

# SIXTH FRAMEWORK PROGRAMME



Project no: 502687

**NEEDS**

**New Energy Externalities Developments for Sustainability**

## INTEGRATED PROJECT

*Priority 6.1: Sustainable Energy Systems and, more specifically,*

*Sub-priority 6.1.3.2.5: Socio-economic tools and concepts for energy strategy.*

### Deliverable n° D3.1 – RS 2b

***“Environmental, economic and social criteria and indicators for sustainability assessment of energy technologies”***

Due date of deliverable: May 2007

Actual submission date: August 2007

Start date of project: 1 September 2004

Duration: 48 months

**Organisation name for this deliverable:** Paul Scherrer Institut (PSI)

**Authors:** Stefan Hirschberg, Christian Bauer, Peter Burgherr, Roberto Dones and Warren Schenler (PSI), Till Bachmann (EIFER), Diana Gallego Carrera (University of Stuttgart)

**With contributions by:** Vincent Maupu, Claire Lecoite and Constance Berthier (EDF), Hélène Connor (HELIO International), Jürgen Hampel and Ortwin Renn (University of Stuttgart)

**Workpackage Partners:** CESIRICERCA, EDF, GLOBE Europe, HELIO International, IIASA, ISIS, University of Stuttgart

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
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CO	Confidential, only for members of the consortium (including the Commission Services)	



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# 1 Introduction

Within the EU Integrated Project NEEDS (New Energy Externalities Developments for Sustainability), the central objective of Research Stream RS2b “Energy Technology Roadmap and Stakeholder Perspectives” is to broaden the basis for decision support beyond the assessment of external costs and to extend the integration of the central analytical results generated by other Research Streams. The ultimate results of the technology roadmap will include mapping the sensitivity of sustainability performance of technological options to stakeholder preference profiles.

Two approaches will be used for the evaluation of the options. The first approach is based on total costs calculations (direct + external); estimation of total costs will be based on the information that is expected to be available from other research streams. The second approach will utilise Multi-Criteria Decision Analysis (MCDA), combining in a structured manner knowledge of specific attributes of the various technologies with stakeholder preferences.

The main efforts undertaken in RS2b concern the development of a framework for the implementation of MCDA. The approach is based on measuring the performance of competing technologies by different decision-making criteria. Performance for each criterion is judged by what may be called “indicators” or “measures” or “metrics.” Such indicators may be either quantitative or qualitative. Quantitative measures can be ascertained with relative objectivity, given stated contributing assumptions. Qualitative measures must still be assigned a value for the multi-criteria assessment, but are based on subjective judgement. Each indicator attempts to quantify a certain aspect of a given criterion.

A fundamental part of such a framework is the establishment of a set of criteria and indicators to be used for the evaluation. The present report provides an overview of the set to be used within NEEDS for the evaluation of electricity generating technologies and the associated fuel cycles. The application will concern future technologies (year 2050) in four countries, i.e. France, Germany, Italy and Switzerland.

The present report builds on results obtained and documented in a number of Work Packages within RS2b, which in turn profited from a variety of experiences with criteria and indicators, accounted for in the literature. For the details we refer to the supporting RS2b publications; here the focus will be on presenting and defining the selected set of criteria and indicators.

Chapter 2 describes the process that led to the establishment of the set of criteria and indicators. In chapter 3 the basic requirements on the indicators are formulated. Chapter 4 provides the basic structure chosen along with the definitions of the selected criteria and indicators within the three dimensions of sustainability, i.e. environment, economy and social. Finally, Chapter 5 contains summary and conclusions.

## 2 Establishment of the set of criteria and indicators

The process leading to the establishment of criteria and indicators is summarized in the following points:

- **Literature survey on past experience with sustainability indicators.**

A literature survey aiming at a review of published criteria and indicators was conducted during the first year of the project. Definitions of sustainability were examined and some basic principles were formulated. Furthermore, requirements on criteria and indicators were established, having in mind the ultimate goal to operationalise evaluation of sustainability of energy technologies.

A comprehensive literature survey of criteria and indicators relevant for the assessment of sustainability of energy systems was carried out. In the course of this work published criteria and indicator sets proposed within international and selected national projects and/or by competent organisations/institutions were reviewed. Strengths and weaknesses of existing criteria and indicator sets were identified and recommendations on improvements were formulated. The findings were summarised in a report (Burgherr et al., 2005).

- **Establishment of social criteria and indicators.**

As anticipated and confirmed by the survey of criteria and indicators (Burgherr et al., 2005) their social component showed to be rather weakly established for the purpose of RS 2b work. Thus, extensive original work was necessary to define a set satisfying the basic requirements of the project. A multi-step approach was applied filtering the initially identified set of 1320 social indicators to 28 that are considered to be capable to measure the social dimension of present and future energy systems. These indicators are attributed to concepts derived from the theoretical concept of social compatibility. The underlying criteria are: (a) Continuity of energy service over time; (b) Political stability and legitimacy; (c) Social components of risks, and (d) Quality of Life.

Based on responses to a questionnaire obtained from 52 European experts and stakeholders, and on a Delphi workshop with 11 contributors, the initial set of criteria and indicators was re-examined. These exercises confirmed that the scope and content of the set are fully relevant. Furthermore, some prioritisation was made indicating the possibilities for reducing the set. On this basis recommendations for further use of social criteria and indicators were formulated.

The analysis and the selected set of social indicators were documented in a report (Renn et al., 2006).

- **Establishment of a full set of criteria and indicators.**

A preliminary full set of criteria and indicators, covering economic, environmental and social aspects was proposed by the stream leader. Practical constraints were taken into account, including prospects for successful quantification in view of expected inputs from other streams and from relevant WPs within RS2b. The proposed set was reviewed within RS2b and by other streams. This helped to assure that: (a) the set does not contain any errors; (b) the expectations on inputs from other streams are realistic; (c) a number of ambiguities about the characteristics of specific inputs and about responsibilities for inputs are resolved both within RS2b and what concerns inputs from other streams. As a result a number of modifications are implemented in the present document. When putting together the full set a number of changes were necessary also in the earlier proposed set of social indicators in order to harmonize the content.

The criteria and indicators provided in this report represent a consensus within stream RS2b and also reflect primarily NEEDS-internal feedbacks. They are being implemented within a questionnaire and will be subject of a survey to be carried out by RS2b among a wide range of stakeholders.

The results of this survey may to a limited extent influence the final set of criteria and indicators that will be used in MCDA. Though quantification of additional or modified indicators will not be generally feasible due to time constraints, it is possible and desirable to reduce the final set, i.e. the stakeholder feedback might allow some final prioritisation.

The current report will be updated to include the results of the survey and recommendations for the final set of criteria and indicators to be used in the MCDA implementation.

