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NEEDS

New Energy Externalities Developments for Sustainability

INTEGRATED PROJECT

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

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"External costs from emerging electricity generation technologies "

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Partner responsibilities for the different sections of this deliverable

Section	Responsible institution
1. Introduction	DLR
2. Methodology for assessing external costs	DLR
3. Assessment of external costs from emerging electricity generation technologies	
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3.2 Fuel cells	POLITO, ifeu, DLR
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3.8 Ocean energy	SPOK
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Appendix A	EDF with the support of CEPN

List of acronyms

BWR	Boiling Water Reactor
Dioxin	Polychlorinated dibenzo-*p*-dioxins and furans expressed in toxic equivalents
EFR	European Fast Reactor
EPR	European Pressurized Reactor
ExternE	Externalities of Energy (project series funded by the European Commission)
FBR	Fast Breeder Reactor
FUND	Climate Framework for Uncertainty, Negotiation and Distribution
GCR	Gas-Cooled Reactor
GDP	Gross Domestic Product
ICRP	International Commission on Radiological Protection
LCIA	Life Cycle Impact Assessment
LWR	Light Water Reactor
NMVOC	Non-methane volatile organic compounds
PCDD/F	Polychlorinated dibenzo-*p*-dioxins and furans expressed in toxic equivalents
PDF	Potentially Disappeared Fraction
PM	Particulate Matter
PWR	Pressurized Water Reactor
SFR	Sodium-Cooled Fast Reactor
UCTE	Union for the Coordination of Transmission of Electricity
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VOLY	Value Of a Life Year
VOSL	Value Of a Statistical Life
YOLL	Years of Life Lost

1. Introduction

The objective of this report is to present quantifiable external costs related to the operation of emerging electricity generation technologies. The results presented in this report rely on methods and data developed in various parts of the NEEDS project. The specification of future reference technologies and the elaboration of related life cycle inventories were carried out by various teams in Research Stream (RS) 1a. Methods for quantifying external costs were developed in Research Stream 1b. Data on external costs per unit of environmental intervention were provided by RS1b via Philipp Preiss and Rainer Friedrich from IER, University of Stuttgart.

Taking into account the overall uncertainties related to both the quantification of external costs as well as to the specification of long term future technology configurations, the present report does not make an attempt to present detailed external cost information for each of the potential technology options analysed in detail in RS1a. It rather provides external cost estimates for typical average configurations, thus indicating the order of magnitude of externalities from future electricity generation technologies.

It is likely that in addition to the impacts that can be quantified and monetised based on the methods developed in RS1b, there are additional sources of potential environmental externalities. Due to a lack of knowledge and/or methodological constraints today we are not able to fully quantify these impacts, and to express the physical impacts in monetary terms. Thus **the report presents quantifiable external costs, which do not represent the total external costs related with electricity generation** from the reference technologies.

The following chapter 2 very briefly summarises the methodology for quantifying external costs developed in RS1b, and provides the ‘unit damage costs’ (external costs per unit environmental intervention) used for calculating the technology specific external costs. Chapter 3 provides for each of the emerging technologies analysed in RS1a a summary of the key LCI data affecting the external cost assessment, and a summary of the quantifiable external costs.

A more detailed documentation of the underlying methods and data is available from the following NEEDS reports:

Specification of emerging energy technologies (technical data and LCI data)

- RS1a-D7.2 Final report on technical data, costs and life cycle inventories of advanced fossil fuels
- RS1a-D8.2 Final report on technical data, costs and life cycle inventories of hydrogen technologies
- RS1a-D9.2 Final report on technical data, costs and life cycle inventories of fuel cell power plants
- RS1a-D10.2 Final report on technical data, costs and life cycle inventories of offshore wind farms
- RS1a-D11.2 Final report on technical data, costs and life cycle inventories of PV applications
- RS1a-D12.2 Final report on technical data, costs and life cycle inventories of solar thermal power plants
- RS1a-D13.2 Final report on technical data, costs and life cycle inventories of biomass power plants
- RS1a-D14.2 Final report on technical data, costs and life cycle inventories of nuclear power plants

External cost assessment

- RS1b-D5.4 “Report on marginal external damage costs inventory of greenhouse gas emissions”
- RS1b-D4.2 “Assessment of biodiversity losses”
- RS1b-TP7.4 “Description of updated and extended draft tools for the detailed site-dependent assessment of external costs”
- RS3a-TP1.4 “Report on marginal costs – preliminary results”
- RS3a-TP1.4 “Report on marginal costs including Excel spread sheet: “ExternalCosts_per_unit_emission_080821.xls”.

Final version of description: Rs3a, WP1: D1.1 “Report on the procedure and data to generate averaged/aggregated data” (M45)

2. Methodology for assessing external costs

The quantification of external costs is based on the ‘impact pathway’ methodology which has been developed in the series of ExternE projects, and is further improved within NEEDS and other related ongoing projects. The impact pathway analysis aims at modelling the causal chain of interactions from the emission of a pollutant through transport and chemical conversion in the atmosphere to the impacts on various receptors, such as human beings, crops, building materials or ecosystems. Welfare losses resulting from these impacts are transferred into monetary values based on the concepts of welfare economics.

Airborne pollutants

Several models are available to quantify impacts of various airborne pollutants on different receptors. Table 1 summarises the pollutants and impacts covered by the methods used for external cost assessment within NEEDS. Work in NEEDS contributed to improve dispersion and fate modelling of pollutants in the environment, to improve exposure-response relationships that are used to describe the response of receptors to an increased level of exposure, and to improve monetary valuation.

The impacts resulting from the emission of a pollutant partly depend on the location of the emission source, the release height, and the concentration of other pollutants in the environment. Taking these different parameters into account, based on detailed model runs RS1b/RS3a produced a set of unit damage costs (damage costs per tonne of pollutant emitted) which differ by the emission source country (all European countries, EU27 average), by release height (average release height, low release height, high release height), and by the year of the background emissions (2010 and 2020). As it is a key objective of RS1a to provide information on the long run dynamics of technology development and its implication on environmental performance, RS1a aims at calculating ‘average’ external costs for typical configurations. For the quantification of external costs RS1a thus uses unit damage costs from RS1b that refer to the EU-27 average and to the average release height. To reflect potential time dynamics, RS1b unit damage costs for the emission year 2010 are used for the calculation of external costs from ‘current technologies’, while the RS1b unit damage costs derived for the emission year 2020 are used to estimate external costs of future technology configurations (2025 and 2050). The unit damage costs used for quantifying externalities from airborne pollutants are summarised in Table 2.

Table 1: Impact categories and pollutants covered by the NEEDS methodology for quantifying external costs from airborne pollutants

Impact	Pollutants
Human health	fine particles, NOx, SO_2, NMVOC, NH_3, Cd, As, Ni, Pb, Hg, Cr, Formaldehyde, Dioxin, several radionuclides
Loss of biodiversity	NH_3, NMVOC, NOx, SO_2
Crop yield	SO_2, NOx
Material damage	SO_2, NOx

Table 2: Unit damage costs for air pollutants in €$_{2000}$ per elementary flow (source: NEEDS Research Stream 1b)

		Emissions in 2010				Emissions in 2020			
		health	biodiversity	crop yield	material damage	health	biodiversity	crop yield	material damage
Emissions to air									
NH_3	€/t	9485	3409	-183		5840	3440	-183	
NMVOC	€/t	941	-70	189		595	-50	103	
NOx	€/t	5722	942	328	71	6751	906	435	131
PPM_{CO} (2.5-10 µm)	€/t	1327				1383			
$PPM_{2.5}$ (< 2.5 µm)	€/t	24570				24261			
SO_2	€/t	6348	184	-39	259	6673	201	-54	259
Cd	€/t	83726				83726			
As	€/t	529612				529612			
Ni	€/t	2301				2301			
Pb	€/t	278284				278284			
Hg	€/t	8000000				8000000			
Cr	€/t	13251				13251			
Cr-VI	€/t	66256				66256			
Formaldehyde	€/t	200				200			
Dioxin	€/t	37,0 E09				37,0 E09			
Aerosols, radioactive	€/kBq	2,57E-04				2,57E-04			
Carbon-14	€/kBq	1,40E-03				1,40E-03			
Tritium	€/kBq	5,10E-07				5,10E-07			
Iodine-131	€/kBq	2,61E-03				2,61E-03			
Iodine-133	€/kBq	3,76E-07				3,76E-07			
Krypton-85	€/kBq	2,75E-08				2,75E-08			
Noble gases, radioactive	€/kBq	5,53E-08				5,53E-08			
Thorium-230	€/kBq	3,86E-03				3,86E-03			
Uranium-234	€/kBq	1,03E-03				1,03E-03			
Uranium-235	€/kBq	8,40E-04				8,40E-04			
Uranium-238	€/kBq	9,01E-04				9,01E-04			
Emissions to water									
Carbon-14	€/kBq	9,38E-06				9,38E-06			
Tritium	€/kBq	1,09E-07				1,09E-07			
Iodine-131	€/kBq	8,17E-03				8,17E-03			
Krypton-85	€/kBq	2,75E-08				2,75E-08			
Uranium-234	€/kBq	2,55E-05				2,55E-05			
Uranium-235	€/kBq	9,20E-05				9,20E-05			
Uranium-238	€/kBq	2,53E-04				2,53E-04			

Biodiversity losses due to land use (based on Ott et al., 2006)

NEEDS Research Stream 1b has developed a new methodology for assessing biodiversity losses from energy related land use. The effects of land use changes and land transformation are based on empirical data of the occurrence of vascular plants as a function of the land use type and the area size. Both the local damage on the biodiversity of the occupied or transformed land area as well as the regional damage on biodiversity of similar ecosystems in the vicinity is taken into account. The **P**otentially **D**isappeared **F**raction (PDF) is used as the characterisation factor and measure for the number of species relative to a reference state (Goedkoop et al., 2000; Koellner 2001). The PDF is expressed as the relative difference between the number of species under the reference conditions and the conditions created by the conversion, or maintained by the occupation. PDF values have been derived for a broad range of different land conversion categories.

The monetary valuation of biodiversity losses due to land use changes caused by energy production and infrastructure is based on the costs for restoring different land use categories. Information on replacement or restoration costs for different land use categories is derived from a meta-analysis of German studies which analysed the costs of restoring damaged habitats to mare valuable habitats. Restoration costs derived for Germany are transferred to other countries by adjusting them to income and price differences of the respective countries. The resulting unit damage costs

Table 3: Unit damage costs for land use in $€_{2000}/m^2$ (source: NEEDS RS1b, Deliverable 4.2)

Land use impact	€/m²
Transformation, from arable, unspecified	0,1700
Transformation, from forest, unspecified	2,6600
Transformation, from pasture and meadow, unspecified	0,5500
Transformation, from pasture and meadow, extensive	0,7600
Transformation, from pasture and meadow, intensive	0,3400
Transformation, from unknown	1,5200

Damage costs of greenhouse gas emissions (based on Anthoff 2007)

Estimates of the damage costs of greenhouse gas emissions differ not only because the underlying integrated assessment models represent key climate and socio-economic relations differently, but also because there are a number of assumptions to be made to which these estimates are highly sensitive, which cannot easily be resolved. Examples include the choice of discount rate and the use of equity weighting. Due to this structure of the problem, one can generate a large range of social cost of carbon estimates even from a single model, by just changing a few key assumptions for different model runs. NEEDS RS1b provides a set of new model results from the integrated assessment model FUND 3.0, and reviews implications of different assumptions with respect to key parameters like discount rate or equity weighting.

The FUND climate impact module includes the following categories: agriculture, forestry, sea level rise, cardiovascular and respiratory disorders related to cold and heat stress, malaria, dengue fever, schistosomiasis, diarrhoea, energy consumption, water resources, and unmanaged ecosystems (Tol 2002a, b). There has been discussion of other damage categories in the literature (see e.g. Watkiss and Anthoff, 2005), but neither have they been modelled in a quantitative way, nor can one even say whether they will be damages of benefits. Such damage categories are not included in FUND.

The NEEDS RS1b work provides estimates of marginal damage from an extra ton of greenhouse gas emissions (CO_2, CH_4, N_2O, SF_6) based on FUND model runs. The set of results from this model exercise is fairly large. The NEEDS report (Anthoff 2007) in a very helpful way categorises the results along various dimensions, explains the parameter choices made for each dimension, and gives recommendations on what values should be considered for policy decisions in what way.

Key parameters affecting the greenhouse gas damage costs are discounting and equity weighting. Discounting is related to the adequate representation of a preference order that fits a decision maker's intertemporal substitutability of consumption. Equity weighting takes into account the attitude towards inequality in average per capita income between different world regions. To give an indication of the potential range of damage cost values, in this report we use a 'low' and a 'high' value for quantifying technology specific external costs. The 'low' value is based on damage costs derived without equity weighting, which is close to represent the view of a regional or national decision maker. The 'high' value includes equity weighting and rather represents the perspective of a benevolent global decision maker. Although decision makers' current revealed preferences do not too much support this perspective, one might argue that successful global climate protection negotiations will be impossible without moving into this direction. As the NEEDS external cost estimates are derived to support European energy policy strategies, the equity weighted results are normalised to Western European average per capita income.

The damage cost values used for assessing external costs of electricity generation are summarised in Table 4. A more detailed discussion on methodology and assumptions is available from NEEDS Deliverable D5.4 RS1b (Anthoff 2007).

Because of the large uncertainties of climate change damage costs, marginal abatement costs for reaching given CO_2 reduction targets are sometimes considered as a surrogate for uncertain or not quantifiable damage costs. The marginal abatement costs depend on the underlying CO_2 target, and on the measures taken to achieve the target. Within NEEDS, a set of marginal abatement costs were suggested by Friedrich (2008) (Table 5). The lower range of abatement costs refers to a European target of reducing CO_2 emissions by 20% until 2020, the upper values refer to the long term target of global CO_2 reduction that result in a stabilisation of atmospheric CO_2 concentration at 365 ppm (to limit global average temperature rise to 2°C compared to pre-industrial level).

Table 4: Marginal damage costs of greenhouse gas emissions in €/t (source: NEEDS RS1b, Deliverable 5.4) (Values for average 1% trimmed, discounted to 2005, 1% pure rate of time preference, without equity weighting and with equity weighting normalised to Western European average per capita income, 1.35 $ per €)

	2005	2025	2045
CO2			
without equity weighting	7	7	5
with equity weighting	98	86	52
CH_4			
without equity weighting	310	238	193
with equity weighting	3562	2648	2080
N_2O			
without equity weighting	12014	9997	8581
with equity weighting	129680	102955	81333

Table 5: Marginal abatement costs of CO_2 emissions in €$_{2000}$/t CO_2 (Friedrich 2008)

	2010	2025	2050
Marginal abatement costs – low (20% CO_2 reduction in Europe by 2020)	23.5	32	77
Marginal abatement costs – high (2°C target)	23.5	51	190

3. Assessment of external costs from emerging electricity generation technologies

External costs are calculated by multiplying the relevant life cycle inventory data compiled in Research Stream 1a with the unit damage costs derived from the work in Research Stream 1b (Figure 1). The main objective of RS1a work in this context is to provide information on the long term potential for reducing external costs of electricity generation from individual technologies due to innovation and technology development. Results are considered to be key information for supporting the development of European R&D and technology deployment strategies in the energy sector.

Taking into account the overall uncertainties related to both the quantification and monetisation of environmental impacts and the specification of future technologies, the present report provide external cost estimates for typical technical configurations under European average conditions. We do not make an attempt here to quantify external costs for all the different technology configurations that were analysed in detail in RS1a, as in most cases differences in quantifiable external costs between different technology options are small compared to the overall uncertainties. A more detailed calculation of external costs for a specific technology configuration under a given environment is however straightforward by linking the LCI data reported in detail in the RS1a technology reports with the country and time dependent unit damage costs described in RS1b reports.

