The quantitative values for all technologies and all indicators had to be restricted to point scores; although desirable the state-of-the-art does not allow general quantification of ranges of uncertainties, which would be subject to substantial research.

4 Aggregation

Aggregation of indicators allows the evaluation of the overall performance of technologies. Two aggregation approaches were used to support the ILK statement.

4.1 Aggregation Based on Total Costs

The total costs are comprised of internal, i.e. production costs, and external ones. The external costs are driven by public health effects caused by an increased level of ambient air concentration of pollutants or an increased level of ionizing radiation due to activities in the various process steps of the energy systems[2] . The external costs must also include the effects of global warming or greenhouse gases, as all of them may contribute significantly. Generally, damages resulting from the emission of a unit of pollutant are high if the number of affected receptors is very large. The fossil systems other than natural gas exhibit much higher impacts than the other options.

The total costs (normalized to kWh units), comprising internal and external Germany-specific costs, are shown in the figure below. External costs associated with global warming are highly uncertain and much less robust than the ones due to air pollutants.

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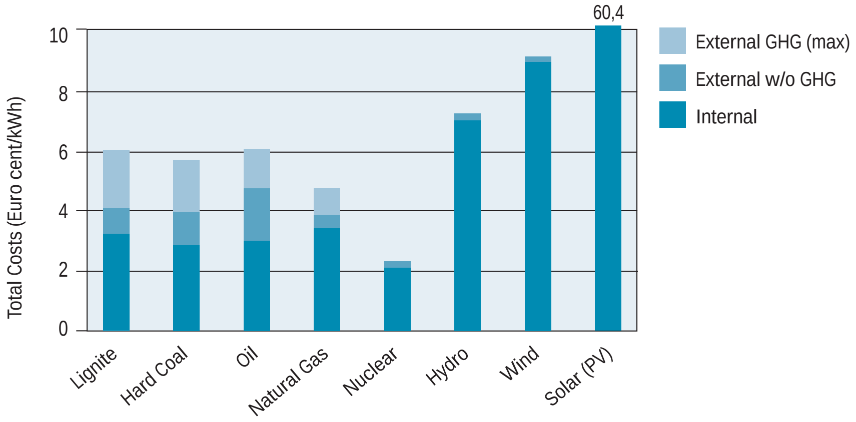
[2] Estimates of external costs also cover health impact from frequency weighted severe accidents within the various energy chains though these contributions are practically negligible compared to the monetary damages from normal operation.



Comparison of normalized total costs of current technologies in Germany (GHG = Greenhouse Gases).

According to the ranking based on total costs nuclear energy is the best performer, followed by natural gas and hard coal. The large margin for nuclear energy is partially due to the fact, that the German nuclear power plants are essentially amortized. This means that investment costs play a minor role and that former investments by the state to advance and develop nuclear energy are not included. However, these government subsidies are fairly negligible, amounting to approximately 0.2 Euro cent/kWh [13], while including investment costs averaged over the plant life would burden nuclear energy, but the resulting increase in (normalized) costs would not change the displayed ranking. Solar energy (photovoltaic) shows by far the highest internal and total costs, respectively, but low external costs. It has to be noted again, that the preceding figure represents an assessment of those technologies currently in operation; however, especially in view of the stated limitations with regard to nuclear energy, this figure cannot serve as the only basis for a decision on future energy technologies.

4.2 Aggregation Based on Multi-criteria Decision Analysis

Multi-criteria Decision Analysis (MCDA) as used in [1] allowed to combine on an aggregated level the central results of the analyses within the economic and environmental sectors with the societal preferences of the users. The technology-specific indicators constitute the analytical input to the evaluation.

The approach used for the evaluation is based on a simple weighted multiple attribute function. The weights reflect the relative importance of the various evaluation criteria and are combined with the normalized indicator values (scores). Normalization is carried out using a linear local scale, defined by the set of alternatives under consideration. For example, the alternative which does best on a particular criterion is assigned a score of 100 and the one which does least well a score of 0; all other alternatives are given intermediate scores which reflect their performance relative to these two end points. This means that the absolute value of the technologies representing these end points does not effect their score, e. g. hard coal will be given a score of 0 in terms of total waste regardless of whether its value is 180 or maybe 500 tons/GWh, as long as it represents the highest value among the options considered. A single overall value is obtained for each alternative by summing the weighted scores for all criteria. Ranking of the available options is then established on the basis of these overall values. A consistency check is certainly necessary, but was not included in the scope of the contract of the commissioned PSI study. Finally it is important to note that the final overall scores for a specific technology only have a relative meaning which defines the relative ranking of this technology in relation to the other options.

