Methodology for the Comparison of Risk Assessment Results from Different Energy Systems

A. Colli[1], C. Kirchsteiger[1], A. L. Vetere Arellano[1], B. Ale[2]
[1]EC DG Joint Research Centre, Nuclear Safety Unit, Petten, Netherlands
[2]TU Delft, Faculty of Technology, Policy and Management, Delft, Netherlands
E-mail: alessandra.colli@jrc.nl christian.kirchsteiger@jrc.nl ana.vetere@jrc.nl
b.j.m.ale@tbm.tudelft.nl

1. Introduction

The European Union (EU) faces the problem of escalating external energy dependence. This requires the need to consider issues related on the one hand to secure the provision of uninterrupted availability of energy products on the market, and on the other hand to aim at minimising the risks to human health and the environment resulting from the use of various technologies for the generation and distribution of energy.

This paper describes a methodology that is the basis of the ERMON (Energy Risks Monitor) project launched by the JRC's Nuclear Safety Unit - Risk Assessment Sector - as a contribution to JRC's SETRIS (Sustainable Energy Technologies Reference and Information System) project coordinated by JRC's Clean Energy Unit. It proposes the development of a general scheme for fuel and life cycles and introduces the recently initiated research on risk indicators.

2. Methodology

The project analysis and development is divided into two main phases described as follows. The first phase includes different tasks, starting with a detailed analysis of different energy systems and the investigation of all steps in their fuel/life cycles, with the purpose to develop a general fuel/life cycle scheme adaptable to all energy technologies. The following task in this first phase focuses on the development of a template of descriptors to characterise risk/benefit aspects.

P.C.R. Gray and P.M. Wiedemann proposed in [1] to use risk management and sustainable development as frameworks for understanding and managing the environmental impacts of human actions, using indicators chosen on the basis of technical and communicative criteria. Following this proposal the descriptors in this project are divided into two main groups: those regarding sustainability and those regarding risk.

From a methodological point of view, the part related to the development of risk characterization descriptors will take into consideration the model of hazard causation.

This "causal model" has been developed by a group of researchers (C. Hohenemser, R.E. Kasperson, R.W. Kates) at CENTED (Center for Technology, Environment and Development) at Clark University in the eighties [2]. The initial aim of this model was to help in the comparison of different technological hazards.

The main objective is to get a set of measures for comparative hazard assessment avoiding arbitrariness. They propose a model of hazard causation anchored at one end in human activities and at the other by consequences, linked through a causal chain. Human activities produce changes in material fluxes, that are the origin of changes in valued environmental components; these changes induce some exposure that have some consequences to people and things that they value. Each link in this chain may be described by some characteristics and each characteristic may be described by a measurable descriptor (descriptors are normalised to some numerical scale). This methodology allows production of meaningful and easily understandable environmental hazard comparisons, in which not only final consequences are considered, but also ethical values also are explicitly taken into account [3].

The causal classification clearly delineates the sequence of events that leads to a risk situation and constitutes a guide for discovering available points for intervention.

For each risk situation, specific descriptors are identified at different stages in the causal structure. The descriptors to be selected would be applicable to all technological hazards in a way to make comparison easier, could be expressed by common units or designations and must be comprehensible not only to experts.

With the view to complement risk indicators, sustainability descriptors are developed based on four individual dimensions of sustainability, influencing each other: economical, environmental, social and political. The choice of the indicators, according to P.C.R. Gray and P.M. Wiedemann [1], should follow specific criteria: *"they should be robust, problem- or action-oriented, chosen according to the particular management task involved and resonant*".

The risk qualification aspects of the project will be carried out based on ongoing work on different types of uncertainty considered in risk models, the way how they are included in the model and the quality (e.g. pedigree) of the information supporting it, i.e. the NUSAP (Numeral Unit Spread Assessment Pedigree) approach [4]. The NUSAP system addresses different types of uncertainty in a risk assessment, along with the quality of the information supporting the assessment. The NUSAP system, as reported by S.O. Funtowicz and J.R. Ravetz in [4], addresses three distinct levels of uncertainty, namely inexactness, unreliability and border with ignorance, providing a conceptual distinction among the technical, methodological and epistemological levels of uncertainty. A key concept in NUSAP is the pedigree of any piece of information included in a risk assessment. Pedigree accounts for the quality of the information. Assessment of pedigree involves the evaluation of several criteria about the scientific soundness of any piece of information. This is done through scoring the quality of information by expert judgement on a number of quality criteria, using semi quantitative scales defined by linguistic descriptors. NUSAP allows to address uncertainty and quality at different locations in a risk assessment, including input data, parameters, scenarios, model structure, model assumptions, indicators used, model system boundary, and problem definitions. NUSAP provides a systematic critical review of the available knowledge base for each of these components of a risk assessment and pinpoints specific weaknesses in the underlying knowledge base. It helps in assessing robustness of outcomes of a risk assessment in view of the uncertainties identified and in the setting of priorities for the improvement of the quality.