### 3 Requirements

Drawing on PSI's work and generally on the rich literature (Burgherr et al. 2005) defined requirements on indicators. Thus, indicators should be:

#### **Scientific:**

- *Measurable and quantifiable*: adequately reflect the phenomenon intended to measure
- *Meaningful*: appropriate to the needs of the user
- *Clear in value*: distinct indication which direction is good and which is bad
- *Clear in content*: measured in understandable units that make sense
- *Appropriate in scale*: not over or under aggregated
- *No redundancy or double counting*: indicators are not overlapping in what they measure
- *Robust and reproducible*: indicator measurement is methodologically sound, fits the intended purpose and is repeatable
- *Sensitive and specific*: indicators must be sensitive to changes in the system under study, and ideally respond relatively quickly and noticeably
- *Verifiable*: it is possible to verify an indicator by external persons or groups
- *Hierarchical*: to allow a user to understand the level of detail necessary

#### **Functional:**

- *Relevant*: for all stakeholders involved
- *Compelling*: interesting, exciting and suggestive of effective action
- *Leading*: so that they can provide information to act on
- *Possible to influence*: indicators must measure parameters that are possible to change
- *Comparable*: if the same indicators are used in several systems, they should be comparable
- *Comprehensive*: the indicator set should sufficiently describe all essential aspects of the system under study

#### **Pragmatic:**

- *Manageable*: not too many to handle; also important in view of interactions with users and stakeholders
- *Understandable*: possible to understand by stakeholders
- *Feasible*: measurable at reasonable effort and cost
- *Timely*: compilable without long delays
- *Coverage of the different aspects of sustainability*: indicators address economic, environmental and social dimensions
- *Allowing international comparison*: to the extent necessary, i.e. in accordance with specific study objectives

Main considerations that were taken into account for the choice of specific indicators for NEEDS include:

- Catching the essential characteristics of technologies and enabling differentiation between them.
- Assuring that indicators are representative (but not necessarily complete).
- Keeping the number of indicators at a reasonable level and striving for a certain balance in terms of number of indicators representing the various dimensions of sustainability.
- Trying to avoid excessive overlapping.
- Aiming at limited aggregation of indicators provided that this involves no or minimum subjectivity.
- Assuring practicability and feasibility; in particular having confidence that the indicators can be generated within research stream RS2b or will be available from other NEEDS research streams.

The most relevant considerations for the choices of criteria and indicators are provided in Table 1, together with their interpretation by the group responsible for economic indicators. These interpretations are generally valid also for indicators covering the two other dimensions of sustainability.

**Table 1 Criteria for the design of criteria-indicators (Bachmann & Schenler, 2007).**

Criteria and indicators should... (Hirschberg, 2006)	This study's interpretation
Catch the essential characteristics of technologies and enabling differentiation between them.	<p>The <b>criteria and indicators</b> should be <b>concrete and readily understandable</b> by stakeholders (e.g. selection of appropriate units), in order to facilitate their decision-making.</p> <p><b>Binary</b> indicators should be avoided as far as possible, in order to allow gradual distinctions between technologies (e.g. 0 or 1 values, or values ranges that have widely disparate outliers).</p> <p><b>Scenario-dependent assumptions</b> should be avoided (such as the future energy mix, technology market penetration, or political or trade boundaries) because the multi-criteria analysis may be based more on the scenario than the technology.</p>
Assure that indicators are representative (but not necessarily complete).	It is supposed that each indicator should be representative for a certain decision making criterion and, thus, be <b>well indicative</b> for a given criterion; at the same time, all indicators together do not need to cover all of a criterion's 'space' ('completeness') but <b>capture all of the main decision criteria</b> .
Keep the number of indicators at a reasonable level and striving for a certain balance in terms of number of indicators.	The number of indicators for each criterion should be limited and relatively consistent across criteria.
Avoid excessive overlapping.	Different indicators should be as independent as possible. Overlapping or double-counting indicators may introduce bias into the multi-criteria analysis.

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**Criteria and indicators should... (Hirschberg, 2006)      This study's interpretation**

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Aim at limited aggregation of indicators provided that this involves no or minimum subjectivity.

The quantification process should be transparent, meaning: the source of the data used for quantification should be specified, the link between these data and the actual indicator should be as simple and direct as possible; and whenever there is no direct link, the calculation process used to obtain the indicator value from the data should be specified, including any assumptions that may have been necessary in order to obtain a result (see also remark on scenario-dependent assumptions above).  
The calculation should be consistent for all technologies.

Assure practicability and feasibility; in particular having confidence that the indicators can be generated within research stream RS2b or will be available from other NEEDS research streams.

Data availability within NEEDS warranted.  
Work to process the data should fall within the scope of the anticipated and contracted person-months.

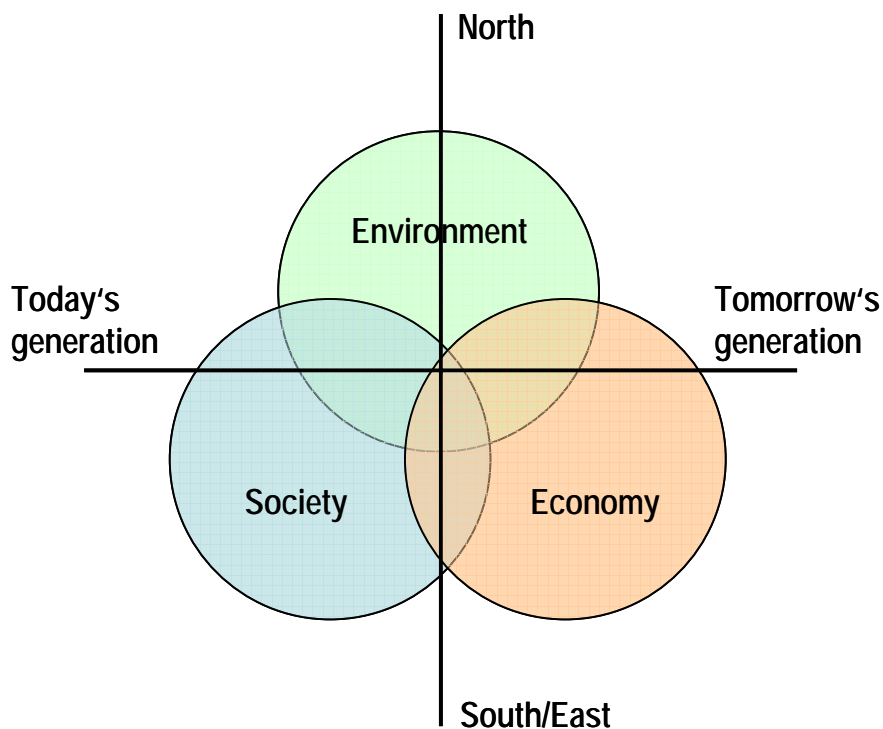
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## 4 Criteria and indicator set

### 4.1 Basic structure

For a review of the various sustainability concepts we refer to the review in (Burgherr et al., 2005). For the purpose of the present work we adopt the three dimensional view of sustainability, based on the mother of all definitions of sustainability as established by the Brundtland Commission (WCED, 1987).

The sustainable development is thus depicted schematically using three circles for the target dimensions of environment, economy and society, to which are added the time (i.e., intergenerational equity) and north-south dimensions (i.e., intragenerational equity), which is illustrated in Figure 1.



**Figure 1** Schematic representation of the central aspects of sustainable development, which is based on the definition of the Brundtland Commission. Modified from SDC & ARE (2004).

The equal treatment of the three dimensions environment, economy and society is not without controversy. An alternative perspective postulates that human society has to develop within the boundaries set by the environment, and that economy has to satisfy societal needs – not the reverse. Though the representation chosen by us implies symmetry rather than a hierarchy, in the MCDA implementation the stakeholders will be free to assign different importance to the three dimensions.

Table 2 provides an overview of the structure of the criteria selected in the present work.

**Table 2 Main environmental, economic and social criteria in the frame of the MCDA for sustainability assessment.**

Criteria
<b>ENVIRONMENT</b>
Resources
Climate Change
Impacts on ecosystems
Waste
<b>ECONOMY</b>
Impacts on customers
Impact in the overall economy
Impacts on the utility
<b>SOCIAL ASPECTS</b>
Security/reliability of energy provision
Political stability and legitimacy
Social and individual risks
Quality of life

In the following the substructure of indicators will be elaborated along with accounting for the definitions.

