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Evaluation of Weighting Methods for Measuring the EU-27 Overall Environmental Impact

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Summary

Background

The EU Thematic Strategy on the Sustainable Use of Natural Resources (COM(2005)670)[1] establishes the main policy context for the weighting method, which is here further elaborated. Three sets of decoupling indicators have been developed[2], which require the definition of an indicator that represents the EU 27 overall environmental impact. Methodologically, this has been achieved through a weighting procedure across a comprehensive range of indicators for different environmental impact categories.

The list of recommended environmental impact categories is provided by the International Reference Life Cycle Data System (ILCD) Handbook[3]. The ILCD Handbook also gives recommendations on the associated environmental impact assessment models and factors.

The setup for arriving at an overall judgment starts with a large number of environmental interventions, covering emissions, extraction of resources and land use. These correspond to the Life Cycle Inventory (LCI) results of a Life Cycle Assessment (LCA). Next, relatively simple and stable models link this large number of interventions to a much smaller number of midpoint effects, like radiative forcing in the context of climate change, primary resources depletion, and acidification. Ultimately, there are effects which are directly important for judgment: health effects, effects on the natural environment, and effects on human welfare. These ultimate endpoint effects can be much more difficult to model and interpret.

Approaches to overall judgment

The weighting methods can be grouped into three main categories: **midpoint methods**, **endpoint methods**, and **integrated methods**.

The panel based **midpoint** weighting refers to midpoint indicators like radiative forcing in the context of climate change, usually presented in terms of carbon dioxide (CO_2) equivalents. Assumptions on further empirical effects towards endpoint effects and their evaluation are combined in one step, starting with a normalisation at midpoint level.

Next, there are models which link interventions to **endpoints**, as in terms of e.g. health effects and biodiversity, in a Life Cycle Impact Assessment (LCIA) framework. These endpoints are subsequently evaluated through a weighting step.

The **integrated** methods are developed by economists. Two domains have been developed for the economic methods, both based on willingness-to-pay (WtP) as estimated through general panel procedures. One domain is the health effects of emissions to air (most detailed available in the NEEDS project). The other domain is the extensive literature on the economic consequences of emissions of greenhouse gases. These economic approaches have been unified into one method of economic valuation, covering as broad a spectrum of environmental interventions as possible.

[1] http://ec.europa.eu/environment/natres/index.htm

[2] For continuously updated information please visit http://lct.jrc.ec.europa.eu/assessment/projects

[3] European Commission - Joint Research Centre - Institute for Environment and Sustainability. International Reference Life Cycle Data System (ILCD) Handbook - Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context. Publications Office of the European Union; in publication, 2011. Will be available online at http://lct.jrc.ec.europa.eu/assessment/projects

As these different approaches all have their strengths and weaknesses, they all have been covered in the project and are also combined in an overall approach to weighting.

Methods selected

There are several operational weighting methods available, globally covering the three main approaches to weighting. Most of these methods are not covering all effects, and often are not fully consistent with the overall aim of weighting. For this project, seven weighting methods have been selected: four from Europe (NOGEPA, EcoIndicator99, ReCiPe-damage cost, and NEEDS); two from the US (BEES and EPA); and one from Japan (LIME)[4].

All weighting sets applied on midpoint level refer to interactive panel weighting, i.e. EPA, BEES, and NOGEPA. Two weighting sets applied on endpoint level refer to panel weighting, i.e. Ecoindicator99 and LIME. One weighting set, ReCiPe-damage, refers to weighting on endpoint level using damage cost based on willingness-to-pay (WtP) valuation. The weighting set in the integrated modelling and weighting refers to different types of costs. These are damage costs for human health, climate change, based on WtP, but as market prices for crop damages due to acidification and eutrophication. Different again, these are restoration costs for biodiversity (WtP) and for damages to buildings (market prices).

In case of missing data, the methods were completed by methods transfer, mostly using the ILCD framework for impact assessment. In case of lack of consistency, they were adapted where possible, especially by replacing cost data with WtP based data.

Pros and cons of methods

The three groups of methods each have their relative strengths and weaknesses. Weaknesses were mostly related to the limited options for prediction of future impacts.

In general, the midpoint evaluation has the most robust modelling, but only to midpoint level. Endpoint models are based on midpoint models, thus they add extra uncertainty on top of the uncertainty already affecting midpoint evaluations by modelling further to the endpoints, whilst also providing additional information. This can reduce the need to use social/economic values to cross-compare impacts at the end-point level, such as in terms of human health, ecosystem impacts, etc.

Open solution: seven sets of weights combined

It seems that neither there is one right method, nor that one single method would be generally accepted.

A more open solution has been chosen, which takes into consideration the different approaches and methods, but not leaving all choices open. ***The seven most broadly applicable and consistent methods (listed above) have not just been chosen. Each of them has been made as consistent as possible and has been expanded so as to apply to the same broad set of environmental interventions and impact categories covered***.

[4] For an in-depth analysis of existing weighting approaches please refer to the CML/JRC background report “Technical review of existing weighting approaches in life cycle impact assessment”.

Though fundamentally different in their structure, the three approaches thus are directly comparable in their results. Also, by using the same methods of data normalisation, they can be adapted easily to new sets of data becoming available.

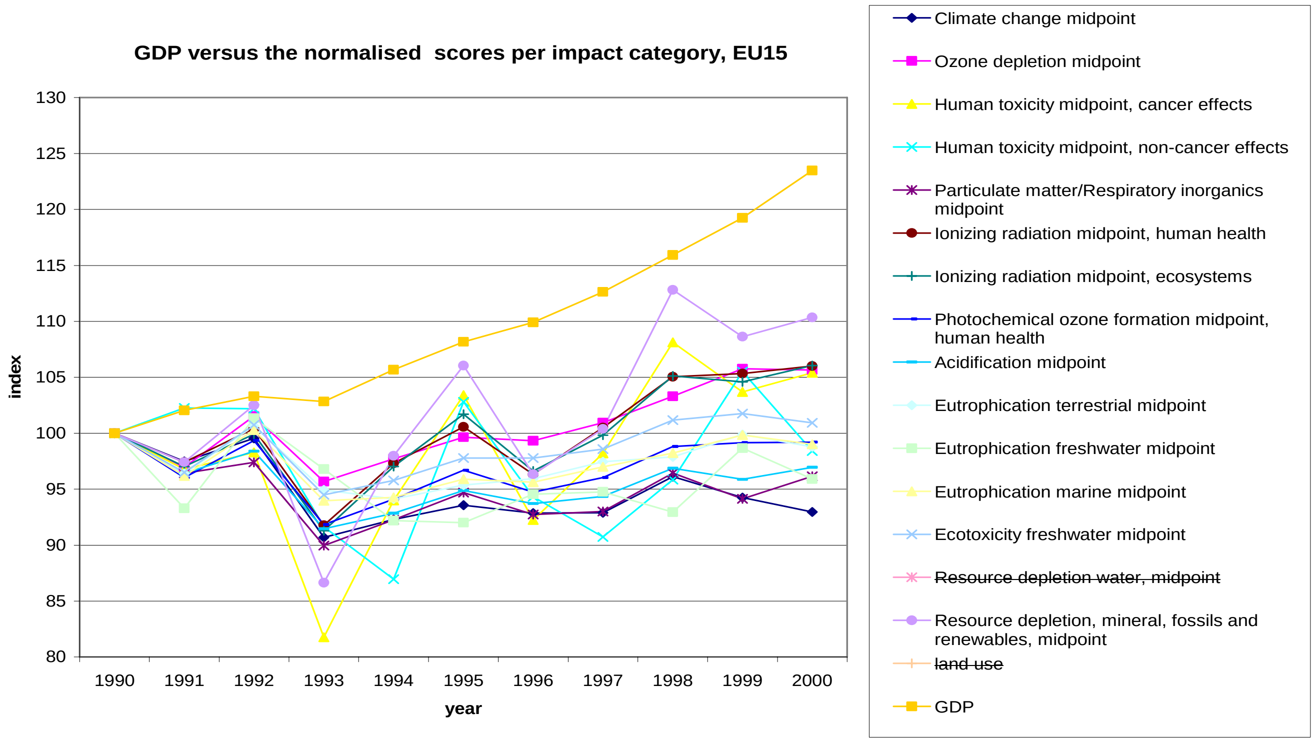
Example of application using EU data

The combined weighting method has been applied to a data set with time series for the EU covering a broad set of environmental interventions. As a complete life cycle inventory time series is not available, an example set close to the goal for the EU15 has been chosen, namely the environmentally weighted material consumption (EMC) (Voet et al., 2009; Voet et al., 2005). EMC builds on data based on material-use combined with LCA-based process data. The outcomes (see graphs), therefore, are exemplary.