The second phase includes the full implementation of method in a web-based Information System and operational agreements with energy data and risks information owners. This last part of the work includes development of different levels of access for different types of users. Representative data sets and case study results will be made part of the model. This paper mainly presents the results of the first phase of the proposed methodology.

3. Development of a General Scheme for Fuel and Life Cycles

An energy system is a complex combination and interaction of many aspects (such as, human factors, technology, organization, policy, interactions with the environment, etc.) leading to the transformation of an energy source into useful power (that can be thermal, electrical or mechanical). Relevant in the energy chain are also human-related aspects, as people are involved in the energy system both as executors of the fuel transformation and conversion, but also as end-users.

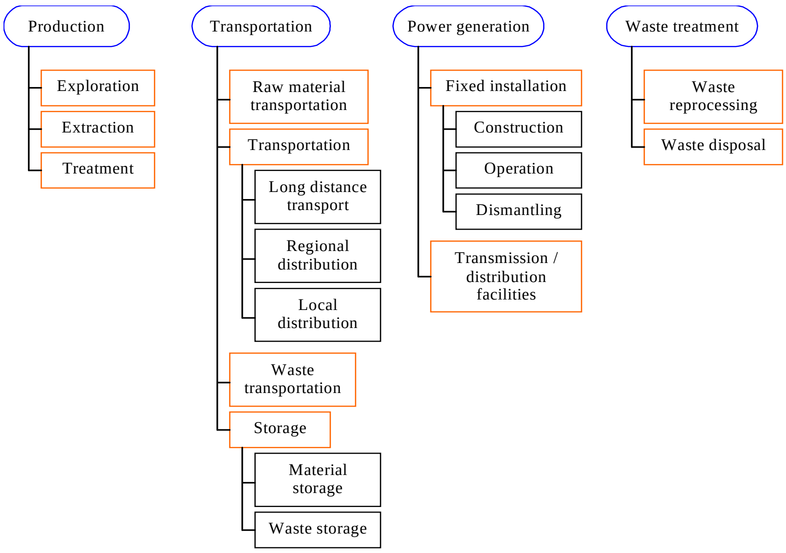
The investigation has been done for the following ten energy systems: coal, natural gas, oil, nuclear, biomass, geothermal, hydro, solar, wind and hydrogen. For the purpose of the ERMON project, the investigation of different energy technologies takes into consideration only heat and electricity production (at different scale level) at the power plant site.

The general fuel/lifecycle scheme for ERMON (Figure 1) has been developed with the intention to be as simple as possible, but not simplistic; thus, it is necessary to be able to designate, for each energy type, different steps of the same single fuel or life cycle.

The scheme developed fits to some of the chains completely (e.g. nuclear), while some others (e.g. hydropower) leave some steps empty. The scheme has been developed focusing on fuel cycles and plant life cycles.

The main idea behind the development of the above-mentioned general scheme is that, however complicated a single chain can be, all its steps can be allocated within this general scheme.

Figure 1: General fuel/life cycle scheme [5].



The scheme is characterised by four main steps:

- **Production** - is related to all production operations (i.e. it can be production of a fuel, as well as a component or a material).
- **Transportation** - includes the operation of transport of raw material, final product or waste. Storage has been considered as a part of the transportation, as the stored material is waiting to be transferred to another intermediate place or to the place of use.
- **Power generation** - is the power plant, including the plant installation and the transmission and distribution facilities.
- **Waste treatment** - is the final step in the chain, receiving waste from the power plant as well as from other production activities. Waste can be treated or can be sent to a final disposal.

Figure 2: Resultant matrix that shows the application of the general scheme.