Research Stream 1a has produced life cycle inventory data for a broad range of emerging technologies under various technology deployment scenarios. In this report we focus on technologies that were described under the 'optimistic-realistic' technology development scenario, which is characterised as follows:

> *"Strong socio-economic drivers support dynamic market uptake and continuous technology development. It is very likely that the respective technology gains relevance on the global electricity market."*

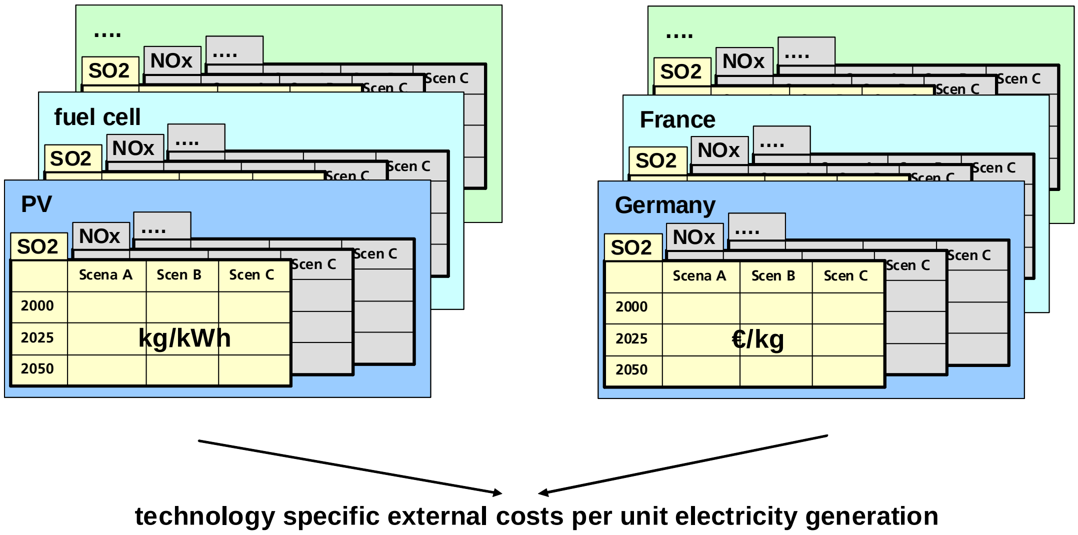

Figure 1: Calculation of technology specific external costs by combining LCI data (from Research Stream 1a) with unit damage costs (from Research Stream 1b)

In RS1a, the effects of variations in the underlying electricity supply system on LCI data of individual technologies has also been analysed in detail. The external costs reported here are based on LCI data calculated with the RS2a ‘440 ppm stabilisation scenario’, as it basically represents current European policy targets.

For each technology external cost estimates are reported for a limited number of ‘typical’ configurations, which partly represent a mix of different technologies within a technology cluster (e.g. PV: crystalline silicon, thin film, organic cells). This way of presenting aggregated results is consistent with the way LCI data from RS1a were processed and aggregated for use in the RS2a scenarios.

The following sections provide the estimates of quantifiable external costs for each of the emerging electricity generation technologies analysed in RS1a. For each technology, the key life cycle environmental burdens that are used for the assessment of external costs are summarised, a more detailed documentation of LCI data is available from the RS1a reports.

3.1. Advanced fossil fuels

Responsible partner: PSI, IER

Lignite power plant, steam turbine, 900 MW

Table 6: Key life cycle emissions and land use per kWh: lignite power plant, steam turbine, 900 MW

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²	6,97E-07	5,49E-07	4,97E-07
Transformation, from forest	m²	8,27E-06	6,46E-06	5,96E-06
Transformation, from pasture and meadow, unspecified	m²	2,01E-07	1,87E-07	1,58E-07
Transformation, from pasture and meadow, extensive	m²	0	0	0
Transformation, from pasture and meadow, intensive	m²	5,51E-10	4,29E-10	3,90E-10
Transformation, from unknown	m²	3,78E-05	4,65E-05	3,76E-05
Emissions to air				
Ammonia	kg	5,49E-06	4,86E-06	4,35E-06
Arsenic	kg	9,03E-09	7,32E-09	6,10E-09
Cadmium	kg	1,29E-09	9,19E-10	7,02E-10
Carbon dioxide, fossil	kg	9,21E-01	8,08E-01	7,31E-01
Carbon-14	kBq	3,29E-04	2,49E-04	2,57E-04
Chromium	kg	2,40E-08	4,03E-08	3,96E-08
Chromium VI	kg	7,45E-10	1,13E-09	1,10E-09
Dinitrogen monoxide	kg	2,20E-05	1,94E-05	1,76E-05
Lead	kg	9,55E-07	8,39E-07	7,61E-07
Methane, fossil	kg	2,48E-04	2,15E-04	1,92E-04
Mercury	kg	2,03E-08	1,77E-08	1,60E-08
Nickel	kg	1,98E-08	1,25E-08	9,95E-09
Nitrogen oxides	kg	7,38E-04	6,41E-04	5,79E-04
NMVOC total	kg	2,36E-05	2,03E-05	1,89E-05
thereof:				
Formaldehyde	kg	5,22E-07	4,50E-07	4,09E-07
PM10	kg	7,61E-05	9,83E-06	9,04E-06
PM2.5	kg	6,47E-05	5,54E-05	5,02E-05
PCDD/F (measured as I-TEQ)	kg	6,52E-14	5,59E-14	4,93E-14
Sulfur dioxide	kg	1,69E-04	1,20E-04	1,07E-04
Aerosols, radioactive, unspecified	kBq	7,93E-08	4,33E-08	1,63E-07
Hydrogen-3, Tritium	kBq	1,86E-03	1,13E-03	5,82E-04
Iodine-131	kBq	1,86E-05	2,22E-07	2,15E-07
Iodine-133	kBq	3,65E-10	8,08E-11	7,39E-11
Krypton-85	kBq	1,47E-04	1,85E-06	3,64E-06
Noble gases, radioactive, unspecified	kBq	3,19E+00	2,04E+00	1,52E+00
Thorium-230	kBq	1,10E-04	7,49E-05	5,63E-05
Uranium-234	kBq	5,11E-07	3,47E-07	2,61E-07
Uranium-235	kBq	2,48E-08	1,68E-08	1,26E-08
Uranium-238	kBq	2,99E-06	2,35E-06	2,08E-06
Emissions to water				
Carbon-14	kBq	1,30E-04	8,53E-05	6,85E-05
Hydrogen-3, Tritium	kBq	1,42E-01	9,53E-02	7,70E-02
Iodine-131	kBq	4,99E-10	1,10E-10	1,01E-10
Uranium-234	kBq	9,71E-07	6,59E-07	4,95E-07
Uranium-235	kBq	1,60E-06	1,09E-06	8,18E-07
Uranium-238	kBq	2,80E-06	1,86E-06	1,31E-06

Table 7: Quantifiable external costs: lignite power plant, steam turbine, 900 MW; in ct_{2000}/kWh

	today	2025	2050
health impacts	0,72	0,67	0,60
Biodiversity	0,07	0,06	0,06
crop yield losses	0,02	0,03	0,02
material damage	0,01	0,01	0,01
land use	0,01	0,01	0,01
sub-total	0,84	0,78	0,70
climate change - damage costs low	0,68	0,59	0,38
climate change - damage costs high	9,40	7,21	3,98
climate change - abatement costs low	2,16	2,59	5,63
climate change - abatement costs high	2,16	4,12	13,89

Lignite power plant, 800 MW, with post-combustion CCS

Table 8: Key life cycle emissions and land use per kWh: lignite power plant, 800 MW, with post-combustion CCS

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²		1,27E-06	1,07E-06
Transformation, from forest	m²		1,51E-05	1,31E-05
Transformation, from pasture and meadow, unspecified	m²		7,36E-07	5,94E-07
Transformation, from pasture and meadow, extensive	m²		0	0
Transformation, from pasture and meadow, intensive	m²		9,88E-10	8,37E-10
Transformation, from unknown	m²		8,34E-05	5,80E-05
Emissions to air				
Ammonia	kg		2,39E-04	2,37E-04
Arsenic	kg		1,00E-08	7,63E-09
Cadmium	kg		1,95E-09	1,44E-09
Carbon dioxide, fossil	kg		1,25E-01	1,02E-01
Carbon-14	kBq		7,57E-04	7,42E-04
Chromium	kg		8,27E-08	7,58E-08
Chromium VI	kg		2,19E-09	2,00E-09
Dinitrogen monoxide	kg		2,35E-05	1,99E-05
Lead	kg		1,01E-06	8,64E-07
Methane, fossil	kg		2,85E-04	2,34E-04
Mercury	kg		2,18E-08	1,87E-08
Nickel	kg		2,81E-08	2,11E-08
Nitrogen oxides	kg		7,80E-04	6,63E-04
NMVOC total	kg		3,80E-05	3,39E-05
thereof:				
Formaldehyde	kg		5,50E-07	4,71E-07
PM10	kg		1,48E-05	1,28E-05
PM2.5	kg		6,77E-05	5,78E-05
PCDD/F (measured as I-TEQ)	kg		8,18E-14	6,89E-14
Sulfur dioxide	kg		1,38E-04	1,28E-04
Aerosols, radioactive, unspecified	kBq		1,32E-07	4,77E-07
Hydrogen-3, Tritium	kBq		3,43E-03	1,65E-03
Iodine-131	kBq		3,36E-07	3,24E-07
Iodine-133	kBq		1,28E-10	1,11E-10
Krypton-85	kBq		2,74E-06	8,05E-06
Noble gases, radioactive, unspecified	kBq		6,22E+00	4,37E+00
Thorium-230	kBq		2,28E-04	1,61E-04
Uranium-234	kBq		1,05E-06	7,46E-07
Uranium-235	kBq		5,11E-08	3,61E-08
Uranium-238	kBq		3,42E-06	2,76E-06
Emissions to water				
Carbon-14	kBq		2,60E-04	1,97E-04
Hydrogen-3, Tritium	kBq		2,91E-01	2,21E-01
Iodine-131	kBq		1,75E-10	1,51E-10
Uranium-234	kBq		2,00E-06	1,42E-06
Uranium-235	kBq		3,31E-06	2,34E-06
Uranium-238	kBq		5,70E-06	3,77E-06

Table 9: Quantifiable external costs: lignite power plant, 800 MW, with post-combustion CCS; in ct_{2000}/kWh

	today	2025	2050
health impacts		0,95	0,83
Biodiversity		0,16	0,14
crop yield losses		0,03	0,02
material damage		0,01	0,01
land use		0,02	0,01
sub-total		1,16	1,02
climate change - damage costs low		0,12	0,07
climate change - damage costs high		1,40	0,74
climate change - abatement costs low		0,40	0,78
climate change - abatement costs high		0,64	1,93

Lignite power plant, 800 MW, with oxy-fuel CCS

Table 10: Key life cycle emissions and land use per kWh: lignite power plant, 800 MW, with oxy-fuel CCS

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m^2		8,93E-07	6,96E-07
Transformation, from forest	m^2		1,16E-05	9,59E-06
Transformation, from pasture and meadow, unspecified	m^2		6,80E-07	5,14E-07
Transformation, from pasture and meadow, extensive	m^2		0	0
Transformation, from pasture and meadow, intensive	m^2		6,84E-10	5,35E-10
Transformation, from unknown	m^2		8,55E-05	5,96E-05
Emissions to air				
Ammonia	kg		2,78E-06	2,21E-06
Arsenic	kg		9,76E-09	7,38E-09
Cadmium	kg		1,28E-09	8,40E-10
Carbon dioxide, fossil	kg		2,70E-02	1,61E-02
Carbon-14	kBq		7,81E-04	7,73E-04
Chromium	kg		7,85E-08	6,15E-08
Chromium VI	kg		2,10E-09	1,65E-09
Dinitrogen monoxide	kg		2,38E-05	2,05E-05
Lead	kg		1,03E-06	8,87E-07
Methane, fossil	kg		2,76E-04	2,31E-04
Mercury	kg		2,18E-08	1,88E-08
Nickel	kg		1,58E-08	1,04E-08
Nitrogen oxides	kg		3,02E-04	2,65E-04
NMVOC total	kg		2,83E-05	2,57E-05
thereof:				
Formaldehyde	kg		5,47E-07	4,74E-07
PM10	kg		1,39E-05	1,17E-05
PM2.5	kg		6,79E-05	5,87E-05
PCDD/F (measured as I-TEQ)	kg		7,07E-14	5,80E-14
Sulfur dioxide	kg		1,23E-04	1,14E-04
Aerosols, radioactive, unspecified	kBq		1,36E-07	4,98E-07
Hydrogen-3, Tritium	kBq		3,54E-03	1,72E-03
Iodine-131	kBq		2,50E-07	2,47E-07
Iodine-133	kBq		1,15E-10	9,56E-11
Krypton-85	kBq		2,03E-06	7,66E-06
Noble gases, radioactive, unspecified	kBq		6,42E+00	4,55E+00
Thorium-230	kBq		2,35E-04	1,68E-04
Uranium-234	kBq		1,09E-06	7,75E-07
Uranium-235	kBq		5,27E-08	3,76E-08
Uranium-238	kBq		3,51E-06	2,87E-06
Emissions to water				
Carbon-14	kBq		2,68E-04	2,05E-04
Hydrogen-3, Tritium	kBq		3,00E-01	2,31E-01
Iodine-131	kBq		1,57E-10	1,31E-10
Uranium-234	kBq		2,07E-06	1,47E-06
Uranium-235	kBq		3,41E-06	2,43E-06
Uranium-238	kBq		5,80E-06	3,84E-06

Table 11: Quantifiable external costs: lignite power plant, 800 MW, with oxy-fuel CCS; in ct_{2000}/kWh

	today	2025	2050
health impacts		0,47	0,42
Biodiversity		0,03	0,03
crop yield losses		0,01	0,01
material damage		0,01	0,01
land use		0,02	0,01
sub-total		0,54	0,47
climate change - damage costs low		0,05	0,03
climate change - damage costs high		0,55	0,30
climate change - abatement costs low		0,09	0,12
climate change - abatement costs high		0,14	0,31

Hard coal power plant with steam turbine, 600 MW

Table 12: Key life cycle emissions and land use per kWh: hard coal power plant, 600 MW