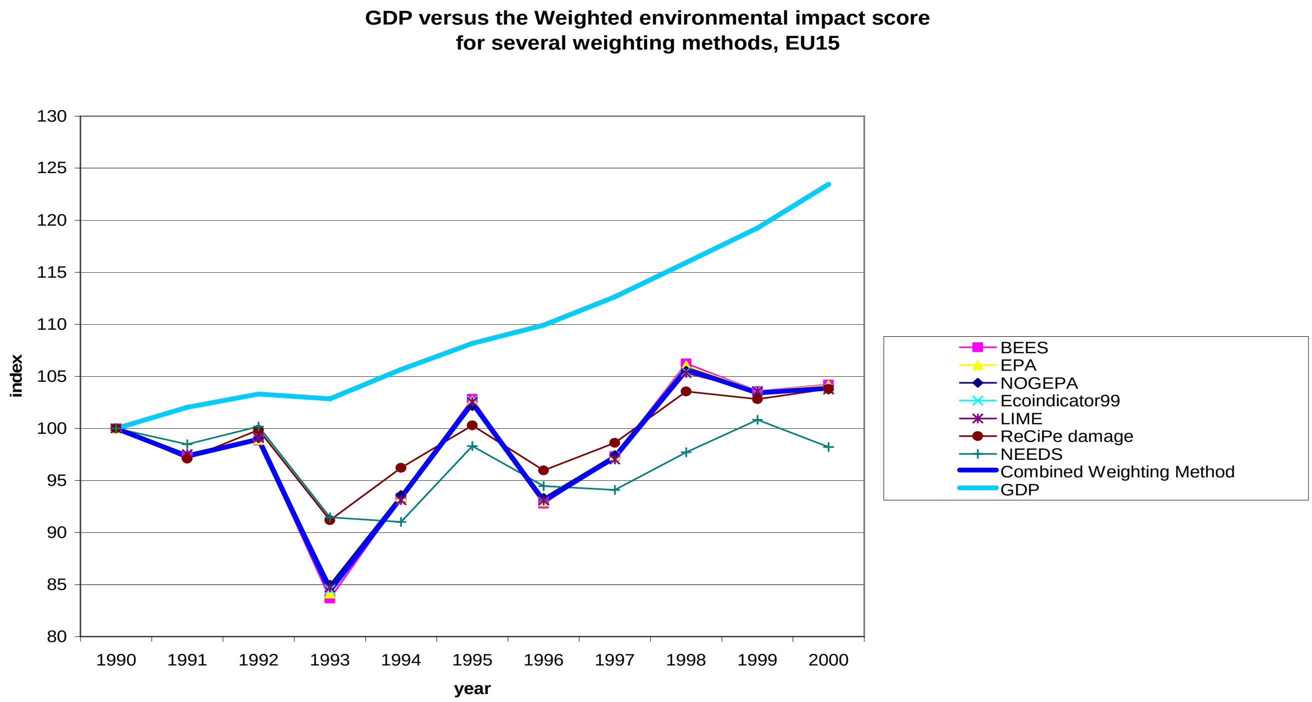
The first graph depicts the scores for the midpoint impact categories. These show quite some variation in their development, hence requiring weighting for arriving at an overall view regarding decoupling. The second graph provides the weighted score per method, and the combined score, the meta-weighting set score, in dark blue. Most striking is the fact that ***methods from such diverse evaluation backgrounds and with such different modelling involved still converge significantly***. There must exist an underlying convergence mechanism which leads to this result, as for example by leaving out outliers with reference to ‘all other methods’. However, it should be noted that the observed convergence may also be linked to some of the adaptations and extrapolations across methods made in this project.

Flexible tool for weighting

To allow for easy application, and for easy adaptation to new developments, the weighting procedure has been implemented in a spreadsheet. The user can easily adapt the contribution of the different weighting sets to the combined result. By setting one method at 100%, the weighting is carried out by only that method.



Striked-through impact categories were not operationally available in the ILCD impact category set at the time of developing of this project (year 2009)[5].



[5] European Commission - Joint Research Centre - Institute for Environment and Sustainability. International Reference Life Cycle Data System (ILCD) Handbook - Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context. Publications Office of the European Union; in publication, 2011. Will be available online at http://lct.jrc.ec.europa.eu/assessment/projects

Conclusion

All weighting methods have specific advantages and disadvantages, on which diverging views exist.

Midpoint approaches have a relatively clear modelling basis, albeit with some mutually inconsistent elements. They rely on explicit subjective estimates in the combined further-modelling-and weighting step. Endpoint models can have a weak modelling step after the midpoint and then are conceptually similar to the valuation step in the economics oriented integrated modelling and weighting. The integrated modelling approach has some strong points in modelling, but is weak in other domains. The valuation step of this approach is best specified, based on thoroughly tried but not undisputed methods.

The transparent use of the Combined Method may be one solution where opposed pros and cons of the three main weighting approaches – and different views on them - are accepted, one method possibly compensating for the deficiencies in other ones. The method is available as a spreadsheet for application in specific studies, and may be linked to modelling software. The results using different methods can equally be compared in a sensitivity analysis.

Contents

1 Selection of three major approaches for weighting of environmental impacts

1.1 Introduction to characterisation, normalisation and weighting in Life Cycle Assessment

In Life Cycle Assessment (LCA), the number of environmental interventions (i.e. emissions and resource extractions), related to a case study is referred to as an inventory list, or Life Cycle Inventory (LCI). By the procedure of **characterisation**, the interventions are aggregated into a limited number of impact category indicators or, simply, impact indicators (more info on the phase of characterisation is provided in chapter 5.1).

These impact category indicators may be midpoint indicators or endpoint indicators. The midpoint impact indicators are, the so called “environmental problems”, like climate change, ozone layer depletion or acidification. For the endpoint impact indicators, these ‘environmental problems’ are further aggregated. Endpoint impact indicators typically express indicators at the level of three Areas of Protection (AoP):

- human health,
- natural environment, and
- natural resources.

There may be more than one endpoint indicator for a given AoP, such as indicators for mortality and morbidity for human health. In this project, the characterisation of emissions and extractions is based ILCD recommended set of impact categories and associated characterisation factors that are used to calculate the indicators from the inventory[6].

The results of the characterisation phase, the impact indicators, are still hard to interpret. The scores for the different impact indicators are expressed in different units and cannot be directly compared. As a first step towards facilitating the interpretation of results in LCA, a **normalization** procedure is often used (more info on the phase of normalisation is provided in chapter 5.2). If the environmental impact assessment is to include a weighting across impact indicators into one overall environmental impact score, normalization is a necessary step in case panel weighting is used (e.g. BEES, NOGEPA, Ecoindicator99, LIME (dimensionless set)). In case the weighting is based on monetized valuation of damages, the normalization

[6] Spreadsheet with characterisation factors, version 3.1 and 3.2, as of February 2010. This set was not yet complete at the time of development of this report. Characterisation factors for water depletion and land use are missing.

is technically possible but not necessary (e.g. ReCiPe damage cost, NEEDS/EXIOPOL). It would lead to a dimensionless score instead of a score in monetary terms.

Therefore, after normalization for each impact indicators the normalized score of the evaluated system is obtained. This normalized score expresses the contribution of the evaluated system relative to the same indicators for a specified region, in this case the total world economy. Thus, for each of the impact indicators the result is expressed as a fraction of contribution to the total world problem. It could equally be further expressed in e.g. person equivalents by dividing by the population. For this normalisation purpose at a world scale, information is needed on the total of extractions and emissions in the world. These data are taken here from a recent normalization study (Wegener Sleeswijk *et al*., 2008). The reference situation refers to the extractions and emissions by the world society in the year 2000[7].

For the final **weighting** across impact indicators, three different approaches are selected (as from figure 1-1):

- midpoint modelling and evaluation;
- endpoint modelling and evaluation;
- integrated modelling and evaluation.

Only the midpoint and endpoint weighting methods are fully compatible with the recommended ILCD characterization factors that are considered in this project for the calculation of impact indicators[8]. The integrated modelling and evaluation approach, as in the NEEDS method, is not compatible with the ILCD characterization factors. Emissions are modelled to monetized endpoint values using economic models and evaluation.

1.2 Weighting approaches considered in this project: an overview

A preceding report "Background review of existing weighting approaches in Life Cycle Impact Assessment" surveyed methods that link detailed environmental interventions to an evaluation of the overall environmental performance.

[7] The accompanying spreadsheet can be downloaded at: http://www.leidenuniv.nl/cml/ssp/download/IES_weighting_D2_methods_applied_on_EU28_world_NL_2000+timeserie_extended_version_NEW_version_ILCD.zip

[8] Spreadsheet with characterisation factors, version 3.1 and 3.2, as of February 2010. This set was not yet complete at the time of development of this report. Characterisation factors for water depletion and land use are missing.

The several methods surveyed can be grouped in three major approaches (figure 1-1). These approaches are based on different modelling procedures and different assumptions; however, all of them translate a given set of environmental interventions into an overall weighted score.

- ***Midpoint modelling and evaluation***. This midpoint weighting method refers to midpoints like climate change and acidification. Here, assumptions on further empirical effects towards endpoints and their evaluation are combined in one step.
- ***Endpoint modelling and evaluation***. This method converts interventions into damages at endpoint levels. These endpoints, as in terms of damages to human health and biodiversity, are subsequently evaluated in a weighting step to aggregate these endpoint scores.
- ***Integrated modelling and evaluation***. This method is developed by economists thus, compared to the previous methods, builds upon a different, yet very relevant domain. The economic method is based on willingness-to-pay (WtP), as estimated through general panel procedures. A number of different economic approaches exist, covering different types of environmental interventions. These economic approaches have been unified into one method of economic valuation, covering as broad a spectre of environmental interventions as possible.

All three approaches bring their own advantages and disadvantages. In overall weighting, a single best method does not exist. Also, all methods have practical deficiencies: completeness as to interventions covered; modelling uncertainties; the mechanisms covered in modelling of effects; the dimensions of effects as modelled may differ substantially amongst different studies. Marginal effects will depend on assumptions for background emissions.

For a given method, there is not one best set of weights. Different authors come up with different levels in economic valuation; different panels will come up with different sets of panel weights. Also, one may argue that future weights may or should differ from current weights.

This being said, it is necessary to take the step from academic discussion to an operational method that properly reflects the different best practices available, as a meta-level best practice[9].

For each of these three major approaches several operational methods are available, though not always covering all environmental interventions.