Stages of the life cycle			Fossil technologies			Nuclear technologies	Renewable technologies							Hydrogen technologies
			Coal	Natural Gas	Petroleum		Biomass	Geothermal	Hydro	Solar	Solar (PV modules)	Wind	Wind (turbines)	
Production	Exploration		Geological investigation	Geological investigation	Geological investigation	Geological investigation	N.A.	Geological, hydrogeological, geophysical, and geochemical investigation	Geographical / geological investigation	Geographical investigation	N.A.	Geographical investigation	N.A.	N.A.
	Extraction		Coal mining	Well drilling, pumping	Well drilling, pumping	Uranium mining	Biomass collection	Drilling	N.A.	N.A.	Feedstock and mineral collection	N.A.	Feedstock and mineral collection	Feedstock collection
	Treatment		Size reduction of mined coal; coal cleaning; coalification (bio-physical-chemical degradation); conversion into liquid or gas	Removal of hydrocarbon and non-hydrocarbon elements; liquefaction / compression	Refinery	Milling, transformation, conversion, enrichment and fuel fabrication	Residue processing, biofuels production	N.A.	N.A.	N.A.	Material processing, component manufacture	N.A.	Material processing, component manufacture	Hydrogen production from feedstock (with other auxiliary energy sources); liquefaction / compression
Transportation	Raw material transportation		Truck, railcar, barge	Upstream pipeline, tanker	Pipeline, ship tanker; short / long distance	Special container by ship, rail, truck	Residue transport	N.A.	N.A.	N.A.	Truck, rail	N.A.	Truck, rail	Pipeline, barge, railroad tank cars, rail, truck
	Transportation	Long distance transport	Railcar, barge	High pressure pipeline	Pipeline, barge, railroad tank cars	Special container by ship, rail, truck	Truck, ship	N.A.	N.A.	N.A.	Truck, rail, ship, plane	N.A.	Truck, rail	Pipeline, barge, air transportation
		Regional distribution	Railcar, barge	High / medium pressure pipeline	Pipeline, railroad tank cars, tank cars	Special container by rail, truck	Truck, ship	N.A.	N.A.	N.A.	Truck, rail	N.A.	Truck, rail	Pipeline, barge, truck
		Local distribution	Railcar	Medium / low pressure pipeline	Truck	Special container by truck	Truck	Pipeline	Water flow, canal, pipeline (also pressurised)	Solar concentrators	Truck, rail	N.A.	Truck, ship, helicopter	Local hydrogen grid, truck
	Waste transportation		Truck	N.A.	Tank cars	Special container by ship, rail, truck	Waste and ashes road / ship transport	Fluid reinjection	N.A.	N.A.	Truck	N.A.	Truck, ship, helicopter	N.A.
	Storage	Material storage	As necessary	As necessary	As necessary storage tank and local terminal	In special container and in the nuclear power plant	As necessary for energy consumption (close to plant)	N.A.	Dam construction and reservoir creation	N.A.	N.A.	N.A.	N.A.	As necessary pressure tank, insulated tank, solid compound
		Waste storage	After production and power generation stages	N.A.	Sludge' storage	Intermediate storage	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Power generation	Fixed installation	Construction	Power plant construction	Power plant construction	Power plant construction	Power plant construction	Power plant construction	Power plant construction	Power plant construction	Solar system manufacturing and installation	Power plant construction	Turbine manufacturing and assembling	Power plant construction	Power plant construction
		Operation	Power plant operation	Power plant operation	Power plant operation	Power plant operation	Power plant operation	Power plant operation	Power plant operation	Power plant operation	Power plant operation	Power plant operation	Power plant operation	Power plant operation
		Dismantling	Dismantling procedures, material recycling and disposal	Dismantling procedures, material recycling and disposal	Dismantling procedures, material recycling and disposal	Dismantling procedures, material recycling and disposal	Dismantling procedures, material recycling and disposal	Dismantling procedures, material recycling and disposal	Dismantling procedures, material recycling and disposal	Dismantling procedures, material recycling and disposal	Dismantling procedures	Dismantling procedures, material recycling and disposal	Dismantling procedures	Dismantling procedures, material recycling and disposal
	Transmission / distribution facilities		Electricity / heat distribution facilities	Electricity / heat distribution facilities	Electricity / heat distribution facilities	Electricity / heat distribution facilities	Electricity / heat distribution facilities	Electricity / heat distribution facilities	Electricity distribution facilities	Electricity / heat distribution facilities	Electricity distribution facilities	Electricity distribution facilities	Electricity distribution facilities	Electricity / heat distribution facilities
Waste treatment	Waste reprocessing		Plant flue gas and ashes recycling	N.A.	Sludge' processing / incorporating	Reprocessing and conditioning	Ashes recycling	N.A.	N.A.	N.A.	Recycling	N.A.	Recycling	N.A.
	Waste disposal		Landfill	N.A.	Landfarm, combustion, underground injection	Final disposal / deposit, final geological repository	Landfill	N.A.	N.A.	N.A.	Landfill	N.A.	Landfill	N.A.

These four main stages are then divided into corresponding sub-steps to have a more clear specification of the chain.

Production.

- Exploration – is the procedure that searches resource and identifies its location. This step mainly includes geographical and geological investigations.
- Extraction – is the process to make the resource available for next transformation or use. Activities like mining, drilling or collecting are included in this phase.
- Treatment – is the step in which the final product to be used, that can be a fuel or a component, is prepared, or in some cases created, and made available for direct use or for transportation. This stage includes steps such as petroleum refinery, as well as purification, compression or liquefaction of natural gas, biomass residue processing or bio-fuels production, as well as photovoltaic modules manufacture or wind turbine manufacture.

Transportation.

- Raw material transportation –route between extraction area and location of resource treatment.
- Transportation:
  - Long distance transportation – transportation between different countries or different continents. This step can include high pressure natural gas pipeline, as well as oil barge transportation.
  - Regional distribution –transportation between different regions of the same country.
  - Local distribution –local transportation, mainly restricted to the area of use. Pipeline transportation mainly includes low pressure pipeline.
- Waste transportation – is the transportation of waste, which can be generated at different levels in the chain. For example, nuclear waste can be transported in special container.
- Storage:
  - Material storage – is the storage before material or fuel use. Part of this stage can be the hydro reservoir, the storage of hydrogen in pressure or insulated tank, the storage of nuclear fuel in special container or in the nuclear power plant.
  - Waste storage – this step can be in the place of production or constitute an intermediate storage before waste final disposal.