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²	1,75E-05	1,60E-05	1,45E-05
Transformation, from forest	m²	1,40E-04	1,27E-04	1,15E-04
Transformation, from pasture and meadow, unspecified	m²	5,72E-07	5,55E-07	4,85E-07
Transformation, from pasture and meadow, extensive	m²	0	0	0
Transformation, from pasture and meadow, intensive	m²	1,41E-08	1,29E-08	1,16E-08
Transformation, from unknown	m²	6,04E-05	7,48E-05	6,09E-05
Emissions to air				
Ammonia	kg	2,08E-05	1,92E-05	1,72E-05
Arsenic	kg	1,51E-08	1,34E-08	1,16E-08
Cadmium	kg	1,70E-09	1,35E-09	1,13E-09
Carbon dioxide, fossil	kg	7,76E-01	7,05E-01	6,37E-01
Carbon-14	kBq	4,74E-04	3,74E-04	3,84E-04
Chromium	kg	7,95E-08	1,36E-07	1,34E-07
Chromium VI	kg	2,55E-09	3,91E-09	3,82E-09
Dinitrogen monoxide	kg	3,36E-05	3,09E-05	2,79E-05
Lead	kg	2,12E-07	1,89E-07	1,70E-07
Methane, fossil	kg	2,36E-03	2,17E-03	1,96E-03
Mercury	kg	3,46E-08	3,15E-08	2,85E-08
Nickel	kg	1,15E-07	9,94E-08	8,84E-08
Nitrogen oxides	kg	8,07E-04	7,26E-04	6,55E-04
NMVOC total	kg	5,94E-05	5,40E-05	4,95E-05
thereof:				
Formaldehyde	kg	5,06E-07	4,49E-07	4,07E-07
PM10	kg	7,48E-05	1,97E-05	1,78E-05
PM2.5	kg	5,31E-05	4,65E-05	4,21E-05
PCDD/F (measured as I-TEQ)	kg	6,95E-14	6,18E-14	5,42E-14
Sulfur dioxide	kg	6,18E-04	5,24E-04	4,72E-04
Aerosols, radioactive, unspecified	kBq	1,13E-07	6,47E-08	2,41E-07
Hydrogen-3, Tritium	kBq	2,67E-03	1,69E-03	8,75E-04
Iodine-131	kBq	2,64E-05	3,81E-07	3,63E-07
Iodine-133	kBq	6,07E-10	2,02E-10	1,83E-10
Krypton-85	kBq	2,09E-04	3,31E-06	5,86E-06
Noble gases, radioactive, unspecified	kBq	4,58E+00	3,06E+00	2,28E+00
Thorium-230	kBq	1,59E-04	1,13E-04	8,47E-05
Uranium-234	kBq	7,35E-07	5,22E-07	3,92E-07
Uranium-235	kBq	3,56E-08	2,53E-08	1,90E-08
Uranium-238	kBq	4,18E-06	3,43E-06	3,02E-06
Emissions to water				
Carbon-14	kBq	1,86E-04	1,28E-04	1,02E-04
Hydrogen-3, Tritium	kBq	2,03E-01	1,43E-01	1,15E-01
Iodine-131	kBq	8,30E-10	2,75E-10	2,50E-10
Uranium-234	kBq	1,40E-06	9,92E-07	7,45E-07
Uranium-235	kBq	2,30E-06	1,64E-06	1,23E-06
Uranium-238	kBq	1,17E-04	1,07E-04	9,61E-05

Table 13: Quantifiable external costs: hard coal power plant, 600 MW; in ct_{2000}/kWh

	today	2025	2050
health impacts	1,05	1,00	0,90
Biodiversity	0,09	0,08	0,07
crop yield losses	0,02	0,03	0,03
material damage	0,02	0,02	0,02
land use	0,05	0,05	0,04
sub-total	1,24	1,18	1,06
climate change - damage costs low	0,66	0,58	0,38
climate change - damage costs high	8,89	6,96	3,95
climate change - abatement costs low	1,82	2,26	4,91
climate change - abatement costs high	1,82	3,60	12,11

Hard coal power plant, 500 MW, with post-combustion CCS

Table 14: Key life cycle emissions and land use per kWh: hard coal power plant, 500 MW, with post-combustion CCS

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²		1,92E-05	1,65E-05
Transformation, from forest	m²		1,55E-04	1,32E-04
Transformation, from pasture and meadow, unspecified	m²		1,14E-06	9,38E-07
Transformation, from pasture and meadow, extensive	m²		0	0
Transformation, from pasture and meadow, intensive	m²		1,54E-08	1,32E-08
Transformation, from unknown	m²		1,12E-04	8,14E-05
Emissions to air				
Ammonia	kg		2,45E-04	2,41E-04
Arsenic	kg		1,70E-08	1,37E-08
Cadmium	kg		2,32E-09	1,82E-09
Carbon dioxide, fossil	kg		1,29E-01	1,04E-01
Carbon-14	kBq		8,36E-04	8,18E-04
Chromium	kg		2,41E-07	2,25E-07
Chromium VI	kg		6,62E-09	6,12E-09
Dinitrogen monoxide	kg		3,67E-05	3,12E-05
Lead	kg		2,57E-07	2,16E-07
Methane, fossil	kg		2,56E-03	2,18E-03
Mercury	kg		3,76E-08	3,21E-08
Nickel	kg		1,28E-07	1,06E-07
Nitrogen oxides	kg		8,74E-04	7,44E-04
NMVOC total	kg		7,52E-05	6,57E-05
thereof:				
Formaldehyde	kg		5,45E-07	4,66E-07
PM10	kg		2,57E-05	2,20E-05
PM2.5	kg		5,72E-05	4,88E-05
PCDD/F (measured as I-TEQ)	kg		8,77E-14	7,40E-14
Sulfur dioxide	kg		3,57E-04	3,15E-04
Aerosols, radioactive, unspecified	kBq		1,45E-07	5,21E-07
Hydrogen-3, Tritium	kBq		3,78E-03	1,84E-03
Iodine-131	kBq		5,16E-07	4,81E-07
Iodine-133	kBq		2,68E-10	2,31E-10
Krypton-85	kBq		4,40E-06	9,98E-06
Noble gases, radioactive, unspecified	kBq		6,86E+00	4,82E+00
Thorium-230	kBq		2,52E-04	1,79E-04
Uranium-234	kBq		1,17E-06	8,27E-07
Uranium-235	kBq		5,65E-08	4,00E-08
Uranium-238	kBq		4,59E-06	3,75E-06
Emissions to water				
Carbon-14	kBq		2,87E-04	2,17E-04
Hydrogen-3, Tritium	kBq		3,20E-01	2,44E-01
Iodine-131	kBq		3,66E-10	3,15E-10
Uranium-234	kBq		2,22E-06	1,57E-06
Uranium-235	kBq		3,66E-06	2,59E-06
Uranium-238	kBq		1,34E-04	1,13E-04

Table 15: Quantifiable external costs: hard coal power plant, 500 MW, with post-combustion CCS; in ct_{2000}/kWh

	today	2025	2050
health impacts		1,15	1,01
Biodiversity		0,17	0,16
crop yield losses		0,03	0,03
material damage		0,02	0,02
land use		0,06	0,05
sub-total		1,43	1,26
climate change - damage costs low		0,19	0,12
climate change - damage costs high		2,16	1,25
climate change - abatement costs low		0,41	0,80
climate change - abatement costs high		0,66	1,97

Hard coal power plant, 500 MW, with oxy-fuel CCS

Table 16: Key life cycle emissions and land use per kWh: hard coal power plant, 500 MW, with oxy-fuel CCS

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²		1,93E-05	1,68E-05
Transformation, from forest	m²		1,55E-04	1,35E-04
Transformation, from pasture and meadow, unspecified	m²		1,09E-06	8,59E-07
Transformation, from pasture and meadow, extensive	m²		0	0
Transformation, from pasture and meadow, intensive	m²		1,55E-08	1,35E-08
Transformation, from unknown	m²		1,15E-04	8,41E-05
Emissions to air				
Ammonia	kg		2,13E-05	1,83E-05
Arsenic	kg		1,71E-08	1,37E-08
Cadmium	kg		1,81E-09	1,37E-09
Carbon dioxide, fossil	kg		4,49E-02	2,75E-02
Carbon-14	kBq		8,60E-04	8,52E-04
Chromium	kg		2,42E-07	1,88E-07
Chromium VI	kg		6,65E-09	5,23E-09
Dinitrogen monoxide	kg		3,74E-05	3,23E-05
Lead	kg		2,60E-07	2,14E-07
Methane, fossil	kg		2,61E-03	2,26E-03
Mercury	kg		3,81E-08	3,30E-08
Nickel	kg		1,21E-07	1,02E-07
Nitrogen oxides	kg		5,94E-04	5,18E-04
NMVOC total	kg		6,79E-05	6,03E-05
thereof:				
Formaldehyde	kg		5,45E-07	4,72E-07
PM10	kg		2,53E-05	2,15E-05
PM2.5	kg		5,74E-05	4,93E-05
PCDD/F (measured as I-TEQ)	kg		7,68E-14	6,34E-14
Sulfur dioxide	kg		3,49E-04	3,11E-04
Aerosols, radioactive, unspecified	kBq		1,49E-07	5,44E-07
Hydrogen-3, Tritium	kBq		3,89E-03	1,91E-03
Iodine-131	kBq		4,64E-07	4,37E-07
Iodine-133	kBq		2,58E-10	2,20E-10
Krypton-85	kBq		3,97E-06	9,87E-06
Noble gases, radioactive, unspecified	kBq		7,05E+00	5,02E+00
Thorium-230	kBq		2,59E-04	1,86E-04
Uranium-234	kBq		1,20E-06	8,60E-07
Uranium-235	kBq		5,81E-08	4,17E-08
Uranium-238	kBq		4,71E-06	3,89E-06
Emissions to water				
Carbon-14	kBq		2,95E-04	2,26E-04
Hydrogen-3, Tritium	kBq		3,29E-01	2,54E-01
Iodine-131	kBq		3,52E-10	3,01E-10
Uranium-234	kBq		2,28E-06	1,63E-06
Uranium-235	kBq		3,76E-06	2,70E-06
Uranium-238	kBq		1,37E-04	1,18E-04

Table 17: Quantifiable external costs: hard coal power plant, 500 MW, with oxy-fuel CCS; in ct_{2000}/kWh

	today	2025	2050
health impacts		0,83	0,72
Biodiversity		0,07	0,06
crop yield losses		0,02	0,02
material damage		0,02	0,01
land use		0,06	0,05
sub-total		1,00	0,87
climate change - damage costs low		0,13	0,09
climate change - damage costs high		1,46	0,88
climate change - abatement costs low		0,14	0,21
climate change - abatement costs high		0,23	0,52

Natural gas combined cycle power plant

Table 18: Key life cycle emissions and land use per kWh: natural gas combined cycle power plant, 400 MW

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²	3,35E-07	2,99E-07	2,82E-07
Transformation, from forest	m²	4,76E-05	4,39E-05	4,13E-05
Transformation, from pasture and meadow, unspecified	m²	1,11E-06	1,03E-06	9,65E-07
Transformation, from pasture and meadow, extensive	m²	0	0	0
Transformation, from pasture and meadow, intensive	m²	0	2,36E-10	2,23E-10
Transformation, from unknown	m²	3,83E-06	5,42E-06	4,48E-06
Emissions to air				
Ammonia	kg	2,08E-07	1,92E-07	1,70E-07
Arsenic	kg	1,66E-09	1,11E-09	7,20E-10
Cadmium	kg	6,27E-10	4,57E-10	3,49E-10
Carbon dioxide, fossil	kg	3,98E-01	3,66E-01	3,46E-01
Carbon-14	kBq	4,87E-05	3,83E-05	4,10E-05
Chromium	kg	2,61E-08	2,45E-08	2,43E-08
Chromium VI	kg	6,04E-10	5,82E-10	5,79E-10
Dinitrogen monoxide	kg	6,98E-06	6,45E-06	6,09E-06
Lead	kg	1,50E-06	2,53E-08	2,37E-08
Methane, fossil	kg	9,94E-04	7,70E-04	4,94E-04
Mercury	kg	1,91E-09	1,72E-09	1,59E-09
Nickel	kg	7,00E-09	5,09E-09	4,14E-09
Nitrogen oxides	kg	3,09E-04	1,82E-04	1,30E-04
NMVOC total	kg	1,01E-04	1,63E-04	1,50E-04
thereof:				
Formaldehyde	kg	2,15E-07	1,98E-07	1,89E-07
PM10	kg	1,23E-05	3,66E-06	3,46E-06
PM2.5	kg	8,22E-06	7,18E-06	6,72E-06
PCDD/F (measured as I-TEQ)	kg	1,00E-14	6,61E-15	3,74E-15
Sulfur dioxide	kg	1,47E-04	1,31E-04	1,22E-04
Aerosols, radioactive, unspecified	kBq	1,16E-08	6,67E-09	2,48E-08
Hydrogen-3, Tritium	kBq	2,75E-04	1,77E-04	1,02E-04
Iodine-131	kBq	3,08E-06	5,53E-07	5,29E-07
Iodine-133	kBq	5,89E-11	2,00E-11	1,90E-11
Krypton-85	kBq	2,55E-05	4,38E-06	4,47E-06
Noble gases, radioactive, unspecified	kBq	4,71E-01	3,17E-01	2,52E-01
Thorium-230	kBq	1,66E-05	1,20E-05	9,65E-06
Uranium-234	kBq	8,32E-08	6,15E-08	5,03E-08
Uranium-235	kBq	3,72E-09	2,69E-09	2,16E-09
Uranium-238	kBq	1,24E-07	7,20E-08	5,92E-08
Emissions to water				
Carbon-14	kBq	1,91E-05	1,32E-05	1,12E-05
Hydrogen-3, Tritium	kBq	2,09E-02	1,48E-02	1,26E-02
Iodine-131	kBq	8,04E-11	2,74E-11	2,60E-11
Uranium-234	kBq	1,46E-07	1,06E-07	8,49E-08
Uranium-235	kBq	2,41E-07	1,74E-07	1,40E-07
Uranium-238	kBq	1,12E-06	9,43E-07	8,33E-07

Table 19: Quantifiable external costs: natural gas combined cycle power plant, 400 MW; in ct_{2000}/kWh

	today	2025	2050
health impacts	0,31	0,24	0,20
Biodiversity	0,03	0,02	0,01
crop yield losses	0,01	0,01	0,01
material damage	0,01	0,01	0,00
land use	0,01	0,01	0,01
sub-total	0,37	0,29	0,23
climate change - damage costs low	0,32	0,28	0,19
climate change - damage costs high	4,35	3,42	1,95
climate change - abatement costs low	0,94	1,17	2,67
climate change - abatement costs high	0,94	1,87	6,58

Natural gas combined cycle power plant with post-combustion CCS

Table 20: Key life cycle emissions and land use per kWh: natural gas combined cycle power plant, 500 MW, with post-combustion CCS

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²		6,50E-07	6,00E-07
Transformation, from forest	m²		5,28E-05	5,00E-05
Transformation, from pasture and meadow, unspecified	m²		1,51E-06	1,30E-06
Transformation, from pasture and meadow, extensive	m²		0	0
Transformation, from pasture and meadow, intensive	m²		4,97E-10	4,30E-10
Transformation, from unknown	m²		3,85E-05	2,40E-05
Emissions to air				
Ammonia	kg		1,58E-06	1,20E-06
Arsenic	kg		2,37E-09	1,50E-09
Cadmium	kg		1,05E-09	8,00E-10
Carbon dioxide, fossil	kg		9,35E-02	8,00E-02
Carbon-14	kBq		5,90E-04	6,00E-04
Chromium	kg		4,63E-08	4,50E-08
Chromium VI	kg		1,12E-09	1,10E-09
Dinitrogen monoxide	kg		7,90E-06	7,00E-06
Lead	kg		4,25E-08	3,40E-08
Methane, fossil	kg		8,81E-04	5,00E-04
Mercury	kg		2,50E-09	2,10E-09
Nickel	kg		1,33E-08	1,00E-08
Nitrogen oxides	kg		1,86E-04	1,50E-04
NMVOC total	kg		1,89E-04	1,70E-04
thereof:				
Formaldehyde	kg		2,34E-07	2,10E-07
PM10	kg		5,67E-06	5,00E-06
PM2.5	kg		9,75E-06	9,00E-06
PCDD/F (measured as I-TEQ)	kg		1,20E-14	7,00E-15
Sulfur dioxide	kg		1,61E-04	1,40E-04
Aerosols, radioactive, unspecified	kBq		1,03E-07	4,00E-07
Hydrogen-3, Tritium	kBq		2,68E-03	1,40E-03
Iodine-131	kBq		6,58E-07	6,00E-07
Iodine-133	kBq		3,53E-11	3,10E-11
Krypton-85	kBq		5,13E-06	9,00E-06
Noble gases, radioactive, unspecified	kBq		4,86E+00	3,60E+00
Thorium-230	kBq		1,78E-04	1,30E-04
Uranium-234	kBq		8,29E-07	6,00E-07
Uranium-235	kBq		3,99E-08	3,00E-08
Uranium-238	kBq		8,65E-07	6,00E-07
Emissions to water				
Carbon-14	kBq		2,03E-04	1,60E-04
Hydrogen-3, Tritium	kBq		2,27E-01	1,80E-01
Iodine-131	kBq		4,83E-11	4,20E-11
Uranium-234	kBq		1,56E-06	1,20E-06
Uranium-235	kBq		2,58E-06	1,90E-06
Uranium-238	kBq		5,10E-06	3,70E-06