[9] All base information on impact assessment modelling and weighting is digitally available, including the data for case applications. See the spreadsheet with characterisation, normalisation and weighting factors at:
http://www.leidenuniv.nl/cml/ssp/download/IES_weighting_D2_methods_applied_on_EU28_world_NL_2000+timeserie_extended_version_NEW_version_ILCD.zip

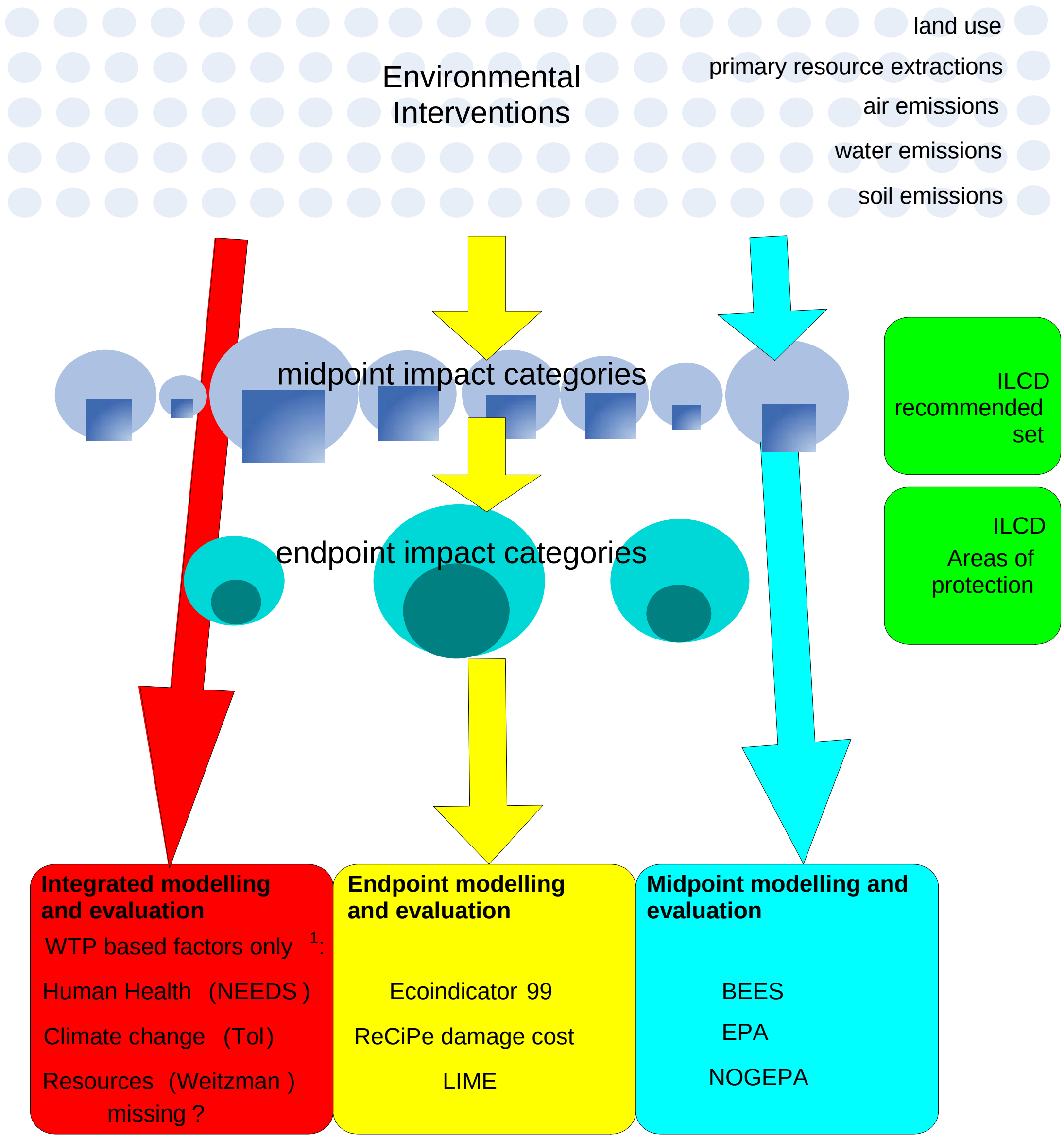


Figure 1-1: Overview of main characterization and weighting approaches and methods

1.3 Midpoint with subjective assessment of endpoints and weights

Table 1-1 presents three weighting sets based on a panel procedure. The original weighting factors are given for 9 to 13 midpoint impact categories, depending on the method.

Table 1-1: Original weighting factors of three panel weighting sets

ILCD recommended midpoint impact categories	**Impact category on midpoint level**	**Panel weighting set**		
		EPA Science Advisory Board[10]	**BEES Stake-holder Panel**[11]	**NOGE PA**[12]
		%	%	%
Climate change	Climate change	16	29	32
Ozone depletion	Ozone depletion	5	2	5
Acidification	Acidification	5	3	6
	Eutrophication	5	6	13
Eutrophication, terrestrial				
Eutrophication, fresh water				
Photochemical ozone formation	Photochemical ozone formation	6	4	8
	Human health ((non)cancerous)	11		16
Human toxicity – cancer effects	Human health cancerous		8	
Human toxicity - non-cancer effects	Human health non-cancerous		5	
Particulate matter / Respiratory inorganics	Human health criteria pollutants	6	9	
	Ecotoxicity	11	7	
Ecotoxicity – fresh water	Fresh water ecotoxicity			6
	Marine ecotoxicity			8
	Terrestrial ecotoxicity			5
Ionizing radiation, human health effects				
Ionizing radiation, ecosystems				
Resource depletion (mineral, fossil and renewable)				
	resource depletion (fossil fuel)	5	10	
Resource depletion water	Water intake	3	8	
	Indoor air quality	11	3	
Land use	Habitat alteration	16	6	
	Total	**100**	**100**	**100**

The midpoint impact categories to a large extent comply with the midpoint impact categories recommended by the ILCD Handbook[13,14]. However, some adaptations

10 Lippiatt, 2007
11 Lippiatt, 2007
12 Huppes *et al.,* 2007
13 Version 3.1 and 3.2, d.d. 01 February 2010 of the ILCD characterisation set is not complete yet. Characterisation factors for water depletion and land use are missing.
14 European Commission - Joint Research Centre - Institute for Environment and Sustainability. International Reference Life Cycle Data System (ILCD) Handbook - Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context. Publications Office of the European Union; in publication, 2011. Will be available online at http://lct.jrc.ec.europa.eu/assessment/projects

and additions were necessary to fully comply with the ILCD recommended midpoint impact categories. These adaptations are discussed in section 4.

1.4 Midpoints with formalised modelling to endpoints and endpoint weights

Table 1-2a presents the endpoint impact categories and Areas of Protection as included in the ILCD recommended impact assessment.

Table 1-2a: Endpoint impact categories and Areas of Protection in the draft ILCD recommended impact assessment [15].

ILCD recommended endpoint impact categories	Impact indicator (unit)	Area of Protection
Climate change endpoint	DALY[16] (yr)	Human health
Ozone depletion endpoint	DALY (yr)	Human health
Human toxicity cancerous endpoint	DALY (yr)	Human health
Human toxicity non-cancerous endpoint	DALY (yr)	Human health
Particulate matter/Respiratory inorganics endpoint	DALY (yr)	Human health
Ionizing radiation endpoint	DALY (yr)	Human health
Photochemical ozone formation endpoint	DALY (yr)	Human health
Climate change endpoint	PDF[17] (-)	Natural environment
Acidification endpoint	AE or PDF (-)	Natural environment
Eutrophication freshwater endpoint	PDF (-)	Natural environment
Ecotoxicity freshwater endpoint	PDF.volume.time (m3.year)	Natural environment
Ionizing radiation endpoint	PDF.volume.time (m3.year)	Natural environment
Resource depletion endpoints	$	Resources
Resource depletion water endpoints	unknown (unknown)	unknown (unknown)
Land use	Unknown (unknown)	unknown (unknown)

Table 2-2a presents that the unit in which the score of a given impact category is expressed is not always clear. In the 2010 draft version of the recommended ILCD set of characterisation factors for the AoP "Natural environment", there are five endpoint impact category indicators, which are expressed partly in different units, hence with different dimensions[18]. For example, for the endpoint impact category *climate change,* the dimension is DALY or PDF; for *acidification* it is AE or PDF and for *fresh water ecotoxicity*", it is PDF.volume.time. As these dimensions differ, the Natural environment endpoint scores cannot be directly added up to one score. Therefore, a conversion factor is necessary to translate the impact category indicators scores into to the same unit. Furthermore, to combine the indicators scores

[15] This table refers to the ILCD Handbook as of February 2010 draft. For up-to-date information please refer to: European Commission - Joint Research Centre - Institute for Environment and Sustainability. International Reference Life Cycle Data System (ILCD) Handbook - Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context. Publications Office of the European Union; in publication, 2011. Will be available online at http://lct.jrc.ec.europa.eu/assessment/projects

[16] Disability Adjusted Life Year (DALY)

[17] Potentially Disappeared Fraction (PDF) of species

[18] For up-to-date info, please refer to the above mentioned ILCD Handbook document.

with the weighting factors of ReCiPe damage (Heijungs, 2007) the indicators should be expressed in PDF.time (unit: yr). This dimension issue could not now be resolved adequately.

In the context of this project it was chosen to convert the indicators and units as reported in the ILCD spreadsheet[19] to the indicator PDF.time (unit: yr). This conversion is disputable, but necessary to generate weighted impact scores. Hence, the fate modelling from midpoint-like indicators to endpoint indicators and the fine tuning of indicators should be further developed. However, this modelling is not part of this project.

Table 1-2b: Conversion factors for ILCD impact indicators to PDF.time.

ILCD recommended endpoint impact categories	**Impact indicator (unit)**	**Area of Protection**	**conversion factors**	
			multiplier	**divider**
			year	**m^3**
Climate change endpoint	PDF (-)	Natural environment	1	1
Acidification endpoint	AE or PDF (-)	Natural environment	1	1
Eutrophication freshwater endpoint	PDF (-)	Natural environment	1	1
Ecotoxicity freshwater endpoint	PDF.volume.time (m3.year)	Natural environment	1	1.25E+14
Ionizing radiation endpoint	PDF.volume.time (m3.year)	Natural environment	1	1.25E+14

Table 1-2b provides the conversion factors that are used to translate the ILCD impact indicators to the indicator PDF.time. It is assumed that the indicators for climate change, acidification, eutrophication are already expressed in the appropriate indicator: PDF.time. Thus, the indicators AE and PDF are assumed to be mistakenly reported in the ILCD spreadsheet[20]. To translate the indicator for ecotoxicity (PDF.volume.time) the indicator score is divided by the total amount of fresh water available on the earth (Harte, 1988).

Table 1-3 presents three weighting sets for the weighting of endpoint impact categories that are distinguished in 3 to 4 Areas of Protection.