Power generation.

- Fixed installation:
  - Construction – this stage includes all the operations of preparing the area of construction and building the power plant or the power installation.
  - Operation – is the operative part, including functioning and maintenance for the power generation.
  - Dismantling – groups all the operations of dismantling the installation and bringing the area in the same environmental conditions as before. Material recycling and disposal related to the power installation are also included in this step. Dismantling procedures can be very expensive, like for nuclear power plant, and the monetary resources necessary for the operations are built up during the lifetime of the installation.

- Transmission/distribution facilities – this step includes all the facilities (pipeline, cable, etc) for heat and electricity transmission and distribution.

Waste treatment.

- Waste reprocessing – includes the operations of recycling materials or fuels (e.g. nuclear fuel), or treating wastes to reduce their hazardousness.
- Waste disposal – is the final allocation of wastes in landfills or in dedicated deposits.

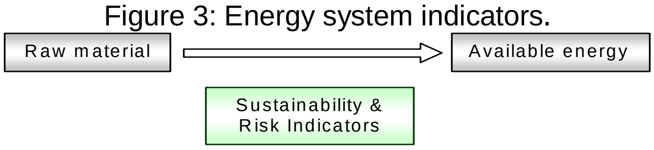
Figure 2 is the resultant matrix that shows the application of the general scheme to the *fuel chains*: coal, natural gas, oil, nuclear, biomass, geothermal, hydro, solar, wind and hydrogen, as well as *life cycles*: solar modules and wind turbine production.

4. Indicators

As described earlier, the current approach is based on two main groups of indicators, related to two important concepts: sustainability and risk. In the development of the ERMON project, this approach is applied to study the energy supply process (*energy supply*: energy made available for future disposition; *supply* can be considered and measured from the point of view of the energy provider or the receiver), covering the whole of the energy system chain.

In this manner losses and benefits of the energy supply process are covered, using two different but complementary concepts, which will be discussed further below.

Figure 3: Energy system indicators.



4.1 Risk Indicators

The aim of risk indicators is to provide comparable information for managing risks. Risk can have two different contexts: continuous risk, resulting from normal operation and activities, and accidental risk, involving incidents/accidents.

According to P.C.R. Gray and P.M. Wiedemann [1], risk has various dimensions, including:

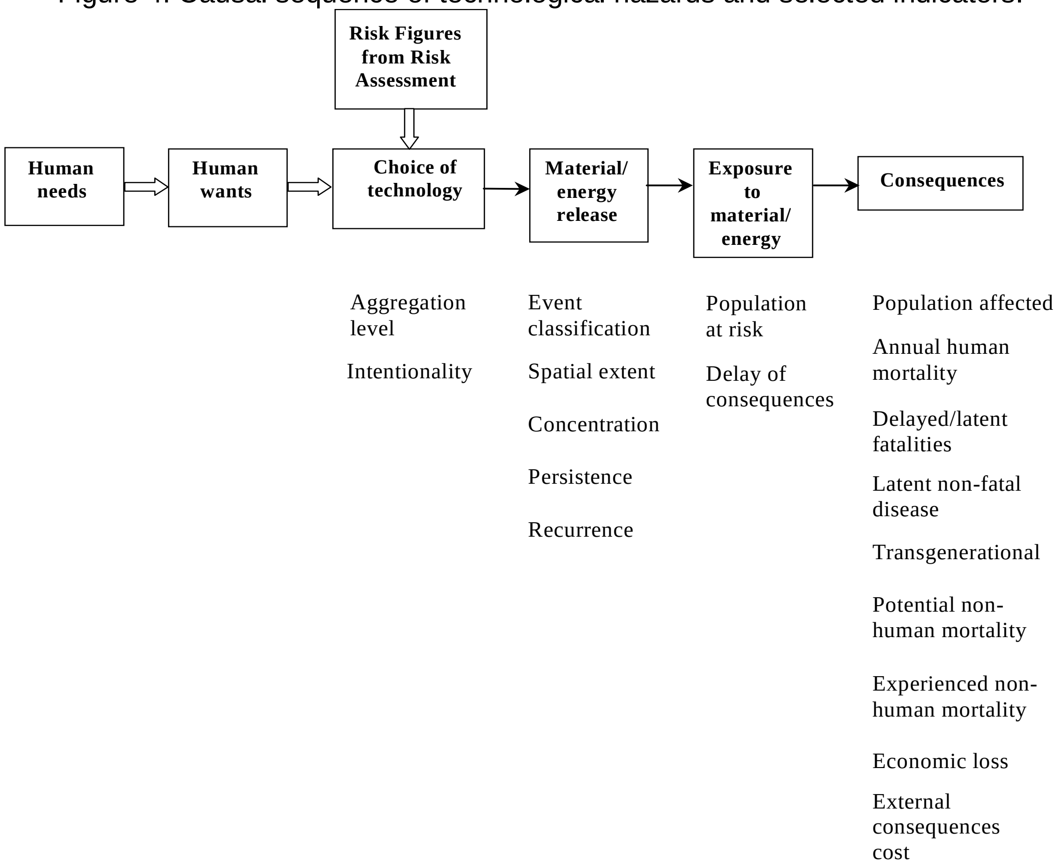
- The potential harm (consequences);
- Individual probability of this harm being experienced;
- Variability in risk within the population;
- Latency of harm;
- Catastrophic or group risk;
- Collective dimension (numbers of individuals exposed).