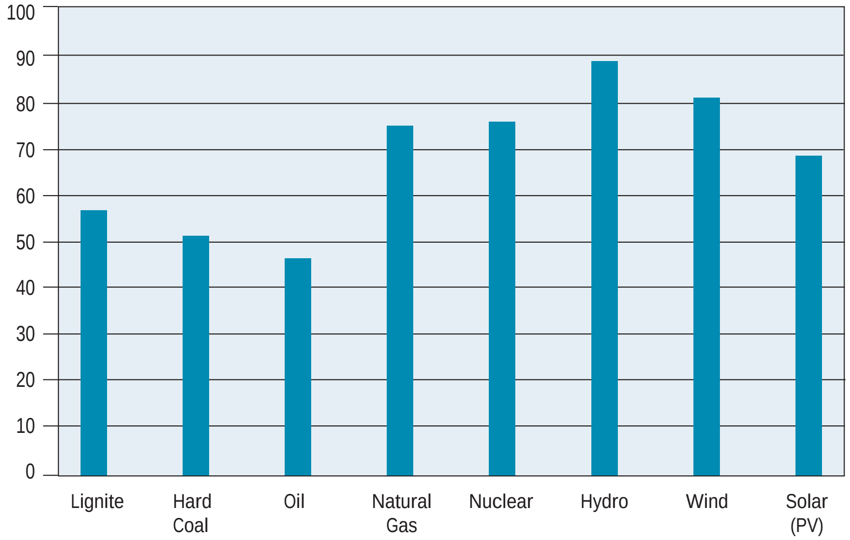
The weights can be obtained from stakeholders. Alternatively, various weighting schemes can be assigned to accommodate a range of perspectives expressed in the energy debate. Use of such alternative weighting schemes, also referred to as sensitivity mapping, has been implemented in the PSI study on the level of the three dimensions of sustainability. Furthermore, as indicated in the following table, weights had to be attributed also at the lower levels of impact areas and indicators. This was done by PSI with view to the priorities in the energy policy. These weighting factors are subject for discussions as the various stakeholders may favor alternative weighting schemes. For instance the much higher weighting for “Human health impacts (normal operation)” compared to “Risk aversion”, as stated in the table, might be surprising, especially when focusing on nuclear energy in particular. As noted in the following discussion though, the sensitivity for the moderate variation of weights at this level is rather low.

Dimension	Impact Area (Weight)	Indicator (Weight)
Economy	Financial Requirements (70)	Production cost (75)
		Fuel price increase sensitivity (25)
	Resources (30)	Availability (load factor) (40)
		Geo-political factors (15)
		Long-term sustainability: Energetic (15)
		Long-term sustainability: Non-energetic (10)
		Load following (20)
Environment	Global Warming	CO_2-equivalents (40)
	Regional Environmental Impact	Change in unprotected ecosystem area (25)
	Non-Pollutant Effects	Land use (5)
	Severe Accidents	Collective risk (15)
	Total Waste	Weight (15)
Societal	Employment	Technology-specific job opportunities (10)
	Proliferation	Potential (5)
	Human Health Impacts (normal operation)	Mortality (reduced life-expectancy) (40)
	Local Disturbances	Noise, visual amenity (15)
	Critical Waste Confinement	“Necessary” confinement time (15)
	Risk Aversion	Maximum damage of potential accident (15)

Weights for impact areas and indicators to be used in MCDA

In one of the evaluation cases only a subset of criteria was employed, i.e. environmental criteria plus health component included in the societal dimension plus production costs. This case has some parallels to the total costs evaluation. The rankings based on the two methods show certain similarities (though they are not identical), with nuclear being the top performer and solar (PV) being the worst.

If the full set of criteria is used along with weights equally distributed between the three main dimensions of sustainability (economy, environment, societal), thus following the concept that sustainability in principle calls for an equal importance of all dimensions, a different set of results is obtained (see the following figure).