Table 21: Quantifiable external costs: natural gas combined cycle power plant, 500 MW, with post-combustion CCS; in ct_{2000}/kWh

	today	2025	2050
health impacts		0,27	0,23
Biodiversity		0,02	0,02
crop yield losses		0,01	0,01
material damage		0,01	0,01
land use		0,02	0,02
sub-total		0,33	0,28
climate change - damage costs low		0,09	0,06
climate change - damage costs high		1,12	0,58
climate change - abatement costs low		0,30	0,62
climate change - abatement costs high		0,48	1,52

3.2. Fuel cells

Responsible partner: POLITO, ifeu, DLR

Fuel cell natural gas

Table 22: Key life cycle emissions and land use per kWh: fuel cell natural gas

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²	n.a.	n.a.	n.a.
Transformation, from forest	m²	n.a.	n.a.	n.a.
Transformation, from pasture and meadow, unspecified	m²	n.a.	n.a.	n.a.
Transformation, from pasture and meadow, extensive	m²	n.a.	n.a.	n.a.
Transformation, from pasture and meadow, intensive	m²	n.a.	n.a.	n.a.
Transformation, from unknown	m²	n.a.	n.a.	n.a.
Emissions to air				
Ammonia	kg	5,78E-07	5,70E-07	9,08E-07
Arsenic	kg	4,74E-09	4,66E-09	5,72E-09
Cadmium	kg	1,49E-09	1,41E-09	1,82E-09
Carbon dioxide, fossil	kg	5,10E-01	4,35E-01	4,24E-01
Carbon-14	kBq	1,05E-04	9,06E-05	1,51E-04
Chromium	kg	1,05E-07	2,16E-07	4,83E-07
Chromium VI	kg	2,56E-09	5,33E-09	1,20E-08
Dinitrogen monoxide	kg	1,05E-06	9,18E-07	9,08E-07
Lead	kg	6,19E-08	5,31E-08	6,46E-08
Methane, fossil	kg	2,33E-03	1,83E-03	1,51E-03
Mercury	kg	3,07E-09	2,73E-09	3,01E-09
Nickel	kg	1,84E-08	1,76E-08	2,92E-08
Nitrogen oxides	kg	2,06E-04	1,70E-04	1,62E-04
NMVOC total	kg	2,77E-04	2,37E-04	2,28E-04
thereof:				
Formaldehyde	kg	2,55E-08	2,27E-08	2,73E-08
PM10	kg	1,77E-05	9,00E-06	1,23E-05
PM2.5	kg	8,72E-06	8,34E-06	1,18E-05
PCDD/F (measured as I-TEQ)	kg	2,17E-14	1,51E-14	1,33E-14
Sulfur dioxide	kg	2,16E-04	1,93E-04	2,15E-04
Aerosols, radioactive, unspecified	kBq	n.a.	n.a.	n.a.
Hydrogen-3, Tritium	kBq	n.a.	n.a.	n.a.
Iodine-131	kBq	n.a.	n.a.	n.a.
Iodine-133	kBq	n.a.	n.a.	n.a.
Krypton-85	kBq	n.a.	n.a.	n.a.
Noble gases, radioactive, unspecified	kBq	n.a.	n.a.	n.a.
Thorium-230	kBq	n.a.	n.a.	n.a.
Uranium-234	kBq	n.a.	n.a.	n.a.
Uranium-235	kBq	n.a.	n.a.	n.a.
Uranium-238	kBq	n.a.	n.a.	n.a.
Emissions to water				
Carbon-14	kBq	4,13E-05	3,16E-05	4,20E-05
Hydrogen-3, Tritium	kBq	n.a.	n.a.	n.a.
Iodine-131	kBq	n.a.	n.a.	n.a.
Uranium-234	kBq	n.a.	n.a.	n.a.
Uranium-235	kBq	n.a.	n.a.	n.a.
Uranium-238	kBq	n.a.	n.a.	n.a.

Table 23: Quantifiable external costs: fuel cell natural gas; in ct_{2000}/kWh

	today	2025	2050
health impacts	0,31	0,28	0,30
Biodiversity	0,02	0,02	0,02
crop yield losses	0,01	0,01	0,01
material damage	0,01	0,01	0,01
land use	n.a.	n.a.	n.a.
sub-total	0,35	0,32	0,34
climate change - damage costs low	0,43	0,35	0,24
climate change - damage costs high	5,84	4,23	2,53
climate change - abatement costs low	1,20	1,39	3,27
climate change - abatement costs high	1,20	2,22	8,06

Fuel cell wood gas

Table 24: Key life cycle emissions and land use per kWh: fuel cell wood gas

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²		n.a.	n.a.
Transformation, from forest	m²		n.a.	n.a.
Transformation, from pasture and meadow, unspecified	m²		n.a.	n.a.
Transformation, from pasture and meadow, extensive	m²		n.a.	n.a.
Transformation, from pasture and meadow, intensive	m²		n.a.	n.a.
Transformation, from unknown	m²		n.a.	n.a.
Emissions to air				
Ammonia	kg		3,89E-05	3,82E-05
Arsenic	kg		7,26E-09	4,50E-09
Cadmium	kg		2,47E-09	1,85E-09
Carbon dioxide, fossil	kg		4,60E-02	2,76E-02
Carbon-14	kBq		1,62E-03	1,55E-03
Chromium	kg		3,43E-07	3,41E-07
Chromium VI	kg		8,52E-09	8,45E-09
Dinitrogen monoxide	kg		3,28E-05	3,18E-05
Lead	kg		8,27E-08	6,43E-08
Methane, fossil	kg		9,11E-05	6,18E-05
Mercury	kg		2,77E-09	2,31E-09
Nickel	kg		3,63E-08	2,79E-08
Nitrogen oxides	kg		4,74E-04	4,54E-04
NMVOC total	kg		1,33E-04	1,34E-04
thereof:				
Formaldehyde	kg		3,74E-08	3,08E-08
PM10	kg		1,29E-05	1,23E-05
PM2.5	kg		3,65E-05	3,53E-05
PCDD/F (measured as I-TEQ)	kg		1,98E-14	1,16E-14
Sulfur dioxide	kg		1,78E-04	1,63E-04
Aerosols, radioactive, unspecified	kBq		n.a.	n.a.
Hydrogen-3, Tritium	kBq		n.a.	n.a.
Iodine-131	kBq		n.a.	n.a.
Iodine-133	kBq		n.a.	n.a.
Krypton-85	kBq		n.a.	n.a.
Noble gases, radioactive, unspecified	kBq		n.a.	n.a.
Thorium-230	kBq		n.a.	n.a.
Uranium-234	kBq		n.a.	n.a.
Uranium-235	kBq		n.a.	n.a.
Uranium-238	kBq		n.a.	n.a.
Emissions to water				
Carbon-14	kBq		5,55E-04	4,12E-04
Hydrogen-3, Tritium	kBq		n.a.	n.a.
Iodine-131	kBq		n.a.	n.a.
Uranium-234	kBq		n.a.	n.a.
Uranium-235	kBq		n.a.	n.a.
Uranium-238	kBq		n.a.	n.a.

Table 25: Quantifiable external costs: fuel cell wood gas; in ct_{2000}/kWh

	today	2025	2050
health impacts		0,56	0,54
Biodiversity		0,06	0,06
crop yield losses		0,02	0,02
material damage		0,01	0,01
land use		n.a.	n.a.
sub-total		0,65	0,62
climate change - damage costs low		0,07	0,04
climate change - damage costs high		0,76	0,42
climate change - abatement costs low		0,15	0,21
climate change - abatement costs high		0,23	0,52

3.3. Offshore wind

Responsible partner: DONG Energy

Table 26: Key life cycle emissions and land use per kWh: offshore windpark

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²	n.a.	n.a.	n.a.
Transformation, from forest	m²	n.a.	n.a.	n.a.
Transformation, from pasture and meadow, unspecified	m²	n.a.	n.a.	n.a.
Transformation, from pasture and meadow, extensive	m²	n.a.	n.a.	n.a.
Transformation, from pasture and meadow, intensive	m²	n.a.	n.a.	n.a.
Transformation, from unknown	m²	n.a.	n.a.	n.a.
Emissions to air				
Ammonia	kg	5,31E-07	2,69E-07	5,32E-07
Arsenic	kg	1,17E-08	6,54E-09	1,05E-08
Cadmium	kg	4,44E-09	2,55E-09	4,57E-09
Carbon dioxide, fossil	kg	7,64E-03	2,14E-03	2,17E-03
Carbon-14	kBq	5,14E-05	1,92E-05	3,27E-05
Chromium	kg	9,88E-09	5,29E-09	7,88E-09
Chromium VI	kg	0	9,25E-11	1,51E-10
Dinitrogen monoxide	kg	0	9,97E-08	1,21E-07
Lead	kg	1,64E-08	8,27E-08	1,89E-08
Methane, fossil	kg	1,69E-05	7,17E-06	7,13E-06
Mercury	kg	0	2,08E-09	2,39E-09
Nickel	kg	2,10E-08	1,03E-08	1,60E-08
Nitrogen oxides	kg	2,17E-05	7,61E-06	9,86E-06
NMVOC total	kg	4,04E-06	2,24E-06	2,97E-06
thereof:				
Formaldehyde	kg	0	2,05E-09	2,66E-09
PM10	kg	3,58E-06	3,32E-06	4,17E-06
PM2.5	kg	1,05E-05	1,52E-06	2,37E-06
PCDD/F (measured as I-TEQ)	kg	2,26E-14	7,50E-15	7,50E-15
Sulfur dioxide	kg	2,26E-05	8,68E-06	1,26E-05
Aerosols, radioactive, unspecified	kBq	n.a.	n.a.	n.a.
Hydrogen-3, Tritium	kBq	n.a.	n.a.	n.a.
Iodine-131	kBq	n.a.	n.a.	n.a.
Iodine-133	kBq	n.a.	n.a.	n.a.
Krypton-85	kBq	n.a.	n.a.	n.a.
Noble gases, radioactive, unspecified	kBq	n.a.	n.a.	n.a.
Thorium-230	kBq	n.a.	n.a.	n.a.
Uranium-234	kBq	n.a.	n.a.	n.a.
Uranium-235	kBq	n.a.	n.a.	n.a.
Uranium-238	kBq	n.a.	n.a.	n.a.
Emissions to water				
Carbon-14	kBq	6,61E-06	5,55E-04	9,23E-06
Hydrogen-3, Tritium	kBq	n.a.	n.a.	n.a.
Iodine-131	kBq	n.a.	n.a.	n.a.
Uranium-234	kBq	n.a.	n.a.	n.a.
Uranium-235	kBq	n.a.	n.a.	n.a.
Uranium-238	kBq	n.a.	n.a.	n.a.

Table 27: Quantifiable external costs: offshore windpark; in ct_{2000}/kWh

	today	2025	2050
health impacts	0,06	0,02	0,03
Biodiversity	0,00	0,00	0,00
crop yield losses	0,00	0,00	0,00
material damage	0,00	0,00	0,00
land use	n.a.	n.a.	n.a.
sub-total	0,07	0,02	0,03
climate change - damage costs low	0,01	0,00	0,00
climate change - damage costs high	0,08	0,02	0,01
climate change - abatement costs low	0,02	0,01	0,02
climate change - abatement costs high	0,02	0,01	0,04

3.4. Photovoltaic

Responsible partner: Ambiente Italia

Table 28: Key life cycle emissions and land use per kWh: photovoltaic, tilted roof, single-crystalline silicium, retrofit, average European conditions

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²	n.a.	n.a.	n.a.
Transformation, from forest	m²	n.a.	n.a.	n.a.
Transformation, from pasture and meadow, unspecified	m²	n.a.	n.a.	n.a.
Transformation, from pasture and meadow, extensive	m²	n.a.	n.a.	n.a.
Transformation, from pasture and meadow, intensive	m²	n.a.	n.a.	n.a.
Transformation, from unknown	m²	n.a.	n.a.	n.a.
Emissions to air				
Ammonia	kg	8,15E-06	2,47E-06	1,33E-06
Arsenic	kg	7,34E-08	3,33E-08	1,09E-08
Cadmium	kg	2,44E-08	1,17E-08	4,02E-09
Carbon dioxide, fossil	kg	5,52E-02	8,60E-03	4,78E-03
Carbon-14	kBq	8,45E-04	1,91E-04	1,04E-04
Chromium	kg	3,86E-07	6,53E-08	5,13E-08
Chromium VI	kg	9,37E-09	1,61E-09	1,24E-09
Dinitrogen monoxide	kg	3,64E-06	9,12E-07	4,00E-07
Lead	kg	5,21E-06	3,78E-08	3,53E-08
Methane, fossil	kg	9,91E-05	1,86E-05	1,30E-05
Mercury	kg	5,58E-09	1,19E-09	1,54E-09
Nickel	kg	1,65E-07	6,55E-08	2,17E-08
Nitrogen oxides	kg	1,36E-04	2,64E-05	1,67E-05
NMVOC total	kg	7,09E-05	2,04E-05	1,09E-05
thereof:				
Formaldehyde	kg	8,08E-08	1,02E-08	5,63E-09
PM10	kg	4,73E-05	6,25E-06	6,91E-06
PM2.5	kg	2,37E-05	4,93E-06	3,90E-06
PCDD/F (measured as I-TEQ)	kg	4,81E-14	1,09E-14	8,11E-15
Sulfur dioxide	kg	2,33E-04	4,15E-05	1,93E-05
Aerosols, radioactive, unspecified	kBq	n.a.	n.a.	n.a.
Hydrogen-3, Tritium	kBq	n.a.	n.a.	n.a.
Iodine-131	kBq	n.a.	n.a.	n.a.
Iodine-133	kBq	n.a.	n.a.	n.a.
Krypton-85	kBq	n.a.	n.a.	n.a.
Noble gases, radioactive, unspecified	kBq	n.a.	n.a.	n.a.
Thorium-230	kBq	n.a.	n.a.	n.a.
Uranium-234	kBq	n.a.	n.a.	n.a.
Uranium-235	kBq	n.a.	n.a.	n.a.
Uranium-238	kBq	n.a.	n.a.	n.a.
Emissions to water				
Carbon-14	kBq	3,26E-04	6,52E-05	2,80E-05
Hydrogen-3, Tritium	kBq	n.a.	n.a.	n.a.
Iodine-131	kBq	n.a.	n.a.	n.a.
Uranium-234	kBq	n.a.	n.a.	n.a.
Uranium-235	kBq	n.a.	n.a.	n.a.
Uranium-238	kBq	n.a.	n.a.	n.a.