[19] 2010 draft version
[20] 2010 draft version

Table 1-3a: Weighting factors for Ecoindicator99 (in EcoIndicator 99 the hierarchist weighting set is recommended) (Goedkoop & Spriensma, 1999)

Endpoint	indicator	unit	Weighting factor				unit
			average	individualist	egalitarian	**hierarchist**	
Human health	DALY	yr	0.4	0.55	0.3	**0.3**	dimensionless
Ecosystem quality	PDF	% plant species m2.yr	0.4	0.25	0.5	**0.4**	dimensionless
Resources	Surplus energy	MJ surplus energy	0.2	0.2	0.2	**0.3**	dimensionless

Table 1-3b: Weighting factors for LIME (Itsubo *et al.*, 2004)

Endpoint (LIME)	indicator	unit	weighting factor	unit	weighting factor	Endpoint (ILCD)
Human health	DALY	yr	0.33	dimensionless	**0.33**	Human health
Ecosystem quality (biodiversity)	EINES	extinct number of species	0.28	dimensionless	**0.52**[21]	Natural environment
Primary production	NPP (net primary production)[22]	Dry-ton	0.25	dimensionless		
Social assets	social cost	JY	0.14	dimensionless	**0.14**	Resources

Table 1-3c: Weighting factors for ReCiPe damage cost (Heijungs, 2008)

Endpoint	indicator	unit	Weighting factor	Unit
Human health	DALY	yr	**60000**	$/yr
Ecosystem quality (biodiversity)	PDF*time	yr	**1.75E+11**	$/yr
Resource availability	Surplus cost	$	**1**	$/$

[21] Both endpoints, ecosystem quality and primary production, refer to the AoP natural environment and, in this report, the weighting factors have been aggregated to one weight

[22] Net primary production together with ecosystem quality refers to the AoP Ecosystem Health and thus both weighting factors are assigned to the AoP "Natural Environment" of the ILCD recommended impact assessment.

1.5 Integrated intervention-to-weighted-endpoint modelling, monetised

For the weighting method “integrated modelling and evaluation” only the value sets that are based on willingness-to-pay (WtP) are used here. Thus, values based on restoration cost, as for losses of biodiversity and damages to economic assets (materials and crops), are excluded.

Table 1-4 presents the external cost for several emissions and extractions based on NEEDS (Preiss, Friedrich & Klotz, 2008)[23] and Weitzman (1999). For Climate change, Tol’s approach (2006) is being considered as used in NEEDS (a revised journal publication is Tol, 2008). Tol specifies a large number of studies, with widely diverging outcomes, but converging central values. However, the damage costs as presented for climate change refer to the marginal damage of the central two degrees Celsius scenario, not to less probable, but more severe outcomes. A development initiated by Weitzman (2009) indicates that such values underestimate the expected damage by up to orders of magnitude. We took a modest adaptation of the NEEDS values, bringing them in the range considered relevant in the Stern Report and accidentally also in the same range as the value which Tol describes as the 99% boundary on the outcomes, that is the 1% chance that the actual damage will be higher. One order of magnitude adaptation brings the value up to 60 Euro per ton of carbon dioxide. This value, and values derived from it are used in the meta-weighting method.

In NEEDS, external costs are available for a limited number of air emissions and emissions of radionuclides to air and water. External costs for depletion of resources and water and costs for restoration of land use are missing. Also important pathways seem to be missing, like loss of biodiversity due to ecotoxic substances. To assess the external cost related to the depletion of non-renewable resources the marginal costs are used as presented by Weitzman (1999).

[23] The costs presented in the table represent damage costs for EU27 average. In NEEDS, country specific data are available. Height of release of emission is assumed to be unknown. Emissions are assumed to be released in 2000. Costs are discounted back to 2000, using 3% (till 2030) and 2% (2030-2300) For Greenhouse Gas emissions three scenarios are used to derive costs. It is recommended to use all three, lower, central and upper values, for sensitivity analysis: 1) Marginal Damage Cost, 2) Marginal Avoidance Cost_ more realistic, 3) Marginal Avoidance Cost _ambitious. For emissions in the year 2000 scenario 2 and 3 generate the same costs.

Table 1-4: External Costs - NPV in 2000 (average EU27) - for emissions in the year 2000 (Preiss *et al.*, 2008)

substance	Compartment	*costs (average EU27)*										
		Human Health	Loss of Biodiversity	Crops: Regional: crops N deposition & crops O3	Crops: SO2	Materials: SO2&Nox	Results from the North Hemispheric modelling	Radionuclide	Climate change (NEEDS adapted)	Climate change (NEEDS)	Climate change (NEEDS)	resources
									marginal damage cost	marginal damage cost	marginal avoidance cost	
		euro/kg	euro/kg	euro/kg	euro/kg	euro/kg	euro/kg	euro/kBq	euro/kg	euro/kg	euro/kg	euro/kg (euro/MJ for fuels)
2,3,7,8-tetrachlorodibenzo-p-dioxin	Air	3.70E+07										
ammonia	Air	9.48	3.41	-0.18			2.71E-03					
arsenic	Air	530										
cadmium	Air	84										
carbon dioxide	Air								6.00E-02	6.00E-03	1.57E-02	
carbon-14	Air							1.40E-03				
cesium-137	Air							9.53E-04				
chromium	Air	13										
chromium III	Air	13										
chromium VI	Air	66										
formaldehyde	Air	0.20										
hydrogen-3	Air							5.10E-07				
iodine-129	Air							8.24E-03				
iodine-131	Air							2.61E-03				
iodine-133	Air							3.76E-07				
krypton-85	Air							2.75E-08				
lead	Air	278										
lead-210	Air							1.29E-04				
mercury	Air	8,000										
methane	Air								2.63	2.62E-01	3.61E-01	
nickel	Air	2.30										
nitrogen dioxide	Air	5.59	0.94	0.33		7.07E-02	0.130986571					
nitrous oxide	Air								101.9	10.19	4.65	
NMVOC	Air	0.58	-0.07	0.19			0.36					

particles (PM10)	Air	1.32					0.002092477					
particles (PM2.5)	Air	24.41					0.157714668					
polonium-210	Air							1.29E-04				
radium-226	Air							7.72E-05				
radon-222	Air							1.45E-08				
sulfur dioxide	Air	6.07	0.18	-0.03	-1.E-02	2.59E-01	0.278179611					
sulfur hexafluoride	Air								5.1	0.51		
thorium-230	Air							3.86E-03				
uranium-234	Air							1.03E-03				
uranium-235	Air							8.40E-04				
uranium-238	Air							9.01E-04				
carbon-14	water							9.38E-06				
cesium-137	water							1.26E-05				
cesium-137	water							1.26E-05				
hydrogen-3	water							1.09E-07				
hydrogen-3	water							1.09E-07				
iodine-131	water							8.17E-03				
strontium-90	water							6.05E-07				
uranium-234	water							2.55E-05				
uranium-234	water							2.55E-05				
uranium-235	water							9.20E-05				
uranium-235	water							9.20E-05				
uranium-238	water							2.53E-04				
uranium-238	water							2.53E-04				
aluminium	Resource											6.28E-02
brown coal; 11.9 MJ/kg	Resource											1.04E-04
copper	Resource											7.32E-01
crude oil; 42.3 MJ/kg	Resource											1.03E-03
gold	Resource											1.18E+03
hard coal; 26.3 MJ/kg	Resource											2.18E-04
iron	Resource											2.00E-02
lead	Resource											1.62E-02
natural gas; 44.1 MJ/kg	Resource											9.11E-04
nickel	Resource											8.05E-01
silver	Resource											3.11E+01
tin	Resource											9.45E-01
zinc	Resource											1.07E-01

2 Expanding the coverage of methods to the required level

2.1 Expanding to the ILCD impact categories

2.1.1 Expanding to the midpoints covered

The midpoint impact categories to a large extent comply with the midpoint impact categories as from the recommended in ILCD[24]. However, some adaptations and additions are necessary to fully comply with the ILCD.

Some operational weighting sets miss weighting factors for some of the draft ILCD recommended impact categories. For example, on the midpoint level the NOGEPA weighting set does not cover ionizing radiation, land use and (abiotic) resource depletion. The BEES weighting set lacks weighting factors for ionizing radiation.

On the other hand, also weighting factors might be available for impact categories that are not part of the recommended ILCD impact assessment. For example, on the midpoint level the BEES weighting set has a superfluous factor for the work environment. Table 2-1 provides the adapted weighting factors.

Table 2-1: Adapted weighting factors of three panel weighting sets and the average weighting set for midpoint weighting.