## 4.2 Environmental criteria and indicators

### 4.2.1 Criterion: Resources

#### Sub-criterion: Energy Resources

Indicator: *“Fossil Primary Energy”*: Total consumption of fossil resources (MJ/kWh)

The consumption of non renewable fossil resources like crude oil, natural gas and coal leads to a steady depletion of these energy carriers. Increasing scarcity of these resources will in turn lead to increasing environmental burdens associated with their extraction. It will lead to higher costs of fossil resources and might cause political tensions, since the resources are not globally even distributed. And crude oil is not only used as fuel, but also as raw material for several applications.

The indicator quantifies the total primary energy content of the fossil resources consumed for the production of 1 kWh of electricity. It contains the energy content of the cumulative consumption of coal, natural gas and crude oil and covers complete energy chains. These three energy carriers are assumed to reflect the consumption of non renewable fossil energy in a representative way, even if there are further, but on the global scale less important fossil energy resources like lignite and peat.

It seems worth discussing whether the different types of fossil energy carriers should get the same weight as it is when summing the primary energy content. One might argue for example that coal resources are much more abundant than natural gas and oil resources. However, in this context it can be assumed that one depleted fossil fuel would be possibly substituted by the remaining one(s), e.g. coal can be gasified or liquefied.

**Indicator:** *“Other non-renewable energy”*: Total consumption of uranium (MJ/kWh)

Besides fossil energy carriers, also uranium is a non renewable energy resource, which is depleted with the use as fuel for nuclear power plants. The consequences associated with the resulting increasing scarcity are similar to those for the consumption of fossil resources: increasing environmental burdens due to uranium extraction at a lower ore grade, higher costs and possible political tensions.

The indicator quantifies the primary energy content of the uranium resources consumed for the production of 1 kWh of electricity. It contains the total consumption of uranium and covers complete energy chains. The calculation of the energy content of uranium is based on the current German fuel cycle, i.e. the use of uranium in light water reactors of currently installed technology.

**Sub-criterion: Mineral Resources (Ores)****Indicator:** *Weighted total consumption of metallic ores (kg(Sb-eq.)/kWh)*

Metals play a key role in the economy as basic input for our technology of today. Metals serve as construction materials for buildings, machines and consumer goods, as catalysts, and for many other purposes. For several applications, single metals cannot be easily (or only for higher costs) substituted by others and therefore, consumption and subsequent depletion of metal ores can be considered as problematic. Similar to energy resources, increasing scarcity of metal ores will be associated with increasing environmental burdens due to their extraction at lower ore grades, higher costs and possible political tensions.

The indicator quantifies the consumption of selected scarce metals consumed for the production of 1 kWh of electricity. It is based on the respective approach of the Life Cycle Impact Assessment method "CML 2001" (Guinée (final editor) et al., 2001a; Guinée (final editor) et al., 2001b; Guinée (final editor) et al., 2001c). The following metals are included: aluminium, antimony, chromium, cobalt, copper, iron, lead, manganese, mercury, magnesite, magnesium, manganese, molybdenum, nickel, palladium, platinum, rhenium, ruthenium, silver, tin, zinc. The consumption of all single metals is expressed in kg antimony-equivalents, reflecting the scarcity of the different ores relative to the reference ore (antimony). This means that metal ores more or less scarce than antimony (depending of today's consumption and reserves of the respective ore) are assigned with a weighting factor higher or lower than one (1= weighting factor of antimony). Even if estimates of ultimate reserves of metal ores are highly uncertain, the current approach is regarded to reflect sustainability concerns in a better way than an unweighted sum of metal consumption only. The indicator covers complete energy chains.

**4.2.2 Criterion: Climate Change****Indicator:** *Global warming potential (kg(CO<sub>2</sub>-eq.)/kWh)*

Climate change is the dominating environmental concern of the international environmental political discussion of today. Global warming is not only an issue for the environment, but rather for human society as a whole, since rising global temperatures might have serious consequences not only on the environment, but on our economy and social life as well. Among the potential consequences are more frequent extreme weather events like heat waves, storms, floodings and droughts, stress due to higher temperatures for plants and humans, rising sea level, and altering occurrence of pathogenic organisms.

The anthropogenic impact on the climate system is due to the emission of CO<sub>2</sub> and other greenhouse gases, directly or indirectly caused by human activities. Direct CO<sub>2</sub> emissions originate e.g. from the combustion of fossil fuels. Methane emissions from cattle breeding are an example for indirectly generated greenhouse gas emissions.

The indicator reflects the potential negative impacts of the global climate change caused by emissions of greenhouse gases for the production of 1 kWh of electricity. It follows the methodology of (IPCC, 2001) and covers complete energy chains.

The quantity of greenhouse gas emissions as such is chosen as an indicator of potential negative effects, since estimates of these effects correlated with increasing global temperatures are highly uncertain today.

### 4.2.3 Criterion: Impact on ecosystems

#### Sub-criterion: Impacts from normal operation

The following three indicators together, based on the Life Cycle Impact Assessment method Eco-indicator 99 (Goedkoop & Spriensma, 1999a; Goedkoop & Spriensma, 1999b) are assumed to represent the human impacts on ecosystems in a comprehensive and scientifically sound way. It is based on actual damage of ecosystems (loss of biodiversity) due to land use, ecotoxicity and acidification and/or eutrophication. Even if expressed with the same unit, the separate quantification allows a more transparent use and weighting of the individual impact categories.

#### Indicator: "Biodiversity": Impacts of land use on ecosystems (PDF\*m<sup>2</sup>\*a/kWh)

Human land use, i.e. changing the natural state of land by human activities, is one of the potential reasons for loss of biodiversity, i.e. loss of species.

Biodiversity is an essential factor for the well-being of the earth's ecosystems. Loss of biodiversity is regarded as a long-term problem negatively affecting the natural functioning of the ecosystems, which in many cases (e.g. agriculture, tourism, etc.) poses a valuable or even essential commodity for human society.

The indicator quantifies the loss of species (flora & fauna) due to land use for the production of 1 kWh of electricity in terms of "Potentially Disappeared Fraction (of species), PDF". It follows the methodology of the Life Cycle Impact Assessment method Eco-indicator 99 (Goedkoop & Spriensma, 1999a; Goedkoop & Spriensma, 1999b) and covers complete energy chains.

#### Indicator: "Ecotoxicity": Impacts of toxic substances on ecosystems (PDF\*m<sup>2</sup>\*a/kWh)

A second potential reason for loss of biodiversity is the emission of ecotoxic substances to air, water and soil. Among those substances are heavy metals, VOCs and particles.

Biodiversity is an essential factor for the well-being of the earth's ecosystems. Loss of biodiversity is regarded as a long-term problem negatively affecting the natural functioning of the ecosystems, which in many cases (e.g. agriculture, tourism, etc.) poses a valuable or even essential commodity for human society.

The indicator quantifies the loss of species (flora & fauna) due to the release of ecotoxic substances to air, water, and soil per kWh electricity produced in terms of "Potentially Disappeared Fraction (of species), PDF". It follows the methodology of the Life Cycle Impact Assessment method Eco-indicator 99 (Goedkoop & Spriensma, 1999a; Goedkoop & Spriensma, 1999b) and covers complete energy chains.

#### Indicator: "Acidification and eutrophication": Impacts of air pollution on ecosystems (PDF\*m<sup>2</sup>\*a/kWh)

The third potential reason for loss of biodiversity is the emission of substances to air, water and soil, which cause acidification and/or eutrophication. Those species include among others nitrogen oxides and sulphur dioxide, two of the most important pollutants emitted by our economy (from power plants, traffic, etc.). Acidification and eutrophication are among the most visible effects of human environmental pollution: whole ecosystems, e.g. lakes and forests can collapse due to these impacts.