Table 29: Quantifiable external costs: photovoltaic, tilted roof, single-crystalline silicium, retrofit, average European conditions; in ct_{2000}/kWh

	today	2025	2050
health impacts	0,47	0,07	0,04
Biodiversity	0,02	0,00	0,00
crop yield losses	0,00	0,00	0,00
material damage	0,01	0,00	0,00
land use	n.a.	n.a.	n.a.
sub-total	0,50	0,08	0,04
climate change - damage costs low	0,05	0,01	0,00
climate change - damage costs high	0,62	0,09	0,03
climate change - abatement costs low	0,13	0,03	0,04
climate change - abatement costs high	0,13	0,04	0,09

3.5. Concentrating solar thermal power plant

Responsible partner: DLR, CIEMAT

Table 30: Key life cycle emissions and land use per kWh: concentrating solar thermal power plant

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²	n.a.	2,35E-04	2,47E-04
Transformation, from forest	m²	n.a.	7,24E-06	5,41E-06
Transformation, from pasture and meadow, unspecified	m²	n.a.	7,35E-07	5,97E-07
Transformation, from pasture and meadow, extensive	m²	n.a.	0	0
Transformation, from pasture and meadow, intensive	m²	n.a.	1,49E-08	1,20E-08
Transformation, from unknown	m²	n.a.	1,11E-05	7,85E-06
Emissions to air				
Ammonia	kg	1,23E-05	8,89E-06	6,30E-06
Arsenic	kg	3,07E-09	3,22E-09	1,66E-09
Cadmium	kg	1,35E-09	1,31E-09	7,98E-10
Carbon dioxide, fossil	kg	1,72E-02	1,51E-02	1,09E-02
Carbon-14	kBq	9,18E-05	8,20E-05	6,76E-05
Chromium	kg	1,24E-07	1,55E-07	1,22E-07
Chromium VI	kg	2,78E-09	3,80E-09	2,98E-09
Dinitrogen monoxide	kg	4,28E-05	2,62E-05	1,84E-05
Lead	kg	7,14E-08	6,91E-08	5,59E-08
Methane, fossil	kg	4,29E-05	3,34E-05	2,20E-05
Mercury	kg	3,92E-09	3,36E-09	2,53E-09
Nickel	kg	2,29E-08	1,81E-08	1,16E-08
Nitrogen oxides	kg	7,34E-05	6,34E-05	4,90E-05
NMVOC total	kg	1,66E-05	1,20E-05	9,47E-06
thereof:				
Formaldehyde	kg	4,11E-08	8,60E-08	6,64E-08
PM10	kg	2,46E-05	1,93E-05	1,57E-05
PM2.5	kg	8,92E-06	9,68E-06	7,31E-06
PCDD/F (measured as I-TEQ)	kg	3,27E-14	1,97E-14	9,10E-15
Sulfur dioxide	kg	4,51E-05	3,26E-05	2,17E-05
Aerosols, radioactive, unspecified	kBq	n.a.	1,48E-08	3,65E-08
Hydrogen-3, Tritium	kBq	n.a.	3,78E-04	1,89E-04
Iodine-131	kBq	n.a.	3,59E-07	3,20E-07
Iodine-133	kBq	n.a.	1,50E-10	1,19E-10
Krypton-85	kBq	n.a.	3,09E-06	3,12E-06
Noble gases, radioactive, unspecified	kBq	n.a.	6,74E-01	4,32E-01
Thorium-230	kBq	n.a.	2,56E-05	1,66E-05
Uranium-234	kBq	n.a.	1,20E-07	7,79E-08
Uranium-235	kBq	n.a.	5,74E-09	3,73E-09
Uranium-238	kBq	n.a.	2,37E-07	1,61E-07
Emissions to water				
Carbon-14	kBq	3,54E-05	2,80E-05	1,89E-05
Hydrogen-3, Tritium	kBq	n.a.	3,12E-02	2,12E-02
Iodine-131	kBq	n.a.	2,05E-10	1,62E-10
Uranium-234	kBq	n.a.	2,25E-07	1,46E-07
Uranium-235	kBq	n.a.	3,71E-07	2,41E-07
Uranium-238	kBq	n.a.	9,13E-07	5,90E-07

Table 31: Quantifiable external costs: concentrating solar thermal power plant; in ct_{2000}/kWh

	today	2025	2050
health impacts	0,12	0,10	0,07
Biodiversity	0,01	0,01	0,01
crop yield losses	0,00	0,00	0,00
material damage	0,00	0,00	0,00
land use	n.a.	0,01	0,01
sub-total	0,13	0,12	0,09
climate change - damage costs low	0,06	0,04	0,02
climate change - damage costs high	0,74	0,41	0,21
climate change - abatement costs low	0,04	0,05	0,08
climate change - abatement costs high	0,04	0,08	0,21

3.6. Biomass power plant with steam turbine

Responsible partner: ifeu, IER

Table 32: Key life cycle emissions and land use per kWh: biomass power plant with steam turbine

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²	3,12E-06	3,12E-06	2,50E-06
Transformation, from forest	m²	3,89E-06	4,09E-06	3,21E-06
Transformation, from pasture and meadow, unspecified	m²	5,38E-07	5,23E-07	3,61E-07
Transformation, from pasture and meadow, extensive	m²	0	0	0
Transformation, from pasture and meadow, intensive	m²	2,51E-09	2,51E-09	2,01E-09
Transformation, from unknown	m²	4,34E-03	6,90E-03	5,61E-03
Emissions to air				
Ammonia	kg	4,93E-05	5,44E-05	4,40E-05
Arsenic	kg	9,03E-10	7,11E-10	4,00E-10
Cadmium	kg	5,97E-10	5,05E-10	3,58E-10
Carbon dioxide, fossil	kg	1,80E-02	1,75E-02	1,36E-02
Carbon-14	kBq	4,42E-05	4,16E-05	3,43E-05
Chromium	kg	1,27E-08	1,35E-08	1,07E-08
Chromium VI	kg	2,72E-10	2,92E-10	2,35E-10
Dinitrogen monoxide	kg	8,19E-05	8,90E-05	7,18E-05
Lead	kg	2,72E-08	2,52E-08	1,78E-08
Methane, fossil	kg	1,95E-05	1,90E-05	1,35E-05
Mercury	kg	1,60E-09	1,44E-09	9,81E-10
Nickel	kg	6,98E-09	7,43E-09	5,47E-09
Nitrogen oxides	kg	1,76E-03	1,78E-03	1,43E-03
NMVOC total	kg	2,22E-04	2,16E-04	1,74E-04
thereof:				
Formaldehyde	kg	7,02E-09	7,70E-09	6,08E-09
PM10	kg	4,86E-05	5,76E-06	4,14E-06
PM2.5	kg	4,25E-05	4,27E-05	2,78E-05
PCDD/F (measured as I-TEQ)	kg	3,25E-13	3,16E-13	2,51E-13
Sulfur dioxide	kg	5,31E-04	5,19E-04	4,18E-04
Aerosols, radioactive, unspecified	kBq	8,54E-09	6,38E-09	1,47E-08
Hydrogen-3, Tritium	kBq	2,18E-04	1,75E-04	9,85E-05
Iodine-131	kBq	1,88E-06	3,45E-07	2,73E-07
Iodine-133	kBq	2,43E-10	2,20E-10	1,74E-10
Krypton-85	kBq	1,52E-05	3,12E-06	2,62E-06
Noble gases, radioactive, unspecified	kBq	3,79E-01	3,19E-01	2,17E-01
Thorium-230	kBq	1,49E-05	1,29E-05	8,96E-06
Uranium-234	kBq	6,95E-08	6,04E-08	4,20E-08
Uranium-235	kBq	3,34E-09	2,89E-09	2,01E-09
Uranium-238	kBq	9,74E-08	7,03E-08	4,88E-08
Emissions to water				
Carbon-14	kBq	1,54E-05	1,32E-05	9,36E-06
Hydrogen-3, Tritium	kBq	1,69E-02	1,47E-02	1,04E-02
Iodine-131	kBq	3,32E-10	3,01E-10	2,38E-10
Uranium-234	kBq	1,31E-07	1,14E-07	7,88E-08
Uranium-235	kBq	2,16E-07	1,87E-07	1,30E-07
Uranium-238	kBq	4,43E-07	3,91E-07	2,67E-07

Table 33: Quantifiable external costs: biomass power plant with steam turbine; in ct_{2000}/kWh

	today	2025	2050
health impacts	1,53	1,70	1,35
Biodiversity	0,19	0,19	0,15
crop yield losses	0,06	0,08	0,06
material damage	0,03	0,04	0,03
land use	0,66	1,05	0,85
sub-total	2,46	3,05	2,45
climate change - damage costs low	0,11	0,10	0,07
climate change - damage costs high	1,25	1,07	0,66
climate change - abatement costs low	0,04	0,06	0,10
climate change - abatement costs high	0,04	0,09	0,26

3.7. Nuclear power plant

Responsible partner: EDF

The nuclear power plant systems concerned here are fully described in the report by Lecointe et al. (2008).

Summary of key emissions

Table 34 summarises the key life cycle environmental burdens from typical configurations of electricity generation in nuclear power plants that are used for the calculation of external costs. For future nuclear power plants, the LCI data for the 'realistic-optimistic' scenario were taken. While this scenario exclusively makes assumptions regarding the techno-economic development of a specific class of technology, different sets of LCI data exist depending on the anticipated policy scenario. The policy scenario most notably affects the composition and thus the emissions from the UCTE mix.[1] The compilation of the LCI data in Table 34 was carried out by DLR based on different LCI data sets provided by EDF R&D (cf. Lecointe et al. 2008) that were further processed by ESU services. To the authors of this section on nuclear power plants, it is unclear which of the policy scenarios were used or how they may have been combined, having an impact on the background emissions from the UCTE mix.

[1] The following policy scenarios were distinguished when defining the emissions from the UCTE mix. These scenarios differ particularly according to assumptions regarding greenhouse gas emission reduction targets (i.e., Business As Usual (BAU) or 440 ppm CO_2-equivalent limit) and the way these are achieved (e.g., by means of renewables) as well as the development of a specific class of technology as used throughout this document (i.e., pessimistic (PE), realistic optimistic (RO) and very optimistic (VO)). The scenarios translate into a certain composition of the power plant park in the UCTE mix. The UCTE's composition in terms of nuclear power plants for the different policy scenarios reads:

Sc1 - PE BAU :	2000: 100% PWR	2025: 70% PWR and 30% EPR	2050: 100% EPR
Sc2 - PE 440ppm :	2000: 100% PWR	2025: 70% PWR and 30% EPR	2050: 100% EPR
Sc3 - RO 440ppm:	2000: 100% PWR	2025: 70% PWR and 30% EPR	2050: 95% EPR and 5% EFR
Sc4 - VO 440ppm :	2000: 100% PWR	2025: 70% PWR and 30% EPR	2050: 95% EPR and 5% EFR
Sc5 - VO Renew :	2000: 100% PWR	2025 &2050: no nuclear in the electricity-mix	

Table 34: Key life cycle emissions and land use per kWh: nuclear power plant (compiled by DLR based on different LCI data sets provided by EDF R&D (cf. Lecointe et al. 2008) that were further processed by ESU services)

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²	2.76E-06	6.32E-07	4.44E-07
Transformation, from forest	m²	4.21E-05	3.84E-06	2.49E-06
Transformation, from pasture and meadow, unspecified	m²	1.01E-06	8.39E-07	4.53E-07
Transformation, from pasture and meadow, extensive	m²	0	0	0
Transformation, from pasture and meadow, intensive	m²	2.22E-09	5.05E-10	3.54E-10
Transformation, from unknown	m²	5.43E-06	6.93E-06	5.36E-06
Emissions to air				
Ammonia	kg	9.67E-07	6.74E-07	5.81E-07
Arsenic	kg	2.51E-09	1.64E-09	8.04E-10
Cadmium	kg	1.04E-09	8.14E-10	5.69E-10
Carbon dioxide, fossil	kg	6.27E-03	4.85E-03	3.76E-03
Carbon-14	kBq	5.09E-02	5.53E-02	6.30E-02
Chromium	kg	1.22E-07	1.09E-07	7.83E-08
Chromium VI	kg	3.04E-09	2.72E-09	1.95E-09
Dinitrogen monoxide	kg	6.35E-07	5.85E-07	4.86E-07
Lead	kg	3.89E-07	3.86E-07	3.61E-07
Methane, fossil	kg	1.10E-05	8.31E-06	5.41E-06
Mercury	kg	5.51E-10	4.58E-10	3.31E-10
Nickel	kg	1.32E-08	1.00E-08	7.25E-09
Nitrogen oxides	kg	3.20E-05	2.66E-05	2.26E-05
NMVOC total	kg	8.01E-06	7.02E-06	6.22E-06
thereof:				
Formaldehyde	kg	1.19E-07	1.39E-08	9.81E-09
PM10	kg	7.45E-06	2.04E-06	1.48E-06
PM2.5	kg	4.99E-06	3.96E-06	3.16E-06
PCDD/F (measured as I-TEQ)	kg	4.73E-15	3.25E-15	1.90E-15
Sulfur dioxide	kg	2.82E-05	2.14E-05	1.81E-05
Aerosols, radioactive, unspecified	kBq	1.38E-05	9.80E-06	3.66E-07
Hydrogen-3, Tritium	kBq	2.96E-01	2.50E-01	1.39E-01
Iodine-131	kBq	3.00E-06	1.37E-06	3.87E-06
Iodine-133	kBq	1.64E-10	1.02E-10	7.03E-11
Krypton-85	kBq	2.40E-05	1.75E-06	4.87E-04
Noble gases, radioactive, unspecified	kBq	5.09E+02	4.71E+02	3.69E+02
Thorium-230	kBq	1.48E-02	1.46E-02	1.36E-02
Uranium-234	kBq	6.82E-05	6.75E-05	6.27E-05
Uranium-235	kBq	3.31E-06	3.28E-06	3.04E-06
Uranium-238	kBq	6.87E-05	6.80E-05	6.31E-05
Emissions to water				
Carbon-14	kBq	2.06E-02	1.96E-02	1.67E-02
Hydrogen-3, Tritium	kBq	2.24E+01	2.15E+01	1.88E+01
Iodine-131	kBq	2.24E-10	1.40E-10	9.60E-11
Uranium-234	kBq	1.30E-04	1.29E-04	1.19E-04
Uranium-235	kBq	2.14E-04	2.12E-04	1.97E-04
Uranium-238	kBq	3.28E-04	3.24E-04	3.01E-04

There is a decrease in most of the emissions from today to 2025 and finally 2050. This is because EPR has grossly a better environmental performance in terms of emissions (Lecointe et al. 2008). Except for C14, EPR results are lower than those of the PWR. The increase in C14 emissions from PWR to EPR can be explained by data constraints (the ecoinvent data for PWR do not provide C14 emissions into air). The share of EPR in the nuclear power plant mix is zero today and increases afterwards. Likewise, EFR results are largely lower than PWR and EPR results, because emissions from the fuel step are marginal. EFR is only considered to operate in 2050 in the non realistic optimistic and very optimistic cases.

Quantifiable external costs

Keeping the limitations in mind that are stated in section 0, Table 35 provides a summary of the external costs from electricity generation in nuclear power plants computed by DLR.

The total quantifiable external costs of today's typical nuclear technology are in the range of 0.09 €-cent/kWh (low) to 0.15 €-cent/kWh (high), and thus are significantly lower than the private costs of nuclear power generation. Technical progress as assumed under the 'optimistic-realistic' technology development scenario results in a reduction of external costs to 0.07 €-cent/kWh (low) to 0.11 €-cent/kWh (high) in 2025 and to 0.06 €-cent/kWh (low) to 0.12 €-cent/kWh (high) in 2050.