	EPA Science Advisory Board	BEES Stakeholder Panel	NOGEPA additional factors	NOGEPA additional factors (add up to 100)	Average EPA BEES NOGEPA
	%	%	%	%	%
Climate change	**16**	**29**	**32**	*25*	*23*
Ozone depletion	**5**	**2**	**5**	*4*	*4*
Acidification	**5**	**3**	**6**	*5*	*4*
Eutrophication	**5**	**6**	**13**	*10*	*7*
Eutrophication, terrestrial	*(5/3)*	*(6/3)*	*(13/3)*	*(10/3)*	*(7/3)*
Eutrophication, fresh water	*(5/3)*	*(6/3)*	*(13/3)*	*(10/3)*	*(7/3)*
Eutrophication, marine	*(5/3)*	*(6/3)*	*(13/3)*	*(10/3)*	*(7/3)*
Photochemical ozone formation	**6**	**4**	**8**	*6*	*5*
Human toxicity - cancer effects	*7*	**8**	*6*	*5*	*6*

[24] This refers to the draft 2010 version. For up-to-date information, please refer to: European Commission - Joint Research Centre - Institute for Environment and Sustainability. International Reference Life Cycle Data System (ILCD) Handbook - Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context. Publications Office of the European Union; in publication, 2011. Will be available online at http://lct.jrc.ec.europa.eu/assessment/projects

Human toxicity - non-cancer effects	*4*	**5**	*4*	*3*	*4*
Particulate matter/Respiratory inorganics	**6**	**9**	*6*	*5*	*7*
Ecotoxicity	*11*	*7*	*19*	*15*	*11*
Ionizing radiation, human health	*(11/2)*	*(3/2)*	*(7/2)*	*(5/2)*	*(6/2)*
Ionizing radiation, ecosystems	*(11/2)*	*(3/2)*	*(7/2)*	*(5/2)*	*(6/2)*
Resource depletion	**5**	**10**	*8*	*6*	*7*
Resource depletion water	**3**	**8**	*6*	*4*	*5*
Land use	**16**	**6**	*11*	*8*	*10*
TOTAL	100	100	130	100	100

The figures in **bold** are data given in the original literature used for specifying weights. The figures in *italic* are derived and/or adapted figures. To obtain them the following adaptations were made:

- For EPA and BEES, the weighting factor for criteria pollutants is used for Particulate matter related to respiratory effects;
- For all methods, the weighting factor for Ecotoxicity is completely attributed to fresh water ecotoxicity;
- The weighting factor of EPA and BEES for indoor air quality as such is superfluous. As a first estimate this factor is used for radiation. The average factor more or less corresponds with the factor when all impact categories are weighted equally;
- For EPA and BEES the weighting factor for depletion of fossil fuels is used for depletion of resources in general;
- For NOGEPA the sub-categories for human health are based on the average proportion given by EPA and BEES;
- Factor for eutrophication is equally distributed over terrestrial, fresh and marine water;
- Missing factors for NOGEPA for ionizing radiation, resources and land use, are based on the average factors of EPA and BEES;
- NOGEPA factors are redistributed to 100.

The last column contains the average weighting set based on EPA, BEES and NOGEPA.

2.1.2 Expanding to the endpoints covered

For the methods that weight on endpoint level, the operational weighting factors of Ecoindicator99, LIME and ReCiPe given for the Areas of Protection (AoP) comply fully to the AoPs included in the ILCD recommended impact assessment. So no further adaptations are necessary.

Note that the AoP in LIME named “Social assets” mainly refers to non renewable resources and that both “Ecosystem quality (biodiversity)” and “Primary production” refer to the AoP “Natural environment”.

Table 2-2 provides the weighting factors of Ecoindicator99, LIME and an average set based on these endpoint panel weighting sets[25].

Table 2-2: Weighting factors for Ecoindicator99 and LIME and an average set

Endpoint	**Ecoindicator99**	**LIME**	**average**	**Unit**
Human health	0.3	0.33	0.32	dimensionless
Ecosystem quality	0.4	0.52	0.46	dimensionless
Resources	0.3	0.14	0.22	dimensionless

2.2 Expanding or constraining to a standard set of interventions

The number of interventions covered by “integrated modelling and evaluation” as in the NEEDS method is rather limited compared to the number of interventions covered by the mid- and endpoint modelling and evaluation, respectively 20 air emissions and 20 emissions of radionuclides vs. 3000 emissions to air, water or soil. Weighting values for missing emissions are estimated based on the available weighting factors as derived by “integrated modelling and evaluation”, using as extrapolation factors the available characterization factors from the recommended ILCD set[26].

Table 2-3 presents some results from the extrapolation exercise. In the table, for some emissions to air both the value given by NEEDS and the extrapolated value are presented. Extrapolation is based on the characterisation factors from the recommended ILCD set, using different reference emissions, i.e. SO_x, NO_x, NH_3 and CO_2.

[25] The average weighting set for endpoint weighting is exclusively the ReCiPe damage weighting set.
[26] Version 3.1 and 3.2, d.d. 01 February 2010 of the ILCD characterisation set is not complete yet. Characterisation factors for water depletion and land use are missing. For up-to-date information, please refer to: European Commission - Joint Research Centre - Institute for Environment and Sustainability. International Reference Life Cycle Data System (ILCD) Handbook - Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context. Publications Office of the European Union; in publication, 2011. Will be available online at http://lct.jrc.ec.europa.eu/assessment/projects

The table suggests that extrapolation by characterisation factors is very unreliable. It depends much on the reference value which is chosen for extrapolation. And the extrapolated results compared to the given values by NEEDS are in many cases far apart. However, to complete the NEEDS factors for missing values, extrapolation based on the 2010 ILCD factors is used with SO_2 as a reference.

Table 2-3: External cost, values given by NEEDS compared to extrapolated values

	Human Health				Loss of Biodiversity				Climate change	
	given by NEEDS	extrapolated	extrapolated	extrapolated	given by NEEDS	extrapolated	extrapolated	extrapolated	given by NEEDS	extrapolated
extrapolation relative to:		SOx	NOx	NH3		SOx	NOx	NH3		CO2
	[Euro2000 per kg]	[Euro2000 per kg]	[Euro2000 per kg]	[Euro2000 per kg]	[Euro2000 per kg]	[Euro2000 per kg]	[Euro2000 per kg]	[Euro2000 per kg]	MAC [Euro2000 per kg]	MDC [Euro2000 per kg]
sulfur dioxide	6.07	6.07	47.17	8.69	0.18	0.18	0.00	1.39		
nitrogen dioxide	5.59	0.72	5.59	1.03	0.94	2.41E+06	0.94	1.82E+07		
ammonia	9.48	6.62	51.45	9.48	3.41	0.45	0.00	3.41		
carbon dioxide									0.01	0.01
formaldehyde	0.20	0.08	0.58	0.11		1.63E+07	6.38	1.23E+08		
non-methane volatile organic compounds	0.58	0.00	0.02	0.00	-0.07					
particles (PM10)	1.32	23.18	180.09	33.19						
particles (PM2.5)	24.41	99.32	771.80	142.23						
2,3,7,8-tetrachlorodibenzo-p-dioxin	3.70E+07	5.59E+05	4.34E+06	8.00E+05		5.29E+13	2.07E+07	4.00E+14		
methane		0.00	0.00	0.00					0.26	0.15
sulfur hexafluoride									0.51	136.74
nitrous oxide									10.19	1.79

2.3 Linking to the global normalisation data

When panel weighting is used (e.g. BEES, NOGEPA, Ecoindicator99, LIME (dimensionless set)), the normalization is a necessary step in the interpretation of the results before the actual weighting is applied. The scores per impact category each have their own dimensions, while weights all are dimensionless or have the same dimension. The normalisation step is used to bring all scores to the same dimension, usually no dimension.

Instead, when the weighting is based on monetized valuation of damages, the normalization (e.g. ReCiPe damage cost, NEEDS/EXIOPOL) is not technically necessary, though it is advisable to ease the comparison.

Normalisation can be applied at any reference level. If we choose the European level and then have data on Europe for a number of years, one of these years could be used for normalisation, with normalised results on all scores of '1', and all other years showing the changes to the reference year. We chose the world as a reference for normalisation. Then the scores per impact category are dimensionless numbers to which the weighting sets can be applied. In the figures below, the start year of the time series is set at index number of 100.

For comparison of the weighted results between monetized and non-monetized weighting methods, it is possible to express the monetized results also relative to a reference situation, e.g. the total of damage cost related to all interventions (extractions and emissions) in the world in e.g. the year 2000. By using this normalization also for the monetized results, it is also possible to combine the results of the different weighting methods into one overall meta-weighting scheme.

Therefore, like for the usual normalization step as applied in LCA at impact category level[27], it is possible to express global totals of monetised environmental interventions. The national or EU27 scores then can be expressed relative to this world reference, in exactly the same way, as it is done in life cycle analysis creating dimensionless weighting fractions.

The total of extractions and emissions in the world (Intervention profile) is based on Wegener Sleeswijk *et al.* (2008). The normalisation factors are the sum-product[28] of this profile and the impact factors. Normalisation factors are derived for impact scores on midpoint and endpoint level. The normalisation factors for the world in the year 2000 are calculated in the spreadsheet that accompanies this report.

[27] Of course the normalisation in life cycle approaches is done at the midpoint level, before weighting.
[28] Sum-product: Within each impact category emissions are multiplied with the corresponding characterisation factors and these products are summed up to an overall impact category indicator score.

3 Applying impact assessment with three weighting routes: midpoint weighting, endpoint weighting and integrated weighting

In this chapter, some preliminary results of the characterisation and weighting are presented for emission profiles on three different levels: the world, the EU28[29] and the Netherlands in the year 2000. The impact assessment is carried out using the ILCD recommended characterisation factors[30] and the different weighting sets as described in chapter 2 of this report. Emissions and extractions of the world, the EU28 and the Netherlands in the year 2000 are taken from Wegener Sleeswijk *et al.* (2008).

3.1 Results midpoint weighting methods

Figure 3-1 presents the impact score for the EU28 in the year 2000. The impact assessment is based on the midpoint modelling and weighting. For the characterisation, the ILCD recommended characterisation factors are used. The characterised impact scores are normalised using as a reference the world in 2000. Thus, as a result, the normalised scores are expressed as fraction of the world overall loads. The weighting is based on the midpoint weighting sets of BEES, EPA, NOGEPA and the average of these sets. Also equal weighting is applied, that is all impact category scores are aggregated using the same weight.

The figure suggests that, according to the weighting methods, the emissions of the EU28 to air, water and soil contribute for about 12% to 14% to the total world problem. The figure also highlights the contribution of the impact categories to the total score. According to the weighting methods the most dominating impact categories are climate change, human toxicity, ionizing radiation humans and ecotoxicity fresh water.

Note that the 2010 draft ILCD recommended characterisation factors does not include factors for the impact categories land use and depletion of water. So, although weighting factors exist for these midpoint categories, the categories are still not accounted for in the total environmental impact score.