MCDA-based ranking for the evaluation case employing the full set of criteria with equal weights assigned to the three main dimensions of sustainability
(the higher the total score, the better the overall system performance)

It should be noted that the results are highly sensitive to a variation of weights at the highest level (three main dimensions). While the weights given to lower levels of criteria (impact areas, indicators, see previous table), may in most cases be regarded as arbitrary, the ranking of systems remains quite stable given a moderate variation of these weights. Again, it is important to note that the absolute values in this figure only serve to define a relative ranking of the individual technologies considered. The displayed figure might lack some credit since the results had to be restricted to point scores and the ranges of uncertainties cannot be given, but this should not be overestimated in this context.

The case with equal top level weights exhibits a top performance of hydro and wind, followed by nuclear and natural gas. Nuclear is at a lower rank than in the “total cost” case - including “environmental criteria plus health plus production cost” -, as the result of inclusion of societal criteria.

A number of sensitivity cases were run, showing specific patterns in the ranking based on economic-, environmental- respectively societal-centered criteria. These cases will be commented upon in the conclusions.

Also, the impact of possible future nuclear-specific technological improvements was examined. This includes strong design-based limitation of the consequences of potential nuclear accidents along with radical reduction of necessary waste confinement times to a historical time scale. The beneficial effects on the ranking of nuclear in the MCDA-based sustainability evaluation were manifested by nuclear attaining the top rank along with hydro. This sensitivity case is mentioned primarily for the sake of illustrating the positive implications of currently pursued major developments in nuclear safety and waste research. It needs to be said that advancements are also feasible and likely for other technologies though at this stage no specific developments of comparably decisive character as for nuclear have been identified. The ILK refers to [1] for the information on systematic investigation of the impacts of evolutionary improvements of electricity generation technologies and associated energy chains on environmental burdens.

5 Conclusions

5.1 Role of Sustainability and Assessment Approach

- The ILK is of the opinion that sustainability considerations should support political decisions concerning energy supply options and associated technological developments.

- The view of the ILK is that the evaluation process needs to be transparent and non-discriminative. Use of consistent and to the extent possible objective quantitative, technology-specific indicators is highly promising, while the associated uncertainties should not be neglected.

- The ILK has put forward a proposal on a suitable evaluation approach that has been implemented and applied to the current major energy chains for electricity generation, representative for Germany. This should be helpful in the context of the energy policy discussion to be conducted in Germany.

5.2 Option-specific Features

- The fossil systems are subject to limited energetic resources and show relatively unfavorable ecological and accident risk features. Natural gas is by far the best performer among fossil energy carriers.

- Under the German conditions nuclear energy exhibits excellent economic as well as environmental and health performance. Within the western world it also has an excellent safety record, as reflected in very low estimates of collective risks. The sensitive issues for nuclear energy include risk aversion and the perceived problems associated with the necessity to assure safe storage of relatively small volumes of radioactive wastes over extremely long periods of time.

- The “new” renewables (solar (photovoltaic) and wind) are environmentally mostly superior to fossil sources but use large amounts of non-energetic material resources and their costs are high. The overall performance of wind energy is favorable using the presented weighting scheme while, given the German climatic conditions, the economic competitiveness of solar (photovoltaic) systems is still extremely low. Because of supply reliability considerations these renewables can contribute only a limited portion to the total energy supply.

5.3 Overall Sustainability Evaluation

- Based on the present results the ILK concludes that evaluations employing a variety of sustainability criteria result in a differentiated picture of the merits and drawbacks of the currently available electricity supply options. No single system exhibits a superior performance on all criteria. Most indicators characterizing nuclear energy are shown to be favorable.

- In the opinion of ILK primarily relative statements on the sustainability of the various electricity supply options are meaningful. The comparative sustainability evaluation can be based on the aggregation of indicators employing either the full cost approach or Multi-criteria Decision Analysis (MCDA).

- Coal and oil chains exhibit the highest normalized external costs especially due to their effects on human health and global warming. The external costs associated with natural gas are the lowest among the fossil chains, i.e. of the same order as for solar (photovoltaic). The nuclear chain exhibits the lowest quantifiable external costs, followed by wind and hydro-power. In terms of total normalized costs nuclear power again shows top performance, under German conditions, and is superior to other currently implemented technologies. In particular, solar (photovoltaic) is presently burdened by high solar cell production costs.