Biodiversity is an essential factor for the well-being of the earth's ecosystems. Loss of biodiversity is regarded as a long-term problem negatively affecting the natural functioning of the ecosystems, which in many cases (e.g. agriculture, tourism, etc.) poses a valuable or even essential commodity for human society.

The indicator quantifies the loss of species (flora & fauna) due to the release of ecotoxic substances to air, water, and soil per kWh electricity produced in terms of “Potentially Disappeared Fraction (of species), PDF”. It follows the methodology of the Life Cycle Impact Assessment method Eco-indicator 99 (Goedkoop & Spriensma, 1999a; Goedkoop & Spriensma, 1999b) and covers complete energy chains.

**Sub-criterion: Impacts of severe accidents**

The following two indicators address impacts on ecosystems caused by severe accidents. As in the case of normal operation full energy chains are considered.

**Indicator: Large release of hydrocarbons (t/kWh)**

This indicator addresses large accidental spills of hydrocarbons to the environment, which can potentially damage affected ecosystems. Only severe accidents are considered, i.e. releases of at least 10,000 tonnes.

**Indicator: Nuclear land contamination (km<sup>2</sup>/kWh)**

This indicator addresses land contamination that could result from hypothetical nuclear accidents. The land area contaminated can be estimated using Probabilistic Safety Assessment (PSA).

#### **4.2.4 Criterion: Wastes**

**Sub-criterion: Special chemical wastes stored in underground depositories**

**Indicator: Total weight of special chemical wastes stored in underground repositories**

Special chemical wastes, which have to be stored in underground depositories, pose a potential risk for the environment, even if in case of proper handling these wastes do not cause any environmental burdens. The correct functioning of the depositories cannot be secured in any case, as examples of the past show. Therefore, another factor to consider is human aversion against such wastes including the difficulties of finding actual sites for such depositories.

The indicator quantifies the masses of special chemical wastes stored in underground depositories caused by the production of 1 kWh of electricity. It covers complete energy chains and does not reflect actual damage to humans or nature.

The masses of such special chemical wastes associated with electricity chains are regarded as representative for both the potential environmental burdens and the aversion against such wastes together.

**Sub-criterion: Medium and high level radioactive wastes to be stored in geological repositories**

**Indicator: Total amount of medium and high level radioactive wastes to be stored in geological repositories (kg/kWh)**

Medium and high level radioactive wastes, which have to be stored in deep geological underground depositories, pose a potential risk for the environment, even if in case of proper handling these wastes do not cause any environmental burdens. Besides their potential harmful impacts, their very long “lifetime” in the order of hundreds of thousands of years is an issue, especially from the social point of view. A key factor for this problem to consider is human aversion against such wastes and underground depositories including the enormous (e.g. in Switzerland) difficulties of finding actual sites for such depositories.

The indicator quantifies the total volumes (including casing) of medium and high level radioactive wastes to be stored in deep geological repositories caused by the production of 1 kWh of electricity. It covers complete energy chains and does not reflect actual damage to humans or nature.

The masses of medium and high level radioactive wastes to be stored in deep geological underground depositories associated with electricity chains are regarded as representative for both the potential environmental burdens and the aversion against such wastes together.

The basic source for the environmental indicators addressing normal operation will be RS1a. However, generic values originating from RS1a will be subject to pragmatic adjustments aiming at reflecting some country-specific conditions.

## 4.3 Economic criteria and indicators

The following part draws on Bachmann & Schenler (2007). Terminology used in the present report has been somewhat adjusted for reasons of consistency.

### 4.3.1 Criterion: Impact on customers

Indicator: "Price of electricity": Average generation cost (€/MWh)

#### Definition

The average generation cost of electricity is defined as the cost per kWh of net generation delivered at the plant busbar to the transmission grid<sup>1</sup>. Net generation means that electricity used to run the plant (e.g. the power used to pulverize coal for coal-fired generation) is subtracted from gross generation before delivery at the busbar. Note the way the average generation costs are calculated for co-generation plants.

#### Discussion

This indicator excludes any costs (or credits) downstream from the busbar, including transmission and distribution costs, utility system overhead costs, non-generation taxes, profits, and energy losses during transmission and distribution, etc. This represents a disadvantage to distributed generation technologies (e.g. rooftop solar PV, or cogeneration based on small, internal combustion motors) that do not require the grid's costs or losses to deliver their power. On the other hand, if these distributed generation technologies are to not require any kind of battery backup storage for outages, then they will instead need a backup grid connection that will diminish their transmission and distribution credit.

Using the average generation cost rather than the actual price of electricity charged to the customer is also due to the fact that calculating the price would require several additional scenario-dependent assumptions for the situation in 2050. Such assumptions already necessarily include forecasts of fuel and heat prices in the countries studied.

However given the emphasis of the NEEDS project on supply side generation technologies, the focus on generation cost at the busbar rather than price to the customer seems appropriate and acceptable.

### 4.3.2 Criterion: Impact on the overall economy

Sub-criterion: Employment

Indicator: Direct labour (person-years/GWh)

#### Definition

This indicator is defined as the amount of direct labour required for each technology chain, averaged over the total generation for the planned life of the plant. It is measured by the average amount of labour in person-years per GWh. Direct labour includes the labour required to build, operate and decommission the plant, and to extract or harvest, process and deliver the fuel. Direct labour does not include the indirect labour content of components or materials supplied to the plant or fuel cycle.

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<sup>1</sup> Also called the busbar cost.

## Discussion

This indicator is based on the average amount of labour used to produce a unit of electricity. It does not give the total number of persons employed (some jobs might be part-time), or the quality of the jobs as measured either by salary or the amount of training or education required. The quality of work issue is instead addressed by one of the social indicators (the “Work Quality” indicator is based on knowledge and training of average worker in each technology chain, using an ordinal scale indicator). Jobs may also have very different amounts of risk or hazard associated with them, which is also addressed under the social category by the expert-based risk estimate indicators of “Reduced life expectancy due to normal operation” (Years of Life Lost, or YOLL/kWh), “Non-fatal illnesses due to normal operation” (Disability Affected Life Years, or DALY/kWh) and “Expected health effects from accidents” (fatalities/kWh in severe accidents of 5 or more deaths). These indicators give effects on the total population, but naturally affect employees more than the general public.

### Sub-criterion: Autonomy of electricity generation

Indicator: *Medium to long-term independence from foreign energy sources (Ordinal scale)*

#### Definition

Utility companies and the societies they serve may be vulnerable to interruptions in service if imported fuels are unavailable due to economic or political problems related to energy resource availability. It combines consideration of energy autonomy and sustainability, based on whether the energy resource for a specific technology is imported, domestic and finite, or domestic and renewable, with some weight given to the relative size of different finite resources. The quantification of this indicator is proposed to follow an ordinal scale, as given in Table 3 below. The scale given runs from zero for energy carriers that must be imported, to ten for renewable resources that are domestically available. Intermediate values for domestic fossil or nuclear resources are based on judgement of the relative time scales for the availability of different fuel types, and some consideration of domestic interaction with global markets. For this indicator, the fuel refers to the primary energy carrier, e.g. synthetic gas made from biomass would be scored a 10, while synthetic gas made from coal would be scored a 6, and natural gas would be scored a 3. This distinction also applies to synthetic oil from various sources v. oil refined from domestic crude reserves.

**Table 3** Values for the indicator “very long-term independence from foreign energy sources”.

Group name	Value	Description
Imported energy carrier	0	Technologies that rely on fuels or energy resources that must be imported.
Domestic oil	2	For oil-fired technologies in countries where domestic oil resources are available.
Domestic gas	3	For gas-fired technologies in countries where domestic gas resources are available.
Domestic coal	6	For coal-fired technologies in countries where domestic coal resources are available.
Domestic uranium	8	For nuclear technologies in countries where domestic uranium resources are available (includes extraction from seawater).
Domestic renewable energy resource	10	For technologies which rely on renewable energy fluxes present in a given country (e.g. hydro, solar, wind, wave and geothermal).

## Discussion

Several possible indicators were originally proposed to measure the contribution of each generating technology to the autonomy of electricity supply. The indicator proposed for short-term autonomy was the lifetime of stored reserves (i.e. short-term stockpiles/current resource use). Estimating future stockpiles and use for the year 2050 however was so uncertain and scenario dependent that this indicator was abandoned. An indicator for long-term autonomy based on domestic energy resources was also proposed, based on long-term reserve life (i.e. currently known and recoverable domestic reserves/current domestic use). There was still considerable uncertainty as to how well this current measure of resource lifetime would apply in the year 2050, but it was deemed acceptable due to the long-term resource life. Modifications based on the substitutability of fuels were also considered and rejected.

However the main problem with using the concept of resource life as an indicator remained that it essentially produces a binary measure. That is, fossil & uranium reserves are finite, no matter how large, and renewables have a resource life that is infinite for all practical purposes. This binary separation of finite v. infinite destroys the possibility of making any discrimination between the different resource lifetimes for the different fossil and nuclear technologies, which are still of significant importance.

It was proposed to resolve this difficulty by imposing an arbitrary, large cap on the resource life of the renewable resources, but it was unclear what the rationale for this should be. Likewise, it would have been possible to use the logarithm of the resource life, which would have compressed the difference between finite and renewable resources, but not really have solved the problem. In the end, it seemed more reasonable to recognize the inherent element of judgement, and the ordinal scale given above was proposed. This element of judgement also allows some recognition of the fact that finite resources with similar resource lifetimes may still have different risks associated with geographic distribution, market forces and international politics.

The evaluation of whether domestic energy resources are available is based on expert judgment, i.e., whether it is now thought that there is sufficient domestic fuel resource to build a generation unit in 2050 and operate it economically for its life. If fossil fuels or uranium are not now domestically present, then the situation is clear. If coal, lignite or uranium is present, then the reserves are likely to last for the commercial life of the plant (40+ years). The situation for oil and particularly gas reserves is more complicated. However, the four countries under consideration (i.e., France, Germany, Italy and Switzerland) will almost certainly not have domestic oil by 2050, or enough domestic gas to count on using it for generation.

### 4.3.3 Criterion: Impacts on the utility

#### Sub-criterion: Financial risks

Indicator: *“Capital investment exposure”*: Total capital cost (€)

#### **Definition**

The total capital cost of a generation plant is a risk factor during financing and construction. This depends upon the size of the investment in proportion to the size of the utility or owner, and the resulting need to share ownership or structure financing. The total cost of a plant may also be a risk if the need to sell arises, under conditions that could force significant losses. For this indicator, it is assumed that total capital cost is the present value of the capital cost, i.e. the trajectory of capital expenditures is brought forward using the appropriate interest rate to give the NPV of capital costs at the base year (conventionally, the year of the start of operation). The values for this indicator will be drawn from the data provided by RS1a, specifically the overnight cost/kW multiplied by the busbar capacity.

**Discussion**

The concept of risk related to financing and resale was originally addressed by a proposed indicator for “liquidity,” i.e. the ability to resell a plant at a “fair” price. However, in the absence of government intervention, an unforced free market sale between a willing buyer and a willing seller was deemed to always be fair, so this original proposal was abandoned.

**Indicator:** *“Impact of fuel price changes” expressed as “Ratio of the fuel cost to the generation cost” (fraction)*

**Definition**

The indicator “impact of fuel price changes” is intended to show which technologies are likely to be most affected in their operation by a sudden change in fuel prices. It is expressed as the “ratio of the fuel cost to the average generation cost” and computed according to:

$$\text{Ratio} = \frac{\text{Average Fuel Cost}}{\text{Average Generation Cost}}$$

**Discussion**

This indicator measures the effect of fuel price changes on the cost of generation, rather than the actual uncertainty or risk of fuel price volatility. In order to assess the risk itself, it would have been necessary to multiply the effect of a price change by the probability of such a change. The current probability is generally reflected by the historical fuel price volatility, but it is difficult to assess fuel price volatility in 2050. One possibility would be to use the historic standard deviation of the fuel price, but this would imply that this standard deviation will roughly remain the same until 2050. This is an uncertain, scenario-dependent assumption, especially considering the debate on the potentially imminent scarcity of fossil fuels.

From a purely economic point of view, using elasticity would be more elegant (and probably more appropriate). But the concept of elasticity is difficult to explain to economic lay persons, which would include most stakeholders.

When defining the indicator’s formula, it is important to be specific what is meant by ‘average fuel price,’ as the cost of fuel increases along the chain from extraction of the primary energy resource to the fuel delivered. For instance, the cost of yellowcake is a relatively small part of the overall cost of nuclear fuel, but it has the largest variability while conversion, enrichment and fabrication costs are more fixed in the short term (over the long-term these other costs may also change).

This indicator uses the average cost of fuel delivered to the plant, as defined above in section 2.2.2. Renewables of course generally have a fuel cost that is zero, which gives them a ratio equal to zero reflecting their insensitivity to fuel cost.

**Indicator:** *“Risk due to changes in boundary conditions”: Construction time” (years)*

**Definition**

This indicator is defined as the construction time, starting with the expenditure of major capital spending through the start of operation.

**Discussion**

There is a period before a plant begins operation when conditions can change in a way that could delay or prevent the start of operation. This could be due to changes in market conditions, public opposition or regulatory delays or changes. This represents a financial risk to investors, which begins with the start of actual capital expenditures. Conditions can also change during the initial phases, including technical investigations on site, a dialogue phase with local community representatives, the acquisition of a license and the construction planning stage. However the cost of these activities is relatively much smaller and can be neglected in the present context. The actual construction period is

also less variable than the preliminary phases, more related to the technology design, and less variable across countries.

There could be a minor concern that the construction period could be correlated to the total cost, and hence represent a double counting within the set of indicators. It is true that smaller plants cost less and take less time to build, but the relationship is not linear and was deemed worthwhile to include the construction period as a financial risk indicator.

#### **4.3.4 Criterion: Operation**

Indicator: *“Merit order for dispatch purposes”*: Total average variable cost, or dispatch cost (€/MWh<sub>e</sub>)

##### **Definition**

The indicator of “merit order for dispatch purposes” is given by the total average variable cost, i.e. the sum of the variable operation and maintenance (O&M) cost and the fuel cost. The dispatch cost for each plant is the variable or marginal cost of operation - that is the cost to run the plant and generate the next kWh, ignoring the fixed costs to build and maintain it. The unit with most expensive dispatch cost sets the marginal cost for the system as a whole.

##### **Discussion**

Dispatch is the act of ordering a plant into or out of operation, or changing the level of power delivered. As system load increases, plants are dispatched in merit order based on dispatch cost from least to most expensive. This means that the baseload plants with the lowest dispatch cost run the most hours, and the peak load plants with the highest dispatch costs run only during peak hours. This is the basic paradigm of system dispatch, but it is also complicated by the cost and time delays to turn plants on and off, slightly different dispatch costs for each plant at different power levels, and the uncertainties related to expected system load and non-dispatchable generation. Non-dispatchable technologies are those that cannot be controlled from the dispatch centre, either because of the random nature of the resource (including solar and wind) or because they are small, distributed generation technologies that lack centralized control. Hydro is a rather specialized case – run-of-river plants are not dispatchable, but storage dams are limited in annual energy and used at the top of the dispatch order despite the fact that their fuel cost is zero (neglecting taxes).

For these reasons, the dispatch cost is one of the most basic characteristics of any generation technology, and of most interest to the generating utility and system operator.

Indicator: *“Flexibility of dispatch” expressed as a composite indicator (ordinal scale)*

##### **Definition**

The indicator for flexibility of dispatch is given on an ordinal scale from 1 to 10, based on the time required to start-up dispatchable units, and the expected time required to forecast the generation available from non-dispatchable technologies. Obviously, dispatchable technologies are preferred to non-dispatchable technologies for the purposes of system control. For this reason, the dispatchable technologies are assigned a number between 6 and 10 based on the log of their (cold) start-up times (in hours), with the shortest times given a 10 and the longest times given a 6. The non-dispatchable technologies (such as solar and wind) are assigned a number between 1 and 5 based on the log of their characteristic forecast times (in hours), with the longest times given a 5 and the shortest times given a 1. In this case, the characteristic forecast time is the time horizon at which one can reasonably dispatch other units based on the forecast of non-dispatchable generation. The log transformation is used because a planner’s preference for advance information is non-linear. That is, an extra hour of time is more useful the closer the planner comes to making an actual decision. For example, there is a bigger planning advantage to have 1 hour v. 2 hours of startup time (or 2 hours v. 1 hour of wind forecast) than there is to have 11 v. 12 hours startup time (or 12 v. 11 hours forecast time, respectively).

## Discussion

Obviously, the dispatch paradigm described in the previous indicator (variable dispatch cost) depends in its execution on the predictability of the system load, the predictability of the non-dispatchable generation, and the response times of dispatchable units. Dispatch response time varies, depending on whether the unit is being started up or shut down, and whether the unit is (or will be) hot or cold. For example, a cold start-up could take 4 hours for a unit, a hot start up could take half an hour, and a unit that is spinning and synchronized to the grid but not generating could increase power almost immediately (such spinning reserve is a valuable resource for system security). For the purpose of this indicator, the cold start-up time has been used. Because the different response times (e.g. hot v. cold start-up or hot v. cold shut-down) are relatively correlated, this seems to be reasonable.

The forecast times for expected wind and solar generation are based on their statistical variability (only during the day for solar, of course). The aggregate variability for the system as a whole will be less than for any one local area, due to averaging across the whole system. Local variations have implications for local grid stability, but for the purposes of the NEEDS project this indicator will use the system-wide variability, supplemented by expert judgement. Distributed generation is considered to be more predictable than either solar or wind power, because small cogenerators are usually controlled according to the on-site heat demand, and the aggregate demand is statistically more predictable than the more random solar or wind resources.

Perhaps the most unusual aspect of this flexibility of dispatch indicator is the way that it combines both the dispatchable and non-dispatchable technologies. This is not necessarily a bad thing, because two separate indicators would both tend to have a zero score for either the dispatchable or non-dispatchable technologies, and would require some weighted combination in the final multi-criteria assessment. The present indicator has done this combination already, using expert rather than stakeholder judgement.

**Indicator:** *“Availability” expressed as “Equivalent Availability Factor” (fraction)*

## Definition

The indicator of availability gives the fraction of time that a generating unit is in principle available for service at full power. All units require some time for planned maintenance and unplanned outages, but obviously the more available a unit is the better. However at some times a unit may be available but unable to operate at full power. For this reason, the equivalent availability factor (EAF) is used instead. It is defined as

$$EAF = \frac{\text{Maximum possible annual generation (MWh/yr)}}{\text{Peak capacity (MW) } \times 8766 \text{ hrs/yr}}.$$

## Discussion

The equivalent availability factor reflects the maximum possible generation available per year based on a unit’s reliability. It forms an upper bound to the capacity factor, which is based on expected dispatch. The equivalent availability factor is the *possible* annual generation divided by the peak capacity times 8766 hours/year, reflecting planned outages (maintenance) and expected forced outages (breakdowns, or reductions in generation capacity). The equivalent availability factor does not really apply to a non-dispatchable technology, which by definition is not available to be put into operation. However for the purposes of the NEEDS project, the expected capacity factor will be used for non-dispatchable technologies. Because sun, wind and water are free, these technologies generate as much electricity as possible, constrained by resource availability. Likewise, distributed CHP units generate as much electricity as possible, given the constraints of heat demand, which is assumed constant over the life of the building.

## 4.4 Social criteria and indicators

For details on the development of relevant social indicators we refer to (Renn et al., 2006).

Within RS2b of the NEEDS Project pioneering efforts were made to define social indicators for the assessment of social effects of energy systems. A multi-step approach was applied. In a first step a search was carried out to identify indicators available in publications from the last twenty years. The keywords “social indicator”; “sustainability”, environmental indicator” and “energy indicator” were used to organise this search process. As a result of this research process 1320 indicators were found. In a second step, these indicators have been tested according to the following meta-criteria:

1. The clarity of the indicators.
2. Whether the indicators are simple and logical.
3. Whether the indicators can be applied throughout Europe.
4. Whether they combine social and energy-system related aspects.

Only 148 of the 1320 criteria passed this step of the search process. These indicators were then tested according to three main questions to make sure that the indicators are suitable with the requirements of the NEEDS-project, i.e. whether:

1. They can be applied to future technologies.
2. Their focus is on the country level and not only on the regional level, and
3. The indicators allow differentiation between energy technologies.

Only 26 of the 148 indicators survived this filter process and are able to measure the social dimension of present and future energy systems. These indicators had been attributed to concepts derived from the theoretical concept of social compatibility (Häfele et al., 1985). With reference to the theoretical concept of social compatibility we allocated the indicators to four main criteria, these criteria are:

1. Continuity of Energy Service over Time
2. Political Stability and Legitimacy
3. Social Components of Risk
4. Quality of Life

For every criterion suitable indicators have been defined. Those mentioned criteria and indicators form the basis of our social indicator-set. Based on responses to a questionnaire obtained from 52 European experts and stakeholders, and on a Delphi-Workshop with 11 participants, the initial set of social criteria and indicators was re-examined. These exercises confirmed that the scope and content of the set are fully relevant. Furthermore, some prioritisation was made indicating the possibilities for reducing the set. On this basis recommendations for further use of social criteria and indicators were formulated.

In the process of harmonisation of environmental, economic and social indicators some further streamlining has taken place, resulting in further slight reduction of the number of selected social indicators and in some modifications of definitions necessitated by consistency requirements.

The indicators will be measured with reference to the four main life cycle phases of energy systems: energy extraction and processing, transport, conversion (electricity generation) and waste management (considering the entire back-end). All indicators to be evaluated on the ordinal scale will be generated on the basis of structured expert interviews.

Below follows a summary of the selected social criteria and indicators.

#### 4.4.1 Criterion: Security/reliability of energy provision

This criterion refers to the stability of the energy system and points out the importance of the security of supply for every person and society

##### Sub-criterion: Political threats to continuity of energy service

Indicator: *“Diversity of primary energy suppliers”: Market concentration in the primary energy supply (Ordinal scale)*

The indicator addresses the market concentration of energy suppliers in each primary energy sector. The evaluation will be based on expert judgment.

Indicator: *“Waste management”: Probability that waste storage management will not be available (Ordinal scale)*

The indicator is based on the possibility that an infrastructure of storage facilities will not be available in time to take deliveries of waste materials from the fuel chain, including from the fuel supply, plant construction, operation and decommissioning of the plant. The evaluation will be based on expert judgment.

##### Sub-criterion: Flexibility and adaptation

Indicator: *Flexibility to incorporate technological change (Ordinal scale)*

The indicator refers to the technical characteristics of each electricity generation technology that may make it flexible in implementing technical progress and innovations. The evaluation will be based on expert judgment.

#### 4.4.2 Criterion: Political Stability and Legitimacy

These two closely related aspects include address the conflicts that may arise if the acceptability of energy systems or political decisions is problematic and the peaceful procedures to resolve such conflicts.

##### Sub-criterion: Potential of energy system induced conflicts that may endanger the cohesion of societies

Indicator: *Potential of energy system induced conflicts (Ordinal scale)*

The indicator refers to conflicts that are based by historical evidence. It is related to the characterisation of energy systems that trigger conflicts. The evaluation will be based on expert judgment.

##### Sub-criterion: Willingness to act (mobilization potential)

Indicator: *Willingness of NGOs and other citizen movements to act against the realisation of an option (Ordinal scale)*

The indicator is based on the potential for mobilization (i.e., opposition) of public opinion, including protests, petitions, signature drives, etc. The evaluation will be based on expert judgment.

##### Sub-criterion: Necessity of participative decision-making processes

Indicator: *Necessity of participative decision-making processes for different technologies (Ordinal scale)*

Indicator: This indicator is based on the fact that certain types of technologies require public, participative decision-making processes, especially for construction or operating permits or licenses. The evaluation will be based on expert judgment.

### 4.4.3 Criterion: Social and individual risks

In this case we differentiate between risks associated with normal operation and with severe accidents as well as between risks estimated by experts and perceived by citizens.

**Sub-criteria: Expert-based risk estimates for normal operation**

**Indicator:** *“Reduced life expectancy due to normal operation”: Mortality due to normal operation (YOLL/kWh)*

This indicator is based on the increased rate of mortality due to normal operation of the electricity generation technology and its associated energy chain. It is measured in the years of life lost (YOLL) by the entire population, compared to the expected lifetimes without the technology in question. The evaluation will be based on the Impact Pathway Approach.

**Indicator:** *“Non-fatal illness due to normal operation”: Morbidity due to normal operation (DALY/kWh)*

The indicator is based on the increased rate of sickness or morbidity due to normal operation of the electricity generation technology and its associated energy chain. It is measured in the years of life affected by disabilities (disability affected life years, or DALY) suffered by the entire population, compared to their expected health without the technology in question. The evaluation will be based on the Impact Pathway Approach.

**Sub-criteria: “Expert-based risk estimates for accidents**

**Indicator:** *“Expected health effects from accidents”: Expected mortality due to severe accidents (Fatalities/kWh)*

The indicator is based on the number of fatalities expected for each kWh of electricity that occur in severe accidents with 5 or more deaths per accident for a particular electricity generation technology chain. The evaluation will be based on historical experience of accidents and on Probabilistic Safety Assessment (PSA).

**Indicator:** *“Maximum consequences of accidents”: Maximum credible number of fatalities per accident (Fatalities/accident)*

This indicator is based on the maximum number of fatalities that are reasonably credible for a single accident for a particular electricity generation technology chain. Implicitly the criterion addresses the aversion towards low-probability high-consequence accidents. The evaluation will be based on historical experience of accidents and on Probabilistic Safety Assessment (PSA).

**Sub-criteria: Perceived risks**

**Indicator:** *“Perceived risk characteristics for normal operation”: Subjectively expected health consequences of normal operation (Ordinal scale)*

The indicator is based on citizens' fear of negative health effects due to normal operation of the electricity generation technology. The evaluation will be based on expert judgment.

**Indicator:** *“Perceived risk characteristics for accidents”: Psychometric variables such as personal control, catastrophic potential, perceived equity, familiarity (Ordinal scale)*

This criterion is based on citizens' perception of risk characteristics, including whether they can control the risk personally, whether the potential damage is small or catastrophic, and their familiarity with the risk. The evaluation will be based on expert judgment.

**Sub-criteria: Terrorist threat**

**Indicator:** *“Potential of attack”*: Potential for a successful attack (Ordinal scale)

The criterion addresses the potential for a successful terrorist attack on a specific technology, based on its vulnerability, the potential damage and public perception of risk. The evaluation will be based on expert judgment. The evaluation will be based on expert judgment.

**Indicator:** *“Likely potential effects of a successful attack”*: Expected number of fatalities (Ordinal scale)

The criterion concerns the potential likely consequences of a successful terrorist attack. The evaluation will be primarily based on expert judgment.

**Indicator:** *“Proliferation”*: Potential for misuse of technologies and substances within the nuclear chain (Ordinal scale)

**4.4.4 Criterion: Quality of Life**

The criterion addresses two categories, i.e. socially compatible development and effects on the quality of landscape area.

**Sub-criteria: Socially compatible development**

**Indicator:** *“Equitable life conditions”*: Share of the effective electricity costs in the budget of social welfare recipient (%)

The indicator quantifies the average fraction of the budget dedicated to electricity by a household receiving social welfare.

**Indicator:** *“Work quality”*: Work qualifications expressed as average years of education for workforce (Ordinal scale)

The indicator is based on the amount of knowledge and training required by the average worker employed within a particular energy technology chain.

**Sub-criteria: Effects on the quality of landscape and residential area**

**Indicator:** *“Effects on the quality of landscape”*: Functional and aesthetic impact of energy infrastructure on landscape (Ordinal scale)

The indicator is based on the overall functional and aesthetic impact on the landscape of the entire infrastructure related to each electricity generation technology chain, including mines, transmission lines or pipelines, structures, etc. The evaluation will be based on expert judgment.

**Indicator:** *“Noise exposure”*: Extent to which residents feel highly affected by noise (Ordinal scale)

The indicator is based on the amount of noise caused by the generation plant, as well as transport of materials to and from the plant (e.g. trucking of fuel and/or waste).The evaluation will be based on expert judgment.

**Indicator** “Contribution to traffic”: Total traffic load (km/kWh)

This indicator quantifies the freight traffic by lorry and train caused by the production of 1 kWh electricity. The criterion covers the most relevant parts of each electricity generation technology chain considering freight traffic.

## 5 Summary

Table 4 provides a summary of the criteria and indicators intended for use in the Multi-criteria Decision Analysis implementation to be carried out by RS2b in year 2008. The criteria and indicators provided in this report represent a consensus within stream RS2b and also reflect feedbacks received from other NEEDS streams. This resulted in the consolidation of economic indicators and more stringent representation of the social ones. The set has been implemented within the questionnaire and is subject of a survey among a wide range of stakeholders.

The basic structure uses the three pillars of sustainability, i.e. environment, economy and society. Within these three dimensions there are four hierarchical levels. The full has been subject to slight reductions in comparison with the earlier, preliminary version and currently comprises 11 environmental, 9 economic and 20 social indicators (among the latter 12 are connected to ecology).

The environmental dimension addresses Energetic and Non-energetic Resources (3 indicators), Climate Change (1 indicator), Impacts on Ecosystems (5 indicators), and Wastes (2 indicators).

The economic dimension addresses Impacts on Customers (1 indicator), Impacts on Overall Economy (2 indicators) and Impacts on Utility (6 indicators).

Finally, the social dimension addresses Security/Reliability of Energy Provision (3 indicators), Political Stability and Legitimacy (3 indicators), Social and Individual Risks (9 indicators) and Quality of Life (5 indicators).

The results of the forthcoming Survey II may to a limited extent influence the final set of criteria and indicators that will be used in MCDA. Though quantification of additional or modified indicators will not be generally feasible due to time constraints, it is possible that the final set will be somewhat reduced, i.e. the stakeholder feedback might allow some final prioritisation. The current report will be updated and extended to include the findings from Survey II.

Table 4 Overview of the set of criteria and associated indicators for the three sustainability dimensions.

Criterion	Indicator	Unit	Estimation Method	Input*
<b>ENVIRONMENTAL DIMENSION</b>				
<b>RESOURCES</b>				
Energy Resources				
Fossil primary energy	Total consumption of fossil resources	MJ/kWh	Life Cycle Impact Assessment (LCIA)	RS1a/PSI
Other non-renewable energy	Total consumption of uranium	MJ/kWh	Life Cycle Impact Assessment (LCIA)	RS1a/PSI
Mineral Resources (Ores)	Weighted total consumption of metallic ores	kg(Sb-eq.)/kWh	Life Cycle Impact Assessment (LCIA)	RS1a/PSI
<b>CLIMATE CHANGE</b>	Global warming potential	kg(CO <sub>2</sub> -eq.)/kWh	Life Cycle Impact Assessment (LCIA)	RS1a/PSI
<b>IMPACT ON ECOSYSTEMS</b>				
Impacts from Normal Operation				
Biodiversity (land use)	Impacts of land use on ecosystems	PDF*m <sup>2</sup> *a/kWh	Life Cycle Impact Assessment (LCIA)	RS1a/PSI
Ecotoxicity	Impacts of toxic substances on ecosystems	PDF*m <sup>2</sup> *a/kWh	Life Cycle Impact Assessment (LCIA)	RS1a/PSI
Acidification and eutrophication	Impacts of air pollution on ecosystems	PDF*m <sup>2</sup> *a/kWh	Life Cycle Impact Assessment (LCIA)	RS1a/PSI
Impacts from Severe Accidents				
Release of hydrocarbons	Large release of hydrocarbons	t/kWh	Risk Assessment (RA)	RS2b/PSI
Land contamination	Nuclear land contamination	km <sup>2</sup> /kWh	Risk Assessment (RA)	RS2b/PSI
<b>WASTES</b>				
Special Chemical Wastes stored in Underground Depositories	Total weight of special chemical wastes stored in underground repositories	kg/kWh	Life Cycle Assessment (LCA)	RS1a/PSI
Medium and High Level Radioactive Wastes to be stored in Geological Repositories	Total amount of medium and high level radioactive wastes to be stored in geological repositories	m <sup>3</sup> /kWh	Life Cycle Assessment (LCA)	RS1a/PSI

\* Specifies primary stream providing input and organisation responsible for the final derivation of each indicator. For LCA- and LCIA-based indicators country-specific adjustments are needed. These will be carried by PSI.

Summary

Table 4 Continued: Economic dimension.

Criterion	Indicator	Unit	Estimation Method	Input*
<b>ECONOMIC DIMENSION</b>				
<b>IMPACTS ON CUSTOMERS</b>				
Price of electricity	Average generation cost	EUR/MWh	Extrapolation of current costs	RS2a/EDF
<b>IMPACTS ON OVERALL ECONOMY</b>				
Employment	Direct labour	Person-years/GWh	Labour due to fuel extraction and transport, plant construction and generation, and decommissioning	RS2b/PSI
Autonomy of electricity generation	Medium to long-term independence from foreign energy sources	Ordinal scale	Expert judgement	RS2b/EDF
<b>IMPACTS ON UTILITY</b>				
Financial Risks				
Capital investment exposure	Total capital cost	EUR	Cost estimation	RS1a/EDF
Impact of fuel price changes	Ratio of the fuel cost to the generation cost	Fraction	Forecast fuel cost divided by forecast average generation cost	RS2a/EDF
Risk due to changes in boundary conditions	Construction time	Years	Estimated construction time	RS1a/EDF
Operation				
"Merit order" for dispatch purposes	Total average variable cost or "dispatch cost"	EUR/MWh <sub>e</sub>	Forecast fuel cost and variable O&M cost	RS2a/EDF
Flexibility of dispatch	Composite indicator	Ordinal scale	Expert judgement	RS2b/EDF&PSI
Availability	Equivalent availability factor	Fraction	Industry statistics	RS2b/EDF

\* Specifies primary stream providing input and organisation responsible for the final derivation of each indicator. For LCA- and LCIA-based indicators country-specific adjustments are needed. These will be carried by PSI.

Table 4 Continued: Social dimension.

Criterion	Indicator	Unit	Estimation Method	Input
<b>SOCIAL DIMENSION</b>				
<b>SECURITY/RELIABILITY OF ENERGY PROVISION</b>				
Political Threats to Continuity of Energy Service				
Diversity of primary energy suppliers	Market concentration in the primary energy supply	Ordinal scale	Expert judgement	U.STUTT
Waste management	Probability that waste storage management will not be available	Ordinal scale	Expert judgement	U.STUTT
Flexibility and Adaptation	Flexibility to incorporate technological change	Ordinal scale	Expert judgement	U.STUTT
<b>POLITICAL STABILITY AND LEGITIMACY</b>				
Potential of Conflicts induced by Energy Systems.	Potential of energy system induced conflicts	Ordinal scale	Expert judgement	U.STUTT
Willingness to act (Mobilization Potential)	Willingness of NGOs and other citizen movements to act against realisation of an option	Ordinal scale	Expert judgement	U.STUTT
Necessity of participative Decision-making Processes	Necessity of participative decision-making processes for different technologies	Ordinal scale	Expert judgement	U.STUTT
<b>SOCIAL AND INDIVIDUAL RISKS</b>				
Expert-based Risk Estimates for Normal Operation				
Reduced life expectancy due to normal operation	Mortality due to normal operation	YOLL/kWh	Impact Pathway Approach (IPA)	PSI
Non-fatal illnesses due to normal operation	Morbidity due to normal operation	DALY/kWh	Impact Pathway Approach (IPA)	PSI
Expert-based Risk Estimates for accidents				

**Summary**

<b>Criterion</b>	<b>Indicator</b>	<b>Unit</b>	<b>Estimation Method</b>	<b>Input</b>
Expected Health effects from accidents	Expected mortality due to severe accidents	Fatalities/kWh	Risk Assessment (RA)	PSI
Maximum consequences of accidents	Maximum credible number of fatalities per accident	Fatalities/accident	Risk Assessment (RA)	PSI
<b>Perceived Risks</b>				
Perceived risk characteristics for normal operation	Subjective health fears due to normal operation	Ordinal scale	Expert judgement	U.STUTT
Perceived risk characteristics for accidents	Psychometric variables such as personal control, catastrophic potential, perceived equity, familiarity	Ordinal scale	Expert judgement	U.STUTT
<b>Terrorist Threat</b>				
Potential of attack	Potential for a successful attack	Ordinal scale	Expert judgement	PSI
Likely potential effects of a successful attack	Expected number of fatalities	Ordinal scale	Expert judgement	PSI
Proliferation	Potential for misuse of technologies and substances within the nuclear energy chain	Ordinal scale	Expert judgement	PSI
<hr style="border-top: 1px dashed black;"/>				
<b>QUALITY OF LIFE</b>				
<b>Socially compatible development</b>				
Equitable life conditions	Share of the effective electricity costs in the budget of a social welfare recipient	%	Expert judgement	U.STUTT
Work quality	Work qualifications expressed as average years of education for workforce	Ordinal scale	Expert judgement	U.STUTT
<b>Effects on the Quality of Landscape and Residential Area</b>				
Effects on the quality of the landscape	Functional and aesthetic impact of energy infrastructure on landscape	Ordinal scale	Expert judgement	U.STUTT
Noise exposure	Extent to which residents feel highly affected by noise	Ordinal scale	Expert judgement	U.STUTT
Contribution to traffic	Total traffic load	tkm/kWh	Life Cycle Assessment (LCA)	PSI

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