[29] EU27 + Switzerland
[30] Version 3.1 and 3.2, d.d. 01 February 2010 of the ILCD characterisation set

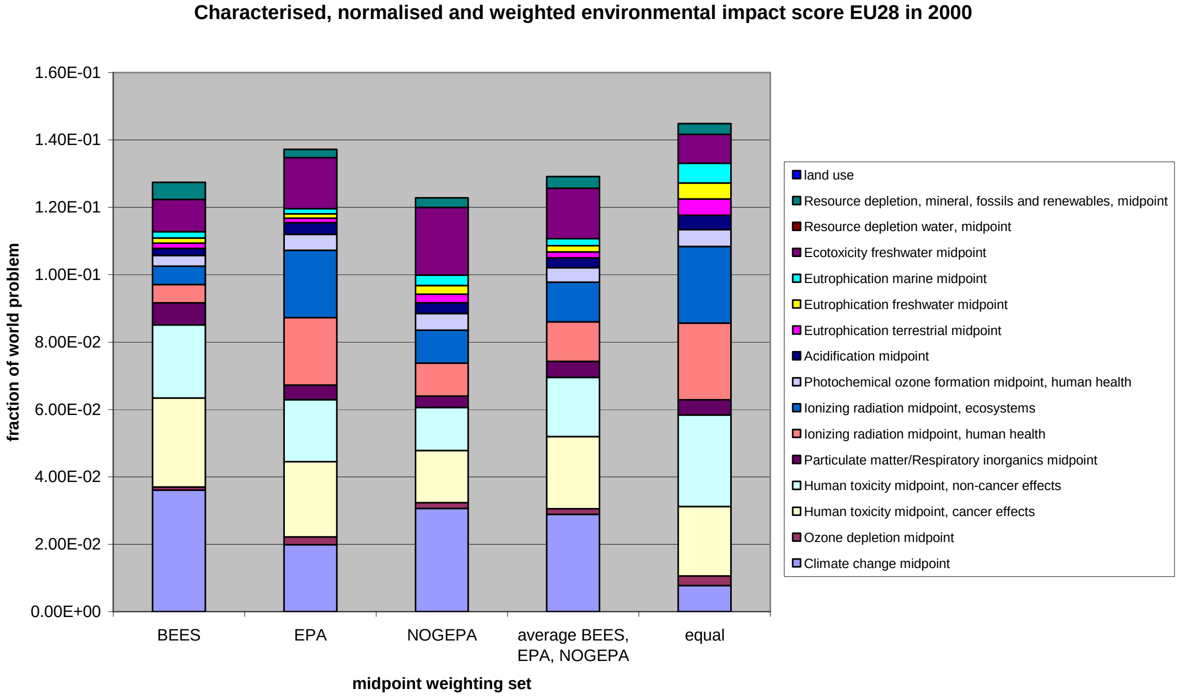


Figure 3-1: Total environmental impact score for EU28 in 2000 using midpoint modelling and weighting

Table 3-1 presents the relative contribution of substance-compartment-emissions to the total environmental impact score of the EU28 in the year 2000. The results are presented using the different weighting sets. This top 20 of substance-compartment-emissions contribute for about 90% to the total environmental impact score. The general picture of most dominant emissions is more or less the same for all weighting methods.

According to the weighting methods, the most dominant emissions are, on average, carbon dioxide, carbon-14, mercury, zinc, hydrogen-3, benzene and nitrogen dioxide. Also other GHG-emissions, like methane and nitrous oxide, bulk emissions like sulphur dioxide, NMVOCs and PM10 are part of the top 20. The remaining part of the top 20 mainly consists of emissions of pesticides to the soil.

This list of top 20 emissions is, more or less, in line with general expectations, but there is quite some discussion possible on why some scores are so high, and others so low. For example, C14 and hydrogen-3 belong to the highest ranking emissions, as the combined effect of the characterisation score of C14 and hydrogen-3 as a radioactive emission, and the weight of radiation in the weighted score. So the question is whether or not this is correct? Is the estimated emission of C14 and hydrogen-3 too high? Or, is there a mistake in the impact assessment, i.e. a characterisation factor or weighting factor for ionizing radiation? The emissions are based on the emission registration of the UK (Environment Agency, 2006) and extrapolated to the EU28 and the world based on nuclear power installed capacity. For the moment, these are the best available data to estimate emissions of radioactive substances. As we will see in section 3.2, also for the endpoint weighting methods the radioactive substance emissions seem to have a large contribution. Thus, it seems most likely that the characterisation models overestimate the impacts of radioactive substance emissions.

Table 3-2 provides the relative contribution of substance-compartment-emissions to the total environmental impact score for the average weighting set of EPA, BEES and NOGEPA. The contributions are given for EU28, the world and the Netherlands in the year 2000.

In general, the picture of most dominant emissions for the world and the Netherlands resembles the contribution of emissions for the EU28. Striking is the far smaller contribution of C14 to the total score for the Netherlands and the world. The contribution scores for the Netherlands suggests that apparently also some pesticides are not used in the Netherlands.

Table 3-1: Top 20 of substance-compartment emissions and their contribution (%) to the total impact score (sorted by average BEES, EPA, NOGEPA; descending)

Contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)						
characterisation		ILCD midpoint				
normalisation		world 2000				
weighting set		BEES	EPA	NOGEPA	average BEES, EPA, NOGEPA	equal
substance	compartment	% contribution to impact score				
carbon dioxide	Emissions to air, unspecified	21.97	11.26	19.34	17.34	4.17
carbon-14	Emissions to air, unspecified	4.77	16.25	8.88	10.14	17.50
mercury	Emissions to air, unspecified	11.50	9.04	7.00	9.20	10.26
zinc	Emissions to air, unspecified	8.59	7.12	6.09	7.28	9.27
hydrogen-3	Emissions to air, unspecified	3.04	10.34	5.65	6.45	11.13
benzene	Emissions to air, unspecified	7.91	6.30	4.95	6.40	5.54
nitrogen dioxide	Emissions to air, unspecified	4.67	4.74	7.41	5.56	9.98
sulfur dioxide	Emissions to air, unspecified	3.20	2.86	2.74	2.93	3.10
methane	Emissions to air, unspecified	2.96	1.54	2.62	2.35	0.59
lead	Emissions to air, unspecified	2.87	2.26	1.75	2.30	2.85
chlorpyrifos	Emissions to agricultural soil	1.27	1.85	2.75	1.95	1.00
nitrous oxide	Emissions to air, unspecified	2.18	1.12	1.92	1.72	0.41
particles (PM10)	Emissions to air, unspecified	2.39	1.48	1.29	1.72	1.46
atrazine	Emissions to agricultural soil	1.15	1.57	2.23	1.64	0.89
iodine-131	Emissions to air, unspecified	0.71	2.42	1.32	1.51	2.61
chlorothalonil	Emissions to agricultural soil	0.92	1.34	1.99	1.41	0.72
non-methane volatile organic compounds	Emissions to air, unspecified	1.05	1.46	1.67	1.39	1.44
phosphate	Emissions to water, unspecified	1.20	0.93	2.08	1.38	3.30
formaldehyde	Emissions to air, unspecified	1.62	1.27	0.99	1.30	1.11
cyanazine	Emissions to agricultural soil	1.16	1.24	1.46	1.28	0.84

Table 3-2: Top 20 of substance-compartment emissions and their contribution (%) to the total impact score for the average weighting set of (BEES, EPA, NOGEPA) (sorted by EU28; descending)

Contribution of substance-compartment-intervention to impact score in 2000 (%)				
weighting set		**average of EPA, BEES, NOGEPA**		
normalisation		world 2000		
characterisation		ILCD midpoint		
substance	compartment	**% contribution to impact score EU28**	**% contribution to impact score NL**	**% contribution to impact score world**
carbon dioxide	Emissions to air, unspecified	17.34	33.56	18.70
carbon-14	Emissions to air, unspecified	10.14	1.75	4.25
mercury	Emissions to air, unspecified	9.20	1.75	3.17
zinc	Emissions to air, unspecified	7.28	3.42	2.25
hydrogen-3	Emissions to air, unspecified	6.45	1.11	2.71
benzene	Emissions to air, unspecified	6.40	5.34	3.40
nitrogen dioxide	Emissions to air, unspecified	5.56	9.15	8.32
sulfur dioxide	Emissions to air, unspecified	2.93	6.53	6.65
methane	Emissions to air, unspecified	2.35	4.67	4.96
lead	Emissions to air, unspecified	2.30	1.06	0.71
chlorpyrifos	Emissions to agricultural soil	1.95	0.14	3.90
nitrous oxide	Emissions to air, unspecified	1.72	3.80	2.25
particles (PM10)	Emissions to air, unspecified	1.72	1.55	3.05
atrazine	Emissions to agricultural soil	1.64	0.00	0.91
iodine-131	Emissions to air, unspecified	1.51	0.26	0.63
chlorothalonil	Emissions to agricultural soil	1.41	2.74	0.78
non-methane volatile organic compounds	Emissions to air, unspecified	1.39	1.46	3.02
phosphate	Emissions to water, unspecified	1.38	2.18	2.75
formaldehyde	Emissions to air, unspecified	1.30	2.56	0.72
cyanazine	Emissions to agricultural soil	1.28	0.00	0.71

3.2 Results Endpoint weighting methods

Figure 3-2 presents the impact score for the EU28 in the year 2000. The impact assessment is based on the endpoint modelling and weighting. For the characterisation, the ILCD recommended characterisation factors are used[31]. The characterised impact scores are normalised using as a reference the world in 2000. As a result, the normalised scores are expressed as fraction of the world overall load. The weighting is based on the endpoint panel weighting sets of Ecoindicator99 and LIME and the Damage cost of ReCiPe. Also equal weighting is applied, that is all impact category scores are aggregated using the same weight.

The figure illustrates that, according to the weighting methods, the emissions of the EU28 to air, water and soil contribute for about 15% to 17% to the total world load. The score according to ReCiPe damage cost seems to be high, with about 25% contribution to the total world load. The figure also illustrates the contribution of the endpoint impact categories to the total score. The picture for the panel weighting sets Ecoindicator99 and LIME are more or less the same. That is, the AoP resources has a relative small contribution to the total score and the contribution of AoPs human health and ecosystem health are more or less equal. Striking is the dominance of the AoP ecosystem health for the weighting set ReCiPe damage. The score for ReCiPe damage cost is completely dominated by damages to ecosystems caused by ionizing radiation and, to a minor extent, climate change. This might suggest that the damage cost for ecosystems as estimated by Heijungs (2007) is too high compared to the damage cost of other AoPs. Furthermore, the large contribution of ionizing radiation ecosystems seems to be disputable.