All these dimensions are affected by the cross-cutting dimension of uncertainty, which will be taken into consideration in the development of a qualification system for the indicators.

Dimensions are important and must be taken into account in the choice of indicators. This selection relies on both *technical* and *communicative* criteria. Technical criteria include robustness and problem orientation, together with specific factors depending on the individual dimensions of risk. Communicative criteria, mentioned in P.C.R. Gray and P.M. Wiedemann [1] and based on the theory of the philosopher H. Grice [6], consists of truthfulness, informativeness, relevance and clarity. It is important to highlight that the selection of indicators is mainly a value-based activity, touching personal, social and political values, giving particular relevance to the process used for selecting indicators, which in turn is a process that does not represent the unique possible way.

The model and the set of twelve descriptors developed by C. Hohenemser, R.W. Kates and P.Slovic [7] consider technological hazards as a sequence of causally connected events leading from human needs and wants, to the choice of the technology and to the consequences caused by the release and the exposure to energy and/or material. The twelve descriptors have relevant characteristics that are applicable to all types of technological hazards, comprehensible to non-experts and expressed in common units.

Figure 4: Causal sequence of technological hazards and selected indicators.



Descriptors are numerically quantified by a categorical distinction (intentionality, transgenerational, potential non-human mortality and experienced non-human mortality) and a logarithmic scale (spatial extent, concentration, persistence, recurrence, population at risk, delay of consequences, annual mortality and maximum potentially killed). The choice of logarithmic scale allows a practical representation, with the quality of matching human perception better than linear scales (like for decibel sound intensity scale or Richter earthquake intensity scale).

The original set of indicators has been slightly modified in this study with the introduction of new elements and, where necessary, more detailed classifications.

Table 1: Example application study of risk expressions for the accidents at Chernobyl and Three Mile Island NPPs, using the proposed risk indicators.

1) 1=not intended to harm; 2=intended to harm non-human organisms; 3= intended to harm human.
2) Value expressed with Log_{10} scale. Base value in meters.
3) Value expressed with Log_{10} scale. Base value in Becquerel.
4) Value expressed with Log_{10} scale. Base value in minutes.
5) Value expressed with Log_{10} scale. Base value in years.
6) Value expressed with Log_{10} scale. Base value in number of people.
7) Value expressed with Log_{10} scale. Base value in minutes.
8) 1=effect on exposed generation; 2=effect on 1 future generation; 3= effect on more than 1 future generation.
9) 1=no mortality; 2=mortality; 3=species extinction.
10) High cost level is considered for more than 1 billion $.

Indicator		Chernobyl		Three Mile Island	
		Value	Qualification	Value	Qualification
Aggregation level		System	Interpretation	Subsystem	Interpretation
Event classification		System accident	Interpretation	Component failure accident	Interpretation
Intentionality [1]		3	Interpretation		
Spatial extent [2]		4.5 (Exclusion Zone)	Exact value	There was little impact outside the US (Radioactive cloud over the Atlantic ocean)	Reference statement
Concentration [3]		18	Exact value	16.6	Exact value
Persistence [4]		7.2	Exact value	3.8	Exact value
Recurrence [5]				3.5 – 3.6	Exact value
Population at risk [6]	First party	5	Exact value		
	Second party				
	Third party	5	Exact value	Absence of harm to the citizenry	Reference statement
	Fourth party				
Delay of consequence [7]					
Population affected [6]	First party	1.3 (fatalities)	Exact value		
	Second party				
	Third party	5 (evacuees)	Exact value	4 – 4.9 (evacuees)	Interpretation
	Fourth party				
Annual human mortality [6]	First party	1.5 (1986)	Exact value		
	Second party				
	Third party				
	Fourth party				
Delayed/latent fatalities [6]	First party				
	Second party				
	Third party			0.3 (Estimation)	Exact value
	Fourth party				
Latent non-fatal disease [6]	First party				
	Second party				
	Third party				
	Fourth party				
Transgenerational (non-human) [8]		2	Interpretation	1	Interpretation
Potential non-human mortality [9]				1	Interpretation
Experienced non-human mortality [9]				1	Interpretation
Economic loss (property and rebuilding costs) [10]		High	Exact value		
External consequences cost [10]	Environmental	High	Exact value		
	Non-environmental	High	Exact value		

The risk indicators are:

1. **Aggregation level**: identifies the level of the event according to the system involved. A system can be divided into four levels [8]:
   a. Part: is considered as the smallest component of a system, for example a valve;
   b. Unit: is a functionally related collection of parts, for example those parts constituting a steam generator;
   c. Subsystem: is an array of units, for example the union of a steam generator and the water system;
   d. System: when different subsystems come together, then we have a system, like a nuclear power plant.