- The ILK considers, that in addition to total costs, the societal dimension should be included in sustainability measures since it plays a central role in the decision process while at the same time not being adequately reflected in the costs as a single aggregate measure. Taking nuclear power as an example, issues such as high level long-lived radioactive wastes, low frequency severe accidents or potential proliferation, contribute marginally or not at all to the external costs. At the same time such issues remain controversial and depending on the socio-political perspective of those involved, can be of great importance to the decision-making process.

- The ILK feels that trade-offs between environmental, economic and societal sustainability components are inevitable. They are sensitive to value judgments. By making these judgments explicit, the proposed methodology will promote debate on specific issues and will hopefully contribute to a consensus-building process. The results of MCDA based on criteria limited to the corresponding scope as the total cost assessment, i.e. equally weighted health and environmental impacts and production costs, lead to technology rankings with a number of similarities. Ranking based on all three pillars of sustainability is relatively robust when these pillars are considered equally important and the weighting of lower level criteria (e.g. financial requirements or employment effects) is subject to variation. Putting emphasis on economy penalizes renewables; emphasis on environment penalizes fossil systems and on societal aspects penalizes nuclear.

- Developments towards strong limitation of the consequences of hypothetical accidents along with a radical reduction of waste confinement times, as supported by ILK [11] and [14], will have a favorable impact on the MCDA-based ranking of the nuclear chain.

5.4 Further Steps

- The problem of evaluating electricity-supplying technologies from the sustainability point of view is very complex. The ILK acknowledges that this problem cannot be solved by mathematical methods alone, since these cannot capture all of the significant societal issues and very large uncertainties that are involved. It is the ILK's belief, however, that analyses such as the one presented here can provide a very useful basis for a societal debate in which specific differences of opinion can be identified and their impact on the decision-making process be evaluated. This structured debate can be a significant step toward consensus building.

- The analysis presented in this ILK statement is of limited scope, focused on current supply technologies, and is intended as a feasibility study rather than a definitive one. It is hoped that this study will provide a stimulating contribution to a wider debate on these issues that will involve major stakeholders and will refine analytical methods and trigger further research. The ILK encourages strongly such a debate and corresponding applications on the sustainability of the German electricity supply scenarios both at the state and the national level.

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ILK Publications:

ILK-01	ILK Statement on the Transportation of Spent Fuel Elements and Vitrified High Level Waste (July 2000)
ILK-02	ILK Statement on the Final Storage of Radioactive Waste (July 2000)
ILK-03	ILK Statement on the Safety of Nuclear Energy Utilisation in Germany (July 2000)
ILK-04	ILK Recommendations on the Use of Probabilistic Safety Assessments in Nuclear Licensing and Supervision Processes (May 2001)
ILK-05	ILK Recommendation on the Promotion of International Technical and Scientific Contacts of the Nuclear Safety Authorities of the German States (October 2001)
ILK-06	ILK Statement on the Draft Amendment dating from July 5, 2001 to the Atomic Energy Act (October 2001)
ILK-07	ILK Statement on Reprocessing of Spent Fuel Elements (November 2001)
ILK-08	ILK Statement on the Potential Suitability of the Gorleben Site as a Deep Repository for Radioactive Waste (January 2002)
ILK-09	ILK Statement on the General Conclusions Drawn from the KKP 2 Incidents associated with the Refueling Outage of 2001 (May 2002)

ILK-10	ILK Statement on the Handling of the GRS Catalog of Questions on the “Practice of Safety Management in German Nuclear Power Plants” (July 2002)
ILK-11	ILK Recommendation on Performing International Reviews in the Field of Nuclear Safety in Germany (September 2002)
ILK-12	Internal ILK-Report on the Intentional Crash of Commercial Airliners on Nuclear Power Plants (March 2003)
ILK-13	ILK Statement on the Proposals for EU Council Directives on Nuclear Safety and on Radioactive Waste Management (May 2003)
ILK-14	ILK Statement on the Recommendations of the Committee on a Selection Procedure for Repository Sites (AkEnd) (September 2003)
ILK-15	ILK Recommendation on the Avoidance of Dependent Failures of Digital I&C Protection Systems (September 2003)
ILK-16	ILK Statement on Sustainability Evaluation of Nuclear Energy and other Electricity Supply Technologies (January 2004)

- CD with presentations held at the ILK Symposium ”Opportunities and Risks of Nuclear Power” in April 2001
- Proceedings of presentations held at the 2nd ILK symposium “Harmonisation of Nuclear Safety Approaches – A Chance for Achieving more Transparency and Effectiveness?“ in October 2003