Note that for the endpoint impact categories land use and depletion of water ILCD recommended characterisation factors were not available in the the 2010 draft. So, although weighting factors exist for these endpoint categories, the categories are still not accounted for in the total environmental impact score here.

Furthermore, the fate modelling from midpoint to endpoint for ecosystem health related indicators is preliminary. In the ILCD recommended set of characterisation factors, as available at present (2010 version), the factors for endpoint impact categories are not fully elaborated. Particularly, for the AoP ecosystem health the set of endpoint impact categories seems to be not consistent. In order to be able to work with the present set of characterisation factors on endpoint level, a rough preliminary adjustment has been made in this project (see sub-chapter 2.2).

[31] 2010 draft version. For up-to-date information, please refer to: European Commission - Joint Research Centre - Institute for Environment and Sustainability. International Reference Life Cycle Data System (ILCD) Handbook - Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context. Publications Office of the European Union; in publication, 2011. Will be available online at http://lct.jrc.ec.europa.eu/assessment/projects

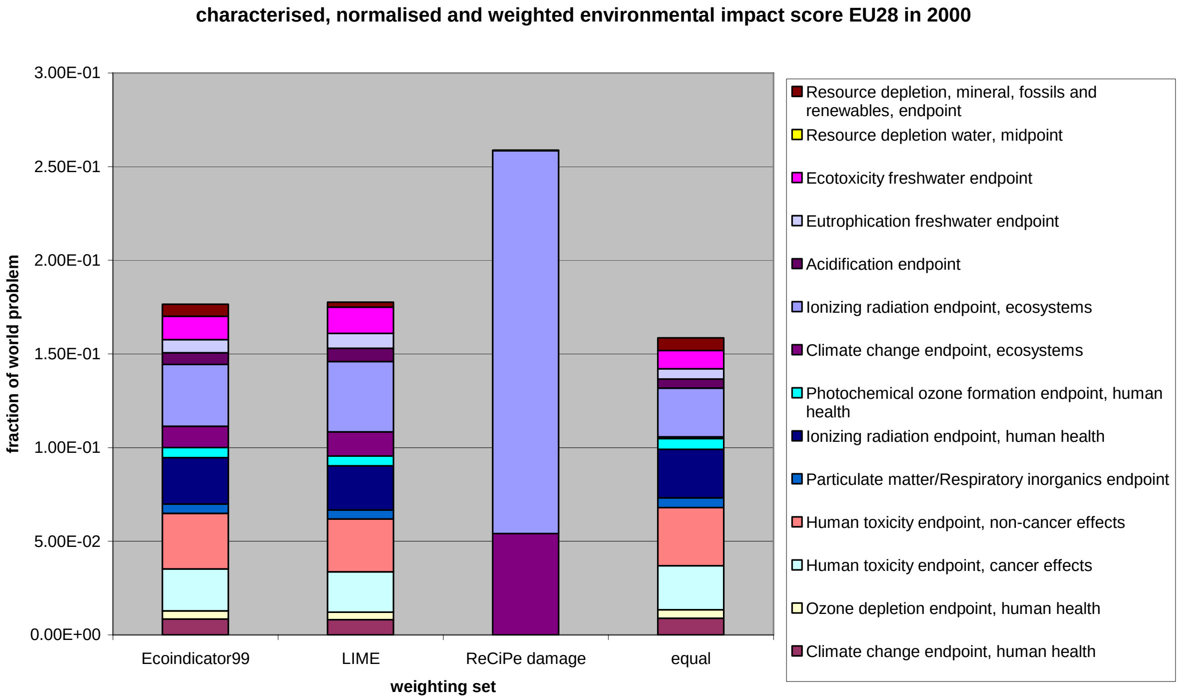


Figure 3-2: Total environmental impact score for EU28 in 2000 using endpoint modelling and weighting

Table 3-3 presents the relative contribution of substance-compartment-emissions to the total environmental impact score of the EU28 in the year 2000 according to the endpoint weighting methods. The results are presented using the different weighting sets. For the panel weighting methods and equal weighting set this top 20 of substance-compartment-emissions contribute for about 90% to the total environmental impact score. For the ReCiPe damage weighting method, the score is completely dominated by the ionizing radiation emissions of hydrogen-3, iodine-131 and carbon-14 and the GHG emission of CO2, which contribute for about 95% to the total score. The general picture of most dominant emissions is, for all weighting methods, more or less the same.

According to the endpoint weighting methods the most dominant emissions are, on average, carbon-14, hydrogen-3 and carbon dioxide, mercury and zinc. Also other GHG-emissions like methane and nitrous oxide, bulk emissions like sulphur dioxide, nitrogen dioxides, NMVOCs and PM10 are part of the top 20. The remaining of the top 20 mainly consists of emissions of pesticides to the soil.

This list of top 20 emissions is quite in line with general expectations. This, however, does not apply to ionizing radiation by C14 and hydrogen-3, which belong to the highest ranking emissions.

Table 3-4 presents the relative contribution of substance-compartment-emissions to the total environmental impact score according to the weighting set of LIME. The contributions are given for EU28, the world and the Netherlands in the year 2000.

In general, the picture of most dominant emissions for the world and the Netherlands resembles the contribution of emissions for the EU28. Striking is the significantly smaller contribution of C14 and hydrogen-3 to the total score for the Netherlands and the world. On a world level, also the contribution of dioxin to the total score is small compared to the EU28 and the Netherlands. On a world level, the emission of phosphate seems to be of relative importance. The contribution scores for the Netherlands highlights that, apparently, also some pesticides are not used in the Netherlands. Finally, for the Netherlands the extraction of natural gas seems of relative large importance to the total environmental score in the Netherlands.

Table 3-3: Top 20 of substance-compartment emissions and their contribution (%) to the total impact score (sorted by LIME; descending)

Contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)					
characterisation		ILCD endpoint			
normalisation		world 2000			
weighting set		ecoindicator99	LIME	ReCiPe damage	equal weighting
substance	**compartment**	**% contribution to impact score**	**% contribution to impact score**	**% contribution to impact score**	**% contribution to impact score**
carbon-14	Emissions to air, unspecified	16.24	15.83	9.99	18.25
hydrogen-3	Emissions to air, unspecified	13.27	14.96	55.85	11.62
carbon dioxide	Emissions to air, unspecified	8.67	9.11	16.14	4.33
mercury	Emissions to air, unspecified	9.18	8.71	0.00	10.71
zinc	Emissions to air, unspecified	8.43	8.09	0.00	9.67
benzene	Emissions to air, unspecified	4.96	4.70	0.00	5.78
phosphate	Emissions to water, unspecified	3.94	4.44	0.02	3.45
iodine-131	Emissions to air, unspecified	3.11	3.51	13.13	2.72
sulfur dioxide	Emissions to air, unspecified	3.24	3.42	0.03	3.22
nitrogen dioxide	Emissions to air, unspecified	2.97	3.08	0.02	3.03
lead	Emissions to air, unspecified	2.55	2.42	0.00	2.98
chlorpyrifos	Emissions to agricultural soil	1.19	1.35	0.00	1.05
methane	Emissions to air, unspecified	1.19	1.24	2.16	0.61
particles (PM10)	Emissions to air, unspecified	1.31	1.24	0.00	1.53
non-methane volatile organic compounds	Emissions to air, unspecified	1.29	1.22	0.00	1.50
atrazine	Emissions to agricultural soil	1.03	1.14	0.00	0.93
HCFC-141b	Emissions to air, unspecified	1.10	1.05	0.09	1.25
HCFC-22	Emissions to air, unspecified	1.00	0.97	0.41	1.02
chlorothalonil	Emissions to agricultural soil	0.86	0.97	0.00	0.75
formaldehyde	Emissions to air, unspecified	1.00	0.95	0.00	1.16

Table 3-4: Top 20 of substance-compartment emissions and their contribution (%) to the total impact score (sorted by EU28; descending)

Contribution of substance-compartment-intervention to impact score in 2000 (%)				
weighting set		LIME		
normalisation		world 2000		
characterisation		ILCD endpoint		
substance	**compartment**	**% contribution to impact score EU28**	**% contribution to impact score NL**	**% contribution to impact score world**
carbon-14	Emissions to air, unspecified	15.83	3.27	7.74
hydrogen-3	Emissions to air, unspecified	14.96	3.09	7.31
carbon dioxide	Emissions to air, unspecified	9.11	21.12	11.46
mercury	Emissions to air, unspecified	8.71	1.99	3.50
zinc	Emissions to air, unspecified	8.09	4.55	2.91
benzene	Emissions to air, unspecified	4.70	4.70	2.92
phosphate	Emissions to water, unspecified	4.44	8.40	10.32
iodine-131	Emissions to air, unspecified	3.51	0.72	1.72
sulfur dioxide	Emissions to air, unspecified	3.42	9.13	9.05
nitrogen dioxide	Emissions to air, unspecified	3.08	6.07	5.37
lead	Emissions to air, unspecified	2.42	1.34	0.87
chlorpyrifos	Emissions to agricultural soil	1.35	0.11	3.15
methane	Emissions to air, unspecified	1.24	2.96	3.06
particles (PM10)	Emissions to air, unspecified	1.24	1.34	2.57
non-methane volatile organic compounds	Emissions to air, unspecified	1.22	1.53	3.09
atrazine	Emissions to agricultural soil	1.14	0.00	0.74
HCFC-141b	Emissions to air, unspecified	1.05	2.48	1.00
HCFC-22	Emissions to air, unspecified	0.97	2.31	0.93
chlorothalonil	Emissions to agricultural soil	0.97	2.27	0.63
formaldehyde	Emissions to air, unspecified	0.95	2.24	0.61

3.3 Results for Integrated weighting methods

Figure 3-3 presents the impact score for the EU28 in the year 2000 according to the weighting factors of NEEDS (adapted version). The impact assessment is based on NEEDS, using integrated modelling and weighting based on damage cost. NEEDS damage costs are adapted for GHG which have been increased by a factor 10. Furthermore, missing factors in NEEDS have been extrapolated based on the available ILCD impact assessment factors. According to this adapted NEEDS, the damage cost of emissions in the EU28 for the year 2000 is about 650 billions euro. The figure also illustrates the contribution of the endpoint impact categories to the total score. According to the adapted NEEDS weighting, the damage cost is dominated by climate change (caused by emissions of CO_2, N_2O CH_4) and human health effects (due to emissions of SO_2, NO_2).