Depending on the magnitude of the costs of greenhouse gas emissions, climate change related external costs may constitute between 4 and up to 57% of the quantifiable external costs, highlighting the sensitivity of the selection of the costs for greenhouse gases. Note that most of the greenhouse gas emissions for nuclear power plant occur during the processes upstream and downstream from electricity generation.

Human health impacts constitute a large portion of the quantifiable external costs without climate change related damages (between 78% and below 90%, today and in the future, respectively). Radionuclide damages contribute roughly about 20% to the overall quantifiable human health related external costs from the nuclear power plants investigated here.

Comparing these external costs to results from other studies is only possible for current techniques. No external costs for future techniques have been carried out to the knowledge of the authors. In this study, the external costs quantified for the state-of-the-art nuclear power plants currently in operation are below those previously reported (ranging between 0.2 and 0.7 €-cent/kWh, cf. European Commission, 2003). Still, these previously reported nuclear power related external costs were at the lower end of the quantified external costs among the assessed techniques (i.e. fossil-fired power plants (coal, lignite, peat, oil and gas), nuclear power plants, and the renewables hydro, wind, photovoltaic and biomass, ibid.).

The discrepancy between the earlier and the current external costs for nuclear power is due to two reasons: (a) methodological differences in the way how external costs are computed and (b) the techniques evaluated are not the same.

Table 35: Quantifiable external costs in €-cent$_{2000}$/kWh: nuclear power plant (computed by DLR), note the limitations mentioned in section 0

	today	2025	2050
health impacts	0.06	0.05	0.05
Biodiversity	0.004	0.003	0.003
crop yield losses	0.001	0.001	0.001
material damage	0.001	0.001	0.001
land use	0.01	0.002	0.002
sub-total	0.08	0.06	0.05
climate change - damage costs low	0.01	0.004	0.002
climate change - damage costs high	0.07	0.05	0.02
climate change - abatement costs low	0.01	0.02	0.03
climate change - abatement costs high	0.01	0.02	0.07

Limitations of the quantified external costs

In general, several points need to be noted here as regards the calculation of external costs in this study:

- The way radionuclide releases are assessed does not comply with current state-of-the-art. This is mainly due to the simplified approach adopted and leads to a "move back" compared to ExternE 1995 (European Commission 1995) in terms of methodology regarding the assessment of radionuclide releases. A more detailed discussion of this issue is presented in the Appendix (A.2). While some radionuclides are assessed (at least) by means of rough assessment factors from international agencies (exposure and risk factors from UNSCEAR and ICRP, respectively), some were derived based on even less reliable sources (based on the Life Cycle Impact Assessment, LCIA, methods IMPACT2002+ and EcoIndicator99). The external costs based on these even less reliable radionuclide external unit costs contribute, however, only negligibly to the overall quantifiable external costs.
- The inconsistent use of unit external costs (or unit damage costs): the valuation of fatalities differs for greenhouse gases and other emissions (such as classical air pollutants, heavy metals, radionuclides, persistent organic pollutants) in two ways: 1) in the context of climate change, a Value Of Statistical Life (VOSL) is used for calculating marginal damage costs while fatalities from non-greenhouse gas emissions are valued by a Value Of a Life Year (VOLY)[2] and 2) the VOSL is not constant in time while the VOLY is kept constant for the purpose of in this report.[3] More precisely, climate change damage costs were computed by means of the FUND model (Anthoff, 2007). In this model, economic growth raises the GDP in the different world regions in the future. The unit value of mortality impacts of global warming occurring in these regions raises at a rate equivalent to the GDP increase in each region. Within the FUND model, the respective future damages are finally discounted to yield the present value in €$_{2000}$. This procedure is different from the calculation of future

[2] *More specifically, the value of a statistical life (VOSL) for valuing fatalities from climate change within FUND is set to be 200 times the annual per capita income.*

[3] *Email communication with Wolfram Krewitt, DLR and RS1a leader as of December 2008 confirming the use of a constant VOLY among other things.*

mortality impacts from emissions other than greenhouse gases that are valued with a temporally and spatially constant VOLY (in this document in general and in Table 35 for nuclear power in particular). For consistency reasons, one should consequently either apply the described uprating-discounting procedure in both cases or do without it entirely.

- Certain emissions and impacts are not included. This particularly applies to radionuclides released from accidents at the power plant and from waste disposal. The external costs of both types of radionuclide releases are, however, assessed to be small. Section A.1 in the Appendix is devoted to the discussion of this issue.

3.8. Ocean energy

Responsible partner: SPOK

Table 36: Key life cycle emissions and land use per kWh: ocean energy

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²	1,65E-06	8,60E-07	8,68E-07
Transformation, from forest	m²	4,86E-06	2,77E-06	2,74E-06
Transformation, from pasture and meadow, unspecified	m²	4,43E-07	2,24E-07	2,14E-07
Transformation, from pasture and meadow, extensive	m²	0	0	0
Transformation, from pasture and meadow, intensive	m²	1,31E-09	6,84E-10	6,88E-10
Transformation, from unknown	m²	2,20E-05	1,30E-05	1,42E-05
Emissions to air				
Ammonia	kg	2,29E-06	1,06E-06	1,03E-06
Arsenic	kg	6,94E-08	1,85E-08	1,36E-08
Cadmium	kg	2,30E-08	6,29E-09	4,97E-09
Carbon dioxide, fossil	kg	1,32E-02	7,83E-03	7,67E-03
Carbon-14	kBq	7,25E-05	3,90E-05	5,12E-05
Chromium	kg	3,29E-07	1,41E-07	1,40E-07
Chromium VI	kg	8,17E-09	3,50E-09	3,48E-09
Dinitrogen monoxide	kg	3,37E-07	1,78E-07	1,68E-07
Lead	kg	6,01E-08	3,71E-08	3,25E-08
Methane, fossil	kg	2,96E-05	1,64E-05	1,40E-05
Mercury	kg	1,91E-09	9,14E-10	9,20E-10
Nickel	kg	1,39E-07	3,75E-08	2,66E-08
Nitrogen oxides	kg	4,89E-05	2,71E-05	2,60E-05
NMVOC total	kg	8,92E-06	5,31E-06	5,44E-06
thereof:				
Formaldehyde	kg	1,03E-08	5,16E-09	5,27E-09
PM10	kg	3,57E-05	1,82E-05	1,66E-05
PM2.5	kg	1,45E-05	6,99E-06	6,34E-06
PCDD/F (measured as I-TEQ)	kg	3,62E-14	1,49E-14	9,58E-15
Sulfur dioxide	kg	6,39E-05	2,19E-05	1,78E-05
Aerosols, radioactive, unspecified	kBq	1,30E-08	6,80E-09	7,01E-09
Hydrogen-3, Tritium	kBq	3,32E-04	1,76E-04	1,57E-04
Iodine-131	kBq	3,57E-07	2,32E-07	2,69E-07
Iodine-133	kBq	2,19E-10	1,43E-10	1,69E-10
Krypton-85	kBq	3,21E-06	2,08E-06	2,66E-06
Noble gases, radioactive, unspecified	kBq	5,91E-01	3,14E-01	3,38E-01
Thorium-230	kBq	2,28E-05	1,23E-05	1,33E-05
Uranium-234	kBq	1,10E-07	5,88E-08	6,35E-08
Uranium-235	kBq	5,12E-09	2,75E-09	2,99E-09
Uranium-238	kBq	2,19E-07	1,12E-07	1,13E-07
Emissions to water				
Carbon-14	kBq	5,09E-07	2,59E-07	8,59E-07
Hydrogen-3, Tritium	kBq	2,72E-02	1,44E-02	1,63E-02
Iodine-131	kBq	2,99E-10	1,96E-10	2,30E-10
Uranium-234	kBq	2,01E-07	1,08E-07	1,17E-07
Uranium-235	kBq	3,31E-07	1,78E-07	1,93E-07
Uranium-238	kBq	1,06E-06	5,41E-07	5,30E-07

Table 37: Quantifiable external costs: ocean energy; in ct_{2000}/kWh

	today	2025	2050
health impacts	0,12	0,06	0,05
Biodiversity	0,01	0,00	0,00
crop yield losses	0,00	0,00	0,00
material damage	0,00	0,00	0,00
land use	0,00	0,00	0,00
sub-total	0,14	0,06	0,06
climate change - damage costs low	0,01	0,01	0,00
climate change - damage costs high	0,14	0,07	0,04
climate change - abatement costs low	0,03	0,03	0,06
climate change - abatement costs high	0,03	0,04	0,15

3.9. Hydrogen

Responsible partner: INE

Table 38: Key life cycle emissions and land use per kWh: hydrogen production (hydrogen compressed gas, at hydrogen fuelling station)

		today	2025	2050
Land use				
Transformation, from arable, unspecified	m²	1,43E-05	2,73E-06	2,73E-06
Transformation, from forest	m²	1,58E-04	4,64E-05	4,64E-05
Transformation, from pasture and meadow, unspecified	m²	1,55E-05	5,02E-06	5,02E-06
Transformation, from pasture and meadow, extensive	m²	0	0	0
Transformation, from pasture and meadow, intensive	m²	1,15E-08	2,01E-09	2,01E-09
Transformation, from unknown	m²	8,28E-05	7,48E-04	7,48E-04
Emissions to air				
Ammonia	kg	1,49E-05	5,28E-06	5,28E-06
Arsenic	kg	5,27E-08	4,96E-09	4,96E-09
Cadmium	kg	1,10E-08	1,77E-09	1,77E-09
Carbon dioxide, fossil	kg	8,53E-01	8,43E-02	8,43E-02
Carbon-14	kBq	2,89E-02	2,43E-02	2,43E-02
Chromium	kg	2,38E-06	4,50E-07	4,50E-07
Chromium VI	kg	6,00E-08	1,12E-08	1,12E-08
Dinitrogen monoxide	kg	2,15E-05	1,12E-05	1,12E-05
Lead	kg	8,97E-07	1,90E-07	1,90E-07
Methane, fossil	kg	1,36E-03	5,14E-04	5,14E-04
Mercury	kg	2,96E-08	3,77E-09	3,77E-09
Nickel	kg	5,86E-07	3,58E-08	3,58E-08
Nitrogen oxides	kg	1,56E-03	2,35E-04	2,35E-04
NMVOC total	kg	2,07E-04	1,63E-04	1,63E-04
thereof:				
Formaldehyde	kg	1,43E-06	2,10E-07	2,10E-07
PM10	kg	3,14E-04	3,01E-05	3,01E-05
PM2.5	kg	2,35E-04	1,65E-05	1,65E-05
PCDD/F (measured as I-TEQ)	kg	1,19E-13	2,35E-14	2,35E-14
Sulfur dioxide	kg	3,52E-03	2,07E-04	2,07E-04
Aerosols, radioactive, unspecified	kBq	7,02E-06	1,58E-05	1,58E-05
Hydrogen-3, Tritium	kBq	1,65E-01	5,34E-02	5,34E-02
Iodine-131	kBq	1,66E-03	2,19E-06	2,19E-06
Iodine-133	kBq	2,52E-08	1,16E-10	1,16E-10
Krypton-85	kBq	1,31E-02	1,93E-04	1,93E-04
Noble gases, radioactive, unspecified	kBq	2,82E+02	1,42E+02	1,42E+02
Thorium-230	kBq	9,69E-03	5,23E-03	5,23E-03
Uranium-234	kBq	4,48E-05	2,42E-05	2,42E-05
Uranium-235	kBq	2,17E-06	1,17E-06	1,17E-06
Uranium-238	kBq	6,55E-05	2,44E-05	2,44E-05
Emissions to water				
Carbon-14	kBq	1,14E-02	6,43E-03	6,43E-03
Hydrogen-3, Tritium	kBq	1,25E+01	7,23E+00	7,23E+00
Iodine-131	kBq	3,44E-08	1,59E-10	1,59E-10
Uranium-234	kBq	8,52E-05	4,60E-05	4,60E-05
Uranium-235	kBq	1,41E-04	7,59E-05	7,59E-05
Uranium-238	kBq	2,41E-04	1,17E-04	1,17E-04

Table 39: Quantifiable external costs: hydrogen production; in ct_{2000}/kWh (hydrogen compressed gas, at hydrogen fuelling station)

	today	2025	2050
health impacts	3,82	0,36	0,36
Biodiversity	0,22	0,03	0,03
crop yield losses	0,04	0,01	0,01
material damage	0,10	0,01	0,01
land use	0,06	0,13	0,13
sub-total	4,23	0,54	0,54
climate change - damage costs low	0,67	0,08	0,06
climate change - damage costs high	9,13	0,98	0,64
climate change - abatement costs low	2,01	0,27	0,65
climate change - abatement costs high	2,01	0,43	1,60

4. References

Anthoff, D. (2007): Report on marginal external costs inventory of greenhouse gas emissions. NEEDS Deliverable D5.2, RS1b

EFR (1998): "EFR 98 – outcome of design studies". J.C. Lefèvre. EFR associates, Lyon.1998.

European Commission (1995). Externalities of Energy - Vol. 5: Nuclear. European Commission DG XII "Science, Research and Development", JOULE, Luxembourg. Online publication at http://www.externe.info/

European Commission (2003). External Costs: Research results on socio-environmental damages due to electricity and transport. Office for Official Publications of the European Communities, Luxembourg. Online publication at http://ec.europa.eu/research/energy/pdf/externe_en.pdf

GIF (2002): A Technology Roadmap for Generation IV Nuclear Energy Systems. US DOE Nuclear Energy Research Advisory Committee and Gen IV International Forum, Online-version available at: http://gen-iv.ne.doe.gov/.

Friedrich, R. (2008): Note on the choice of values of marginal external costs of greenhouse gas emissions. NEEDS Working Paper, July 15, 2008.

International Commission on Radiological Protection (ICRP) (1991). 1990 Recommendations of the International Commission on Radiological Protection - Users' Edition, 60. Pergamon Press, Oxford. p. 83. Available at http://intl.elsevierhealth.com/catalogue/title.cfm?ISBN=9780080411446.

International Commission on Radiological Protection (ICRP) (2006). P101: Assessing Dose of the Representative Person for the Purpose of Radiation Protection of the Public and The Optimisation of Radiological Protection: Broadening the Process. Annals of the ICRP 36(3) 1-104. Available at http://www.sciencedirect.com/science/journal/01466453

International Commission on Radiological Protection (ICRP) (2007). P103: The 2007 Recommendations of the International Commission on Radiological Protection. Annals of the ICRP 37(2-4) 1-332. Available at http://www.sciencedirect.com/science/journal/01466453

Koellner (2001): Land use in product life cycles and its consequences for ecosystem quality University of St. Gallen, ETH Zürich.

Lecointe, C., Lecarpentier, D., Maupu, V., Le Boulch, D., Richard, R. (2008) Final report on technical data, costs and life cycle inventories of nuclear power plants. NEEDS Deliverable D14.2, RS1a, WP14, EDF R&D, Paris (With contributions from Garzenne, C., Bachmann, T.M. (EDF R&D) and a literature survey on costs and provision of LCI data by Dones, R. (PSI))

Markandya, A., Dale, N., Schneider, T. (Eds.), (1998). Improvement of the assessment of the external costs of severe nuclear accidents. CEPN report N°260. Centre d'étude sur l'Evaluation de la Protection dans le domaine Nucléaire (CEPN), Fontenay-aux-Roses, France.

Ott, W., Baur, M., Kaufmann, Y., Frischknecht, R., Steiner, R. (2006): Assessment of biodiversity losses. NEEDS Deliverable D4.2, RS1b, WP4.