   This classification wants to take mainly into account the technological systems and the way they work. Humans are considered as part of the system and they may constitute a part, a unit, as well as a subsystem.

2. **Event classification**: based on [8]:
   a. Incident: involves damages to parts or unit (whether the failure disrupts the system or not);
   b. Accident: is a failure in a subsystem or in the system as a whole;
   c. Component failure accident: involves one or more component failures (part, unit or subsystem) that are linked in an anticipated sequence;
   d. System accident: involves the unanticipated interaction of multiple failures.

   The last two categories are distinguished on the basis of whether any interaction of two or more failures is anticipated, expected, or comprehensible to the persons who designed the system, and those who are adequately trained to operate it.

3. **Intentionality**: measures the degree to which technology is intended to harm.

4. **Spatial extent**: maximum distance over which a single event has significant impact.

5. **Concentration**: measures the concentration of released energy or materials to natural background.

6. **Persistence**: measures the time over which a release remains a significant threat to humans.

7. **Recurrence**: mean time interval between releases above a minimum significant level.

8. **Population at risk**: number of people potentially exposed to hazard. People are classified into first party (operators of the system), second party (associated with the system as non-operating personnel, suppliers or users, but without influence over it), third party (innocent bystanders) and fourth party (fetuses and future generation) [8].

9. **Delay of consequence**: delay time between exposure to hazard release and occurrence of consequences.

10. **Population affected**: number of fatalities, injured and evacuees in a single event. People are divided according to the classification used for population at risk.

11. **Annual human mortality**: average annual deaths. People are divided according to the classification used for population at risk.

12. **Delayed/latent fatalities**: number of people affected by delayed or latent effects. People are divided according to the classification used for population at risk.

13. **Latent non-fatal disease**: number of people affected by non-fatal diseases originated from the event (cancer). People are divided according to the classification used for population at risk.
14. **Transgenerational**: number of future generations at risk.
15. **Potential non-human mortality**: maximum potential of non-human mortality.
16. **Experienced non-human mortality**: non-human mortality that have been experienced.
17. **Economic loss**: takes into account only property and rebuilding costs.
18. **External consequences cost**: distinguishes between environmental (impact on public and occupational health, agriculture, forests, biodiversity effects, aquatic impact, impact on materials, global impact) and non-environmental (impact on public infrastructure, security of supply, government actions) costs [9].

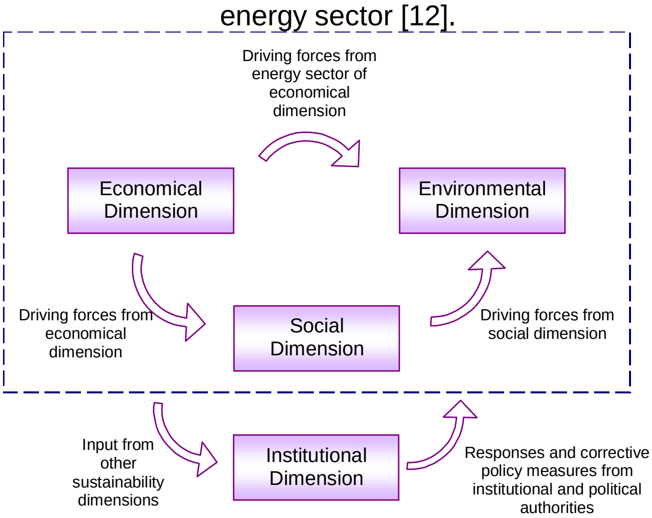
The proposed set of indicators takes into consideration impacts on human health, environment and economical losses. In addition, the temporal dimension is also taken into account. The long-term effect is evident in indicators like persistence, transgenerational and, concerning human health effects, by the fourth party classification.

Table 1 presents an example application study comparing risk expressions for the nuclear accidents of Chernobyl [10] and Three Mile Island [11]. The comparison was made by collecting available, open source information, which were categorized according to the above-described indicators. From Table 1, it can be observed that the Chernobyl accident shows a higher degree of risk.

4.2 Sustainability Indicators

The sustainability descriptors have been developed according to the four key dimensions of sustainability, covering economical, environmental, social, and political/institutional aspects with a future-oriented perspective. Sustainability means the capacity for an activity to be carried on indefinitely in the future, which involves changes and improvements compatible with the highlighted dimensions in a present and long-term perspective.