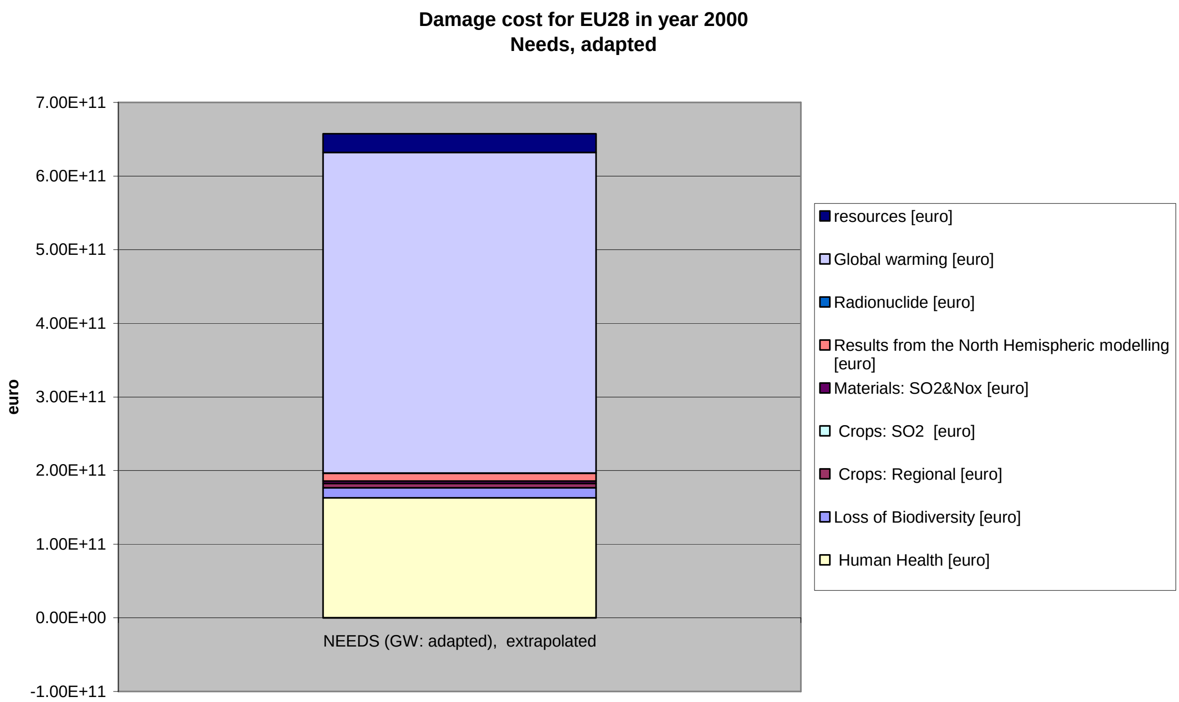


Figure 3-3: Total environmental damage cost for EU28 in year 2000 based on NEEDS damage cost for endpoints.

Table 3-5 presents the relative contribution of substance-compartment-emissions to the total environmental damage cost based on NEEDS. The contributions are given for EU28, the world and the Netherlands in the year 2000.

The contribution profile of NEEDS is different compared to the profiles given for the midpoint and endpoint weighting. In NEEDS, the emission of C14 and hydrogen-3 are far less important. In NEEDS, the score is dominated by emissions to air of carbon dioxide, nitrous oxide, nitrogen dioxide, sulphur dioxide and methane. These substance emissions are also present in the top 20 of midpoint and endpoint modelling and weighting but here are far less dominant. The resources oil and natural gas should be noted, as they display a substantial contribution in the total damage cost.

Note that the characterisation of the interventions is based on the NEEDS factors for integrated modelling. These factors are not consistent with the factors of the recommended ILCD characterisation set[32]. The list of interventions in NEEDS for which characterisation factors are available is limited. The limited list of interventions from NEEDS only explain about 30 to 50% of the score as calculated by the endpoint and midpoint modelling and weighting based on the current 2010 draft recommended ILCD characterisation set. However, in this project the missing NEEDS factors are extrapolated using the 2010 draft recommended ILCD characterisation set.

Furthermore, several impacts are not taken into account, like ecotoxicity, land use, radiation ecosystems, and depletion of water. However, land use and depletion of water are also not taken into account in the 2010 ILCD recommended characterisation set.

[32] 2010 draft version

Table 3-5: Top 20 of substance-compartment emissions and their contribution (%) to the total impact score (damage cost).

Contribution of substance-compartment-intervention to impact score in 2000 (%)				
weighting set		NEEDS and Weitzman		
normalisation		not normalized		
characterisation		NEEDS and Weitzman		
		GHG: marginal Damage Cost		
substance	**compartment**	**% contribution to impact score EU28**	**% contribution to impact score NL**	**% contribution to impact score world**
carbon dioxide	Emissions to air	36.705	35.739	27.390
nitrous oxide	Emissions to air	20.769	23.072	18.743
nitrogen dioxide	Emissions to air	12.728	10.537	13.178
sulfur dioxide	Emissions to air	8.990	10.074	14.106
methane	Emissions to air	8.606	8.604	12.580
zinc	Emissions to air	3.712	0.878	0.793
non-methane volatile organic compounds	Emissions to air	1.883	0.994	2.833
crude oil; 42.3 MJ/kg	Resources from ground	1.845	0.406	2.407
natural gas; 44.1 MJ/kg	Resources from ground	1.558	8.163	1.447
particles (PM10)	Emissions to air	0.505	0.229	0.619
ammonia	Emissions to air	0.489	0.436	3.107
mercury	Emissions to air	0.282	0.027	0.067
lead	Emissions to air	0.231	0.053	0.049
carbon monoxide	Emissions to air	0.212	0.000	0.620
hard coal; 26.3 MJ/kg	Resources from ground	0.209	0.047	0.396
HCFC-22	Emissions to air	0.182	0.181	0.103
phosphate	Emissions to water	0.153	0.121	0.210
HCFC-141b	Emissions to air	0.140	0.139	0.079
benzene	Emissions to air	0.136	0.057	0.050
copper	Resources from ground	0.072	0.000	0.155

4 Linking operational weighting methods into a meta-weighting tool

In the previous chapters, seven separate weighting sets have been described, belonging to three different weighting methods: midpoint modelling, endpoint modelling and integrated[33] modelling. For the “integrated modelling and evaluation” method, only one weighting set is available. This set is already a combination of valuation methods for different endpoints using different literature sources (NEEDS, Tol, Weitzman). For the other weighting methods (i.e. midpoint and endpoint), different operational weighting sets are available, like BEES 1&2 and NOGEPA for midpoint weighting, and Ecoindicator99, ReCiPe and LIME for endpoint weighting.

The question is if/how these different weighting sets available for midpoint and endpoint weighting methods can be aggregated into one. Three possibilities exist:

1. Present separate weighted scores and leave the aggregation to the user;
2. Select one of the weighting sets as recommended, thus avoiding the aggregation issue;
3. Combine the weighted scores by (again: weighted) aggregation by means of a **meta-level weighting procedure**.

For this project, the third option has been chosen, so as to obtain a single outcome from the weighting procedure. This also allows to figure out the extent to which results depend on the weighting method.

The technical meaning of the meta-level weighting procedure may be intended as a number of transformation steps ultimately leading to an evaluation dimensionless score. The magnitude of this dimensionless score can possibly range from mini-point to mega-points. By rescaling, a convenient number can be selected, avoiding fractions and avoiding large numbers. However, the weighted scores for e.g. the city of Monaco may still be several orders of magnitude different from those for e.g. China. An option for a straightforward interpretation is to link the scores to a reference situation, like “100 for country x in year y”. The other scores would then refer this base score, with percent point changes. In this way, an index is constructed to allow for easy interpretation of time series, as it is also done for economic scores like GDP.

[33] Note that the weighting set of the “integrated modelling and evaluation” has a somewhat different status. The impact pathway approach and climate models both are not compatible with the recommended ILCD characterization factors. And the number of interventions that is covered in the weighting set is rather limited. For this reason this weighting set maybe should be presented as an illustration only and should not be taken into account when assembling weighted results of different weighting sets into one score.

The outcomes of the economic type of integrated evaluation are expressed in monetary units, e.g. euro. This may also be the case for the endpoint methods considered here. Also, the meta-weighting method could be transformed into a monetary version by setting one reference value, e.g. the monetary value of 1 kg of CO_2 emissions, and expressing all outcomes in this unit. One should be careful to link these euro outcomes to current income euros. This depends on two reasons. First, LCA-based endpoint methods probably refer to flow magnitudes in an equilibrium situation, while the economist's values are time integrated net present values. Second, there is a fundamental dispute that questions the adequacy of monetised weighting approaches.

We leave the setting of a reference score to users, who then may choose different references for different applications of the weighting method.

Also, the meta-weighting method might have a more appealing name. The references now are ***Integrated Environmental Score,*** the ***Combined Method,*** or the ***Combined Weighting Method*** or just the ***Meta-Weighting Method.*** We did not consider further names for this integrated score.

5 Strengths and weaknesses of weighting methods

To discuss the strengths and weaknesses of the methods a clear distinction must be made among the steps in the Life Cycle Impact Assessment (LCIA) preceding the weighting step: classification (i.e. assigning the elementary flows to the one or more relevant impact categories), characterisation (i.e. multiplication of the individual elementary flows with relevant factors expressing the individual contribution to the impact factor of each elementary flow relative to a reference flow, e.g. CO2 for climate change) and, especially