Preiss, P., Klotz, V., 2008. EcoSenseWeb V1.3: User's Manual & "Description of Updated and Extended Draft Tools for the Detailed Site-dependent Assessment of External Costs". Technical Paper no. 7.4 - RS1b of the NEEDS project. Institute of Energy Economics and the Rational Use of Energy, University of Stuttgart, Stuttgart. p. 63. Online publication at http://www.isis-it.net/public/needs/freports/EcoSenseWeb_UM_080110.pdf

Tol, R. S. J. (2002). "Estimates of the damage costs of climate change, Part II. Dynamic estimates." Environmental and Resource Economics **21**(2): 135-160.

Tol, R. S. J. (2002). "Estimates of the damage costs of climate change. Part 1: Benchmark estimates." Environmental and Resource Economics **21**(2): 47-73.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (2000). Sources and effects of ionizing radiation: UNSCEAR 2000 report to the General Assembly, with scientific annexes. Vol. 1: Sources. United Nations, New York. p. 654. ISBN: 92-1-142238-8. Available at http://www.unscear.org/unscear/en/publications/2000_1.html.

Vaillant, L., Schneider, T., (2008). Nuclear fuel cycle external costs: Review of the EcoSenseWeb methodology. Report for the European Institute for Energy Research, Karlsruhe. CEPN NTE/08/15. Centre d'étude sur l'Evaluation de la Protection dans le domaine Nucléaire (CEPN), Fontenay-aux-Roses, France. p. 44.

Watkiss, P., D. Anthoff, et al. (2005). The Social Costs of Carbon Review – Methodological Approaches for Using SCC Estimates in Policy Assessment. London, United Kingdom, Defra.

APPENDIX A COMMENTS RELATED TO THE ASSESSMENT OF EXTERNAL COSTS FOR RADIONUCLIDE RELEASES

Responsible partner: EDF with the support of the Centre d'étude sur l'évaluation de la protection dans le domaine nucléaire (CEPN)

In the following, two issues are addressed:

1) A discussion of the main unquantified externalities related to nuclear power (i.e. radionuclide releases from waste disposal and due to (severe) accidents, cf. section A.1)
2) A discussion of the way how external costs from radionuclide releases were quantified in this study (section A.2).

The CEPN was asked to provide its expert point of view on these issues. The following text is mainly based on the report by Vaillant and Schneider (2008).

A.1 Other potential environmental impacts

The current NEEDS methodology for quantifying environmental external costs does not include all external effects. This disregard of several externalities needs careful consideration in developing future energy strategies.

The main unquantified externalities related to nuclear power are the consideration of radionuclide releases from waste disposal and due to (severe) accidents to which we turn next.

A.1.1 Radionuclide releases from waste disposal repositories

Previous studies (European Commission 1995) indicated that externalities from waste disposal facilities lead to very low externalities (low and high level waste disposals lead to external costs of between $3.02*10^{-3}$ and $8.52*10^{-7}$ €-cent/kWh when discounted at a discount rate of 0 % and 3 %, respectively). External costs associated with the disposal of radioactive waste were found to be negligible compared to those from electricity generation and reprocessing of irradiated fuel (European Commission 1995).

Not taking into account an altered scenario (i.e. abnormal evolution of the disposal facility, for example due to human intrusion, for which the probability of occurrence is quite low), radionuclides from deep geological repositories would reach the environment in the very distant future (at least several thousand years): for any discount rate higher than 0, external costs associated with the disposal of radioactive waste are equal to 0 €-cent/kWh (European Commission 1995). In addition, the methodology for evaluating a collective dose from the discharges from a deep geological repository, as used in ExternE 1995 (European Commission 1995), is not well suited. This is due to the difficulty to identify a relevant critical group of the population in the very far future. At least one can expect that due to normalization, the external cost for a discount rate of 0 % remains quite low (the normalization factor is based, for the French context, on the electricity produced by 58 units for an average of 30 years).

Elements taken from UNSCEAR 2000 report shall be stressed: "*Doses from solid waste disposal have been estimated based on the projected eventual migration of radionuclides through the burial site into groundwater. These estimates depend critically on the assumptions used for the containment of the solid wastes and the site characteristics and are, accordingly, highly uncertain in a general sense. The* *approximate normalized collective effective dose from low and intermediate-level waste disposal is, however, quite low, of the order of 0.5 man.Sv.GWa^{-1}…*” (UNSCEAR 2000, paragraph 161).

A.1.2 Radionuclide releases due to accidents

The EcoSenseWeb User’s Manual (Preiss and Klotz 2008) does not suggest a way how to assess external costs from accidents of any fuel cycle. It is thus appropriate not to evaluate such an event for the nuclear fuel cycle either. Nevertheless, this issue is particularly sensitive as regards severe nuclear accidents. One may therefore ask for the reason why this choice was made. Reasons detailed within the EcoSenseWeb User’s Manual are appropriate: “*Mostly owing to the expected low probability of such accidents to occur, quantifications in the past came to the conclusion that the severe accidents only marginally contribute to the overall external costs (e.g. ExternE Methodology 2005 update, p. 225f)*” (Preiss and Klotz 2008, p. 30). In fact, ExternE 1995 results (Table 40**Fehler! Verweisquelle konnte nicht gefunden werden.**) show low external costs that are above all due to the rather low probability of a severe accident (nowadays close to 10^{-6} to 10^{-5} per reactor.year) and the choice made to normalize the calculated costs (entire lifetime electricity production of a power plant). Furthermore, the difficulties associated with the assessment of accident scenario should be mentioned which may induce releases into the environment: in fact, most of the studies in this field are dedicated to the safety analysis of the power plant and no detailed investigations have been published concerning potential damages to the environment due to accidents.

Table 40: Cost of the risk of the different accident scenarios considered (European Commission 1995)

Source term	Core melt probability	Conditional probability	External cost (mECU per kWh)
ST2	5.10^{-5}	0.19	0.104
ST21	5.10^{-5}	0.19	0.021
ST22	5.10^{-5}	0.19	0.0042
ST23	5.10^{-5}	0.81	0.0023

The total quantifiable external cost for the nuclear fuel cycle, as calculated by European Commission (1995), is 2.48 mECU.kWh^{-1}

Another issue regarding the monetary evaluation of the consequences associated with a nuclear accident on the basis of a probabilistic approach is that of the possible discrepancy between the social acceptability of the risk and the average monetary value. This monetary value corresponds in principle to the compensation of the consequences for each individual of the population affected by the accident. This issue can be taken into account by integrating risk aversion into the external cost calculations. This may be based on the use of the expected utility approach to propose multiplying factor according to the degree of risk aversion towards a severe accident. Such calculations were carried out in 1998 (Markandya et al. 1998) and led to external costs of 0.087 m€/kWh for a severe nuclear accident including risk aversion (ST21 scenario). This value must however be carefully looked at as based on a rather debated theoretical approach.

An overview of values outlining the fluctuation margin of damage costs for nuclear accident is provided in Table 41**Fehler! Verweisquelle konnte nicht gefunden werden.** which draws on

Markandya et al. (1998). It outlines the difficulty to develop a relevant and convincing methodology for the assessment of cost from severe nuclear accident. Other remarks on the overview of this Table are provided in the CEPN report NTE/08/15 (Vaillant and Schneider 2008).

In fact, the results of the different studies presented in Table 41**Fehler! Verweisquelle konnte nicht gefunden werden.** point out the difficulties in the derivation of external costs to cope with the issue of nuclear accidents. Nevertheless, because of the sensitivity of this issue, the EcoSenseWeb User's Manual would benefit from a brief reflection on externalities from releases of radionuclides from severe accident even if the calculation of the associated external costs cannot be performed by EcoSenseWeb.

Table 41: Overview of results: damage costs of the impacts of reactor accidents (m€/kWh); source: Vaillant and Schneider (2008) mainly taken from Markandya et al. (1998), p. 2-1-2

Study	Fluctuation margin of damage costs for nuclear accidents	Particularities in results
Hohmeyer (1989)	6.0 - 60	Chernobyl accident taken as a basis
Hohmeyer (Supplement, 1990)	17.4 - 105	Chernobyl accident taken as a basis. Studies by Hohmeyer are based on the use of collective dose estimates associated with Chernobyl accident, fold by a factor of 7 (for 1989 evaluation) to take into account inhabitant density in Germany. A further 5 fold factor was used in the 1990 study. In addition Hohmeyer studies only use the core melt probability without consideration regarding the conditional probability (see Table 40**Fehler! Verweisquelle konnte nicht gefunden werden.**).
Ottinger *et al.* (1990)	18.4	Chernobyl accident taken as a basis
Ewers/Rennings (1992)	21.5	Chernobyl accident taken as a basis Ottinger and Ewers/Rennings studies are based on Hohmeyer methodology. In Ottinger study there is no change of the collective dose as estimated for the Chernobyl accident but higher values are used for cancer cost values.
Friedrich *et al.* (1990)	0.04 - 0.35	
Pearce *et al.* (1992)	0.00085 - 0.0021 0.25 - 0.625 / 3.38	Expected value (without risk aversion) With two alternative approaches of risk aversion. A dedicated mathematical function is used that balance the risk function (probability * number of exposed persons) with a calculated factor. 2 methods are discussed : use of the square of the number of exposed people or use of a multiplying factor of 300.
Infras/Prognos (1994)	0.006 - 1.02 11.4 - 189.6	Expected value (without risk aversion) Risk aversion included by using the standard deviation of damage instead of the mean
ORNL/RFF (1995)	SE: 0.083 SW: 0.0477	SE: South-east site (East Tennessee). SW: South-west site (New Mexico). Non-health effects (property etc.) are higher by far than damages of health; health effects calculated with 3 % discount rate; Non-health effects include "onsite" (plant-related expense) such as loss of utility assets and utility site cleanup
ExternE (CEPN) (1995)	0.0014 - 0.0235	Costs of reactor accidents only calculated with 0 % discount rate
Krewitt (1996)	0.0085 0.002	0 % discount rate 3 % discount rate
Rowe *et al.* (1995)	0 - 0.08	Share of the cost category "accidents" is not separately identifiable from available data source
Hirschberg/Cazzoli (1994)	0.0008 - 0.031	
Wheeler/Hewison (1994)	0.0014 - 0.0016	

CEPN (1998)	0.046	France - With risk aversion.

A.2 Remarks on the approach to assess external costs from radionuclides

Within the NEEDS project, there are two approaches how to assess external costs from radionuclides:

1) An online tool called EcoSenseWeb and
2) Damage factors or unit external costs.

Both approaches have been developed and endorsed by the Institute of Energy Economics and the Rational Use of Energy (IER), University of Stuttgart. Both approaches are related and rely upon the same original studies, most notably by competent authorities such as UNSCEAR or ICRP. In the frame of the external cost quantification as performed here, use was made of the damage factors for radionuclides as well as for any other elementary flow of the Life Cycle Inventory. Given the relatedness between EcoSenseWeb and the damage factors and due to the better documentation of the EcoSenseWeb tool until the second half of August 2008, the approach taken in EcoSenseWeb will be discussed in the following. The aspects raised equally apply to the damage factors. This section starts, however, with some general information as regards the radionuclide risk assessment in general and the ExternE approach to quantify related external costs prior to NEEDS.

A.2.1 General considerations as regards radionuclide risk assessment and the ExternE approach to quantify related external costs prior to NEEDS

The evaluation of nuclear fuel cycle external costs is a very difficult task, as there is a need to take account of the specificity of the dispersion of radionuclides in the environment in time and space and to assess the potential effect on human health according to the different exposure pathways which differ with the type of radionuclide. Particular care must be taken to achieve this in a rather transparent way, as it is a very sensitive issue as regards the perception by the general public.

Quantification of health and environmental impacts associated with the nuclear fuel cycle raises a lot of issues: temporal scope of the assessment, global effects, distribution of life expectancy reductions over time and their valuation for example. Any choice must be discussed regarding the level of uncertainties associated with it and its relevance. It is thus of first importance to clearly state which assumptions are made, to detail associated uncertainties and to provide the user of calculated external costs with elements that will help to discuss and interpret these values in a relevant way.

A methodology for the assessment of the nuclear fuel cycle external costs was developed by the CEPN at the beginning of the 1990ies within the ExternE research program. It is based on a step-by-step analysis and the Impact Pathway approach. At that time, only the health impacts associated with radionuclide discharges were taken into account.

Regarding the release of radionuclides into the environment (atmosphere, river or sea), the assessment of health effects is based on the concept of collective dose. Individual doses are summed over large space (the earth) and time (up to 100 000 years) scales, resulting in “significant” collective doses. With help of the estimated collective doses, a number of health effects can be calculated by means of the ICRP detriment (or risk) factors. These health effects can then be valued in monetary terms. This collective dose-based approach is often criticised (see for instance ICRP 101 and 103 reports) as high collective doses are based on the sum of very low individual doses and the level of uncertainties associated with their calculation is quite large. In order to take into account these criticisms, results calculated within the ExternE program were split over time (short 0 - 1 year, medium 1 -100 years and long term 100 - 100 000 years) and space (local 0 - 100 km, regional 100 - 1 000 km and global > 1 000 km), so as to allow any end-user to better be able to interpret the results and associated uncertainties. In particular, this scheme allows to better appreciate the influence of the discount rate on the final results (more or less important contribution of the long term effects in the final results).

Since the end of the 1990ies, there has been no further development within the European Commission research program regarding the assessment of the nuclear fuel cycle external costs.

A.2.2 Overall evaluation of the approach taken in NEEDS for the radionuclides emissions assessment: the EcoSenseWeb tool

Recently, the EcoSenseWeb tool has been developed by IER in order to propose an integrated evaluation of the external costs of electricity production, including the nuclear fuel cycle. The CEPN has been asked to provide its expert point of view on the EcoSenseWeb tool version 1.3 and the way it allows to evaluate nuclear fuel external costs (cf. Vaillant and Schneider, 2008). The main conclusions of its review are summarized below in sections a) and b).

a) <u>General comments</u>

Within the development of the EcoSenseWeb tool, the choice has been made to rely on the available data from the UNSCEAR 2000 report. Although the UNSCEAR report provides data which have been validated by international experts, it has to be acknowledged that the aim of these values is not focussed on a detailed assessment of the various nuclear fuel cycles. Therefore, the level of detail of the assessment of releases from the nuclear fuel cycle calculated by the EcoSenseWeb tool on the basis of UNSCEAR data is clearly lower than what was achieved within past studies (real site dependent assessment, detailed source terms, up to date knowledge regarding risk factors, discussion of the overall fuel cycle…). Such a situation is difficult to understand given the efforts in the past devoted to the development of a detailed and well documented methodology. Furthermore, the future users of the EcoSenseWeb tool may question the relevance of the methodology for the nuclear fuel cycle and the comparison between nuclear and other fuel cycles.

Its review of the EcoSenseWeb tool for the radionuclides emissions assessment has led the CEPN to formulate the following general statements which are discussed in detail in the CEPN report (Vaillant and Schneider 2008) from which this synthesis is excerpted.

1. First of all, the general comment is that the EcoSenseWeb tool leads to a significant "move back" compared to ExternE 1995 (European Commission 1995) in terms of methodology regarding the assessment of the nuclear fuel cycle external cost, especially concerning the impacts of radionuclides release. This is mainly due to the simplified approach adopted by this tool which does not allow to appropriately cope with the characteristics of the impacts associated with the nuclear fuel cycle.

2. Calculations are no more real site-related but achieved for an average site. The methodological approach for the nuclear fuel cycle is different from the one used for other technologies. The

approach is site-dependent for any facility, while for nuclear a site-dependent dispersion modelling is not implemented in the software. This is questionable: modelling tools exist for both the dispersion of radioactive gaseous and liquid releases and had been used more than 10 years ago within the ExternE EC funded program.