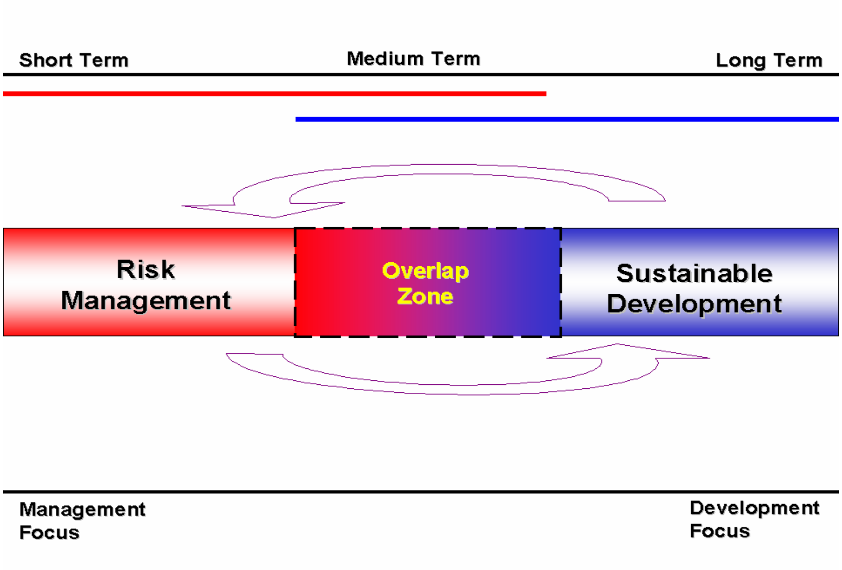
Figure 5: Interrelations among the different dimensions of sustainability, in relation to the energy sector [12].



Sustainability aspects do not have a stand-alone position, but interact with each other as shown in Figure 5. It is also important to stress that sustainability indicators are considered complementary and linked to risk indicators (see Figure 6), two set of descriptors partly integrated into one another (overlap zone), with different aspects in common; all indicators from both parts are equally important and useful to each other in the evaluation of risk and benefits of energy systems.

Sustainability descriptors will be developed on the basis of the set of Energy Indicators for Sustainable Development presented in [13], which is the result of collaborative initiative between International Atomic Energy Agency (IAEA), United Nations Department of Economic and Social Affairs (UNDESA), International Energy Agency (IEA), Eurostat and European Environment Agency (EEA).

Figure 6: Risk Management vs. Sustainable Development



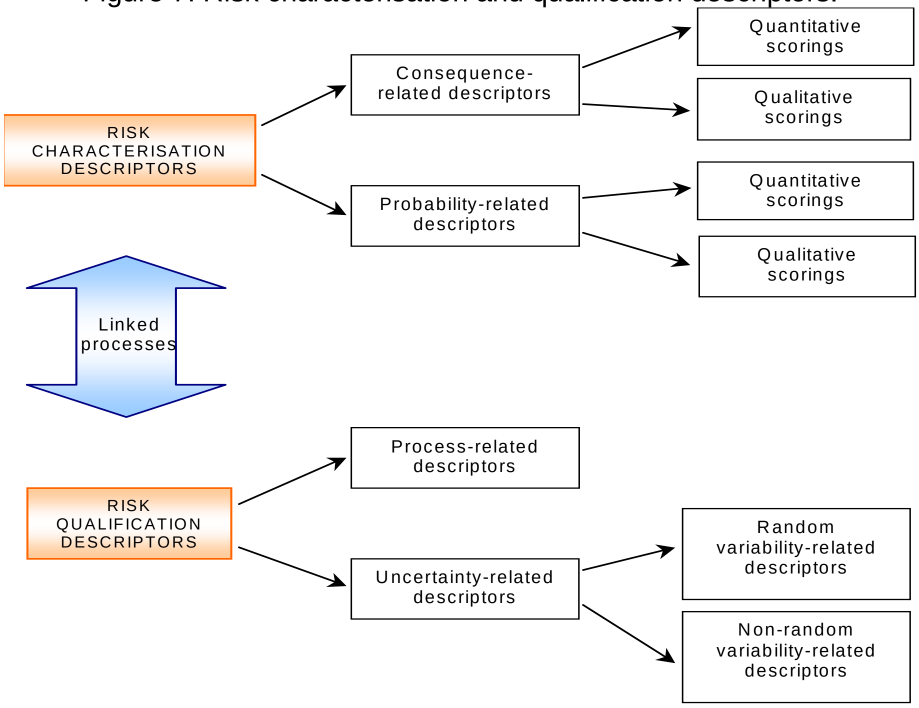
5. Further Development

After development of indicators to characterise risks and benefits of different energy systems, the work will focus on the evaluation of qualitative aspects affecting the value of the information provided (*cfr*. Section 2), as shown in Figure 7 for risk-related descriptors.

Quality can be affected by two main aspects: process and uncertainty. The first consideration about quality of data takes into account the process of collecting data from failures, anomalies, incidents, accidents occurred on equipment in operation on industrial sites to join a database. Starting from raw data, the quantitative information passes through a process of validation, interpretation and quantification, until their use. During this process, the interpretation and the judgment of data by experts are relevant [14]. Concerning uncertainty, two types are distinguished: random variability, i.e. statistical uncertainty related to a numerical statement, and non-random variability, i.e. refers to factors like model and knowledge uncertainty [15].

Uncertainty evaluation will be carried out using an uncertainty matrix, as addressed by the NUSAP method. The NUSAP method offers a tool for a quality-of-the-process evaluation, using a specific case-adapted pedigree matrix. Furthermore, an attempt will be made elaborate an indicator that aims to qualify risk expressions according to different aggregation levels (*cfr.* Section 4.1).

Figure 7: Risk characterisation and qualification descriptors.



After development, the method will be validated with some case studies, according to the availability of data. Supported by positive results, the methodology could be further implemented in a web-based Geographical Information System (GIS) with different levels of access for different types of users. In addition, it will also include representative data sets and case study results, along with other information obtained through operational agreements with risk owners.

The resulting Information System, which will be supplied with data on the technological, safety, risk and availability aspects of the different energy technologies across their chains, coupled with a cost/benefit model evaluating energy policy alternatives, will form the knowledge base for the ERMON Information System, which will be operated as a decision support tool for EC policy services on a continuous basis.

6. Conclusions

The results of this work serve as base for the ERMON project, which will help to compare the results of any existing risk study and incident/accident statistics analysis for different energy systems across all steps in their specific fuel cycle or life cycle chains. The objective of ERMON is to compare the results in a consistent way. The comparison is based on the generic fuel/life cycle model presented in the paper.

The development of both the risk characterization and risk qualification template to create an energy risk compass supported by the creation of an energy risk knowledge base, has the purpose to improve the understanding and the communication of risks among all stakeholders (policy-makers, public, utilities, etc.), and to increase the acceptance and use of risk assessment approaches.

Such an energy risk knowledge base and tool present the benefit of providing users with a flexible methodology applicable to different energy systems in their fuel and life cycles. Furthermore, it allows different stakeholders to access and use the information according to their needs. Lastly, it provides a significant amount of and valid information, which can lead to a comprehensive evaluation of a specific energy-related hazard. This will also provide information about the quality-related elements of the energy risk assessment underlying the considered risk expression, in order to allow a comparison of different understandings of similar hazards and different risks from different energy systems, in order to judge their sustainability and to make decisions concerning policy-related issues, like environment, human safety, etc.

References

[1]“Risk Management and Sustainable Development: Mutual Lessons from Approaches to the Use of Indicators”, P.C.R. Gray, P.M. Wiedemann, Journal of Risk Research 2 (3), 201-218, 1999.

[2] “Causal Structure in Perilous Progress: Managing the Hazards of Technology”, C. Hohenemser, R.E. Kasperson, R.W. Kates, Boulder, CO: Westview Press.

[3] “Global Environmental Risk”, J.X. Kasperson and R.E. Kasperson editors, United Nations University Press, 2001.

[4] “Uncertainty and Quality in Science for Policy”, S.O. Funtowicz and J.R. Ravetz, Kluwer Academic Publishers, 1990. See also http://www.nusap.net/

[5]“Development of a General Scheme for Fuel Cycles and Life Cycles from all Energy Technologies as a Basis for the European Energy Risk Monitor (ERMON)”, A. Colli, A.L. Vetere Arellano, C. Kirchsteiger, EUR 21735 EN, Publication of the European Commission Joint Research Centre, Petten, The Netherlands, 2005.

[6] “Logic and Conversation. Speech Acts, Syntax and Semantics”, H. Grice edited by P.Cole and J.L. Morgan, Vol. 12, pp. 41-58, 1975, New York.

[7] “The Nature of Technological Hazards”, C. Hohenemser, R.W. Kates, P. Slovic, chapter 10 from the book: “The perception of Risk. Risk, Society and Policy”, P. Slovic, Earthscan, 2000.

[8] “Normal Accidents. Living with High-Risk Technologies”, C. Perrow, Princeton University Press, 1999.

[9] "Project GaBE: Comprehensive Assessment of Energy Systems. Severe Accidents in the Energy Sector", S. Hirschberg, G. Spiekerman, R. Dones, First edition, Paul Scherrer Institut, November 1998, ISSN-1019-0643.

[10] “The Chernobyl Accident. A Comprehensive Risk Assessment”, G.J. Vargo Ed., Battelle Press, 2000.

[11] “Megawatts + Megatons. The Future of Nuclear Power and Nuclear Weapons”, R.L. Garwin, G. Charpak, University of Chicago Press, 2002.

[12] “Indicators for Sustainable Energy Development”, IAEA, IEA, http://www.iea.org/textbase/papers/2001/csd-9.pdf

[13] “Energy Indicators for Sustainable Development: Guidelines and Methodologies”, International Atomic Energy Agency, UN Department of Economic and Social Affairs, International Energy Agency, Eurostat and European Environment Agency, IAEA, Vienna, 2005, http://www-pub.iaea.org/MTCD/publications/PDF/Pub1222_web.pdf

[14] “Handbook on Quality of Reliability Data”, ESReDA Working Group Report, Det Norske Veritas, 1999.

[15] “Technical Communication on Status in Developing a Compass for Risk Assessment”, C. Kirchsteiger, Safety Science, Elsevier Ltd., 2003.