3. The way the calculated collective doses are distributed over time, which is of first importance as soon as discounting with discount rates larger than 0% is performed, is not clear and, as a consequence, the results of external costs assessment for the nuclear fuel cycle are questionable. With help of the rough estimates by UNSCEAR, it is possible to take temporally resolved collective doses associated with globally dispersed radionuclides into account. This was apparently considered in the meantime (as of August 2008) for the calculation of the damage costs for C-14 (released to water and air) and H-3 (released to air). Temporally resolved exposure factors for Rn-222 were also derived, however, in a way that is not fully reproducible from the provided documentation.

4. Even if justified from a quantitative point of view, the restriction to focus only on three steps of the fuel cycle (i.e., uranium mining and milling, electricity generation, and irradiated fuel reprocessing; whereas a complete evaluation was achieved within ExternE) may raise significant questions for the users, especially as the nuclear fuel cycle issue is a very sensible one. In addition, it is not completely coherent with UNSCEAR data that were used as a support for the calculations, and it will limit further investigations on various fuel cycle options, for which different steps of the fuel cycle may vary.

5. The methodology detailed in the EcoSenseWeb User's Manual is not consistent with UNSCEAR data for the global dispersion of radionuclides which are released in the sea or the river.

6. Risk factors provided from ICRP for the assessment of the radiological exposure detriment have been recently updated (see ICRP 103 report, 2007). This change leads to a decreased number of human health effects (fatal cancers and hereditary effects) associated with ionising radiation exposure, but this was not taken into account in the EcoSenseWeb tool.

7. The distribution of the radiological detriment over time (for an exposure at year T, the detriment is distributed from T to T+100 years) has apparently not been taken into account even though it is strongly recommended in order to get results consistent with other pollutants. In particular, the distribution of life expectancy losses over time is a key parameter for external cost calculations when using a discount rate higher than 0.

8. Final results are no more provided in a disaggregated way concerning space (local, regional and global scale) and time (short, medium and long term). This makes it difficult to allow a relevant analysis of the results and their associated uncertainties, as outlined above, and limits the capability of the users to put the results into perspective with the impacts associated with other fuel cycles.

These quantitative as well as qualitative statements on the EcoSenseWeb tool lead to the conclusion that the use of this tool for relevant and transparent calculations of external costs for the nuclear fuel cycle is not recommended.

b) <u>Comparison of the EcoSenseWeb approach with that of ExternE 1995 (European Commission 1995) regarding radionuclide releases</u>

The way key elements regarding the evaluation of nuclear fuel cycle external costs (source term, site location, modelling of radionuclide dispersion and associated exposures, considered health effects and their economic valuation) are taken into account in the EcoSenseWeb tool and the ExternE 1995 report (European Commission 1995) are detailed in Table 42**Fehler! Verweisquelle konnte nicht gefunden werden.** here after.

In addition to the missing elements, inconsistencies and methodological insufficiencies mentioned above, Table 42**Fehler! Verweisquelle konnte nicht gefunden werden.** clearly emphasises the gaps between the past and current methodology. All in all, the use of the EcoSenseWeb tool, as described in the user Manual V1.3 (Preiss and Klotz 2008), cannot be supported as such for the assessment of radionuclides.

Table 42: Comparison of EcoSenseWeb and ExternE 1995 approaches

Evaluation criterion	ExternE 1995	EcoSenseWeb
	Source terms	
– Comprehensiveness (e.g. stage covered, accidental and/or normal operation releases)	Clear description of the fuel cycle based on the French context (all facilities from the nuclear fuel cycle exist in France, except the HVL disposal for which calculations are based on EC research program results). Detailed radionuclides discharges have been provided by nuclear operators.	Relying on UNSCEAR 2000 data. Only 3 stages are taken into account. The level of detail of the source term is low.
o Mining / milling	COGEMA facility, Lodève, France.	UNSCEAR 2000 generic scenario
o Enrichment and fuel fabrication	COGEMA facility, Pierrelatte and Malvési.	Not taken into account
o Electricity Production	Tricastin NPP, EDF, France. The case of a severe accident is evaluated for different releases scenarios.	UNSCEAR 2000 generic scenario
o Reprocessing	COGEMA La Hague facility.	UNSCEAR 2000 generic scenario
o Waste disposal	Partly based on results from the PAGIS program for HVL disposal.	Not taken into account
– Units	$Bq.year^{-1}$	$Bq.kWh^{-1}$
– Other aspects	Transportation of radioactive material is also taken into account.	Global dispersion of radionuclides into liquid effluents (^{14}C mainly) is not considered, contrary to the UNSCEAR 2000 scheme.
	Fate analysis	
– Dispersion modelling	Modelling tools: PC CREAM for gaseous discharges, POSEIDON for liquid discharges in sea/ocean) and RIPARIA for liquid discharges (river).	See UNSCEAR Report 2000. No calculations are carried out regarding the modelling of dispersion.
– Considered radionuclides / stages of the nuclear fuel cycle		

Evaluation criterion	ExternE 1995	EcoSenseWeb
o Mining / milling	Rn 222, U 234, U 235, U 238	Pb-210, Po-210, Rn-222, Ra-226, Th-230, U-238
o Enrichment and fuel fabrication	U 234, U 235, U 238	Not taken into account
o Electricity Production	H 3, C 14, Mn 54, Co 58, Co 60, Ag 110m, Sb 124, I 131, I 133, Cs 134, Cs 137.	Emissions to Air: Noble gases (incl. Kr-85, distinguished into PWR, BWR and GCR), Iodines, Particles, Kr-85, H-3, C-14; Emissions to Water: Particles, H-3
o Reprocessing	H 3, C 14, Co 60, Kr 85, Sr 90, Ru 106, Ag 110m, Sb 125, I 129, I 131, I 133, Cs 134, Cs 137, U 238, Pu 238, Pu 239, Pu 240, Am 241, Cm 244	Emissions to Air: H-3, C-14, Kr-85, I-129, I-131, Cs-137; Emissions to Water: H-3, C-14, I-129, Cs-137
o Waste disposal	ILW: H 3, C 14, I 129 / HLW: see PAGIS study.	Not taken into account
– Underlying assumptions	Dispersion is based on a site approach (see description of the nuclear fuel cycle)	Average site approach
Exposure analysis		
– Exposure modelling	Modelling tools: PC CREAM for gaseous discharges, POSEIDON for liquid discharges in sea/ocean) and RIPARIA for liquid discharges (river). Dispersion and exposures calculations are provided by the same software tools.	UNSCEAR 2000 exposure factors.
– Considered radionuclides / stages of the nuclear fuel cycle	Detailed source terms for radionuclide emissions from nuclear operators and real sites.	Source term description based on the UNSCEAR 2000 report data. Average sites are considered.
– Underlying assumptions	Real meteorological conditions, environment, agricultural productions, inhabitant density… Exposure situations are described.	Average site approach. Evaluation based on UNSCEAR assumptions.
Impact / Risk assessment		
– Risk factors	ICRP 60 (ICRP 1991)	ICRP 60 (ICRP 1991)
– Severity measures (e.g. YOLLs)	Fatal and non-fatal cancer, severe hereditary effects. The distribution of health effects over 100 years following exposure is communicated and considered in the calculation of external costs.	YOLL associated with occurrence of a cancer, severe hereditary effects. No element regarding the distribution of YOLL over time.
– Remark	There is a need for both approaches to update the risk factors according to the ICRP 103 publication.	
Monetary valuation		

Evaluation criterion	ExternE 1995	EcoSenseWeb
– Monetary values used	VOSL 2.6 M ECU for lethal cancer and hereditary effects.	VOLY approach with a 40 000 € value.
– Endorsed discount scheme	Detailed calculations for a discount rate of 0%, 3% and 10%. Work achieved by CEPN for French operators in the 2000ies makes it possible to carry out calculations for any discount scheme.	No information regarding the use of discounting.
– Other aspects	Reporting of of health effects associated with exposures over time is done.	Reporting of health effects associated with exposures over time is not done.

Another interesting point regarding the comparison between ExternE 1995 methodology and EcoSenseWeb is the way final results are reported, as previously mentioned. The ICRP, in its 101 publication (ICRP 2006), explains that particular attention must be paid to the use of the collective dose, especially when it is used to evaluate health effects on large space and time scales. It is recommended to communicate collective doses in a temporally and spatially resolved way. This allows an easy reading and interpretation of the results and of the associated uncertainties. ExternE 1995 (European Commission 1995) provides such a scheme for the reporting of external cost calculation results. As an example, results from the ExternE program are provided in Table 43**Fehler! Verweisquelle konnte nicht gefunden werden.** (for a discount rate of 0%). Such a detailed reporting is not output by the EcoSenseWeb tool as results are only provided distinguished into the regional and global scale.

Table 43: Nuclear fuel cycle external costs (source: taken from ExternE 95)

DR 0%	Short term			Medium term			Long term			Sub-total
m€/kWh	Local	Regional	Global	Local	Regional	Global	Local	Regional	Global	
Mining and Milling	$1.48\ 10^{-2}$	0	0	$3.23\ 10^{-2}$	$1.69\ 10^{-2}$	$1.94\ 10^{-5}$	$3.15\ 10^{-4}$	$1.82\ 10^{-4}$	0	$6.45\ 10^{-2}$
Conversion	$6.25\ 10^{-4}$	0	0	$3.43\ 10^{-4}$	$3.20\ 10^{-7}$	$1.77\ 10^{-7}$	$4.17\ 10^{-6}$	$1.54\ 10^{-6}$	0	$9.74\ 10^{-4}$
Enrichment	$1.18\ 10^{-3}$	0	0	$1.46\ 10^{-6}$	$1.00\ 10^{-7}$	$7.25\ 10^{-8}$	$3.91\ 10^{-6}$	$6.94\ 10^{-7}$	0	$1.19\ 10^{-3}$
Fuel fabrication	$8.19\ 10^{-4}$	0	0	$1.07\ 10^{-3}$	$1.63\ 10^{-6}$	$9.64\ 10^{-10}$	$6.22\ 10^{-8}$	$1.09\ 10^{-8}$	0	$1.89\ 10^{-3}$
Electricity generation										
Construction	$3.37\ 10^{-2}$	0	0	0	0	0	0	0	0	$3.37\ 10^{-2}$
Operation	$1.31\ 10^{-2}$	0	0	$5.28\ 10^{-2}$	$3.19\ 10^{-3}$	$2.77\ 10^{-2}$	$1.23\ 10^{-8}$	$2.25\ 10^{-9}$	$3.19\ 10^{-1}$	$4.16\ 10^{-1}$
Dismantling	0	0	0	$1.70\ 10^{-2}$	0	0	0	0	0	$1.70\ 10^{-2}$
Reprocessing	$2.96\ 10^{-3}$	0	0	$2.98\ 10^{-4}$	$9.63\ 10^{-3}$	$1.60\ 10^{-1}$	$3.45\ 10^{-6}$	$1.67\ 10^{-3}$	1.74	1.92
Low Level Waste disposal	-	0	0	$1.50\ 10^{-5}$	0	$1.24\ 10^{-4}$	$2.36\ 10^{-6}$	0	$4.66\ 10^{-3}$	$4.80\ 10^{-3}$
High Level Waste disposal	-	0	0	$8.98\ 10^{-8}$	0	0	$2.54\ 10^{-2}$	0	0	$2.54\ 10^{-2}$
Transportation	$3.55\ 10^{-4}$	0	0	$4.24\ 10^{-4}$	0	0	0	0	0	$7.79\ 10^{-4}$
Sub-total	$6.75\ 10^{-2}$	0	0	$1.04\ 10^{-1}$	$2.97\ 10^{-2}$	$1.88\ 10^{-1}$	$2.57\ 10^{-2}$	$1.86\ 10^{-3}$	2.06	2.48

A.2.3 Comments on the calculation of the external cost for radionuclide emissions by means of unit damage or unit external costs

Within the NEEDS project, external costs of the nuclear fuel cycle are calculated with unit external costs, i.e. external cost values per released Bq, which are used for any site and any fuel cycle stage. This section provides an advice on the calculation and use of these unit external costs.

In line with the UNSCEAR values, EcoSenseWeb uses fuel cycle stage-specific exposure factors. This approach has been discussed above. During the calculation of external costs per power plant in the frame of NEEDS RS1a, unit external costs are used that do not distinguish between fuel cycle stages. As UNSCEAR does not provide aggregated exposure factors and no corresponding documentation was provided by IER, it was tried to trace back how this aggregation was done (cf. Table 44).

The currently proposed set of unit external costs for radionuclides does not only rely upon an approach that takes UNSCEAR exposure and ICRP risk factors into account. Some of the unit external costs are based on the Life Cycle Impact Assessment (LCIA) approaches EcoIndicator 99 and Impact2002+, known to LCA practitioners. This concerns unit external costs for the radionuclides I-133 and U-235 released to air as well as I-131, U-234, U-235 and U-238 released to water. How their unit external costs were derived is however documented in a way that is far from understandable. In addition, these LCIA methods need to be classified as even less reliable than the UNSCEAR/ICRP approach as regards radionuclide risk assessments. Not taking these non-UNSCEAR/ICRP unit external costs into account, however, does not have a noticeable impact on the quantifiable external costs (below 0.01 % of change).

According to the statements made on EcoSenseWeb, it is already clear that a more detailed approach than the one taken within the EcoSenseWeb tool would be valuable for radionuclides as it provides not only more flexibility for the use and the interpretation of the final results, but also more transparency on how these results are obtained. The use of a “more” aggregated approach (i.e. the unit damage or unit external costs) is thus seen as an even more questionable approach (from a qualitative point of view).

In addition, as detailed above, quantitative values provided by the EcoSenseWeb tool not complying with current state-of-the-art, and as fuel-cycle stage-independent values from RS1b are based, for the nuclear part, on the EcoSenseWeb methodology, related external costs are not reliable. The same comments as on the EcoSenseWeb methodology also apply to any calculations carried out with the unit external costs as provided by RS1b.

Table 44: Comparison of exposure factors as used during the calculation of unit external costs and within EcoSenseWeb for radionuclide emissions into air and water [manSv/PBq] (only radionuclides considered for which exposure factors by UNSCEAR have been available)

	Approach					
	Unit external costs	**EcoSenseWeb**				
Fuel cycle stage	**Generic**	**Mining & Milling**	**Generation**		**Reprocessing**	
Scale	**Generic**	**Generic**	**Local & regional**	**Global**	**Local & regional**	**Global**
Releases into air						
Noble gases, incl. Kr-85 (PWR)			0.11			
Noble gases, incl. Kr-85 (BWR)	0.43		0.43			
Noble gases, incl. Kr-85 (GCR)			0.9			
I-129	64000				44000	20000
Iodines (expressed in terms of I-131)	20300		300	20000		
I-131	see above				300	
Particles	2000		2000			
Kr-85	0.214		0.014	0.2	0.0074	0.2
H-3	4.1		2.1	2.0	2.1	2.0
C-14	92270		270	92000	270	92000
Cs-137	7400				7400	
Pb-210	1000	1000				
Po-210	1000	1000				
Rn-222	2.5	2.5				
Ra-226	600	600				
Th-230	30000	30000				
U-238	7000	7000				
U-234	8000	8000				
Releases into water						
Particles			330			
H-3	0.85		0.65	0.2	0.0014	0.2
C-14	1000				1000	
I-129					99	
Cs-137	98				98	
Sr-90	4.7				4.7	
Ru-106	3.3				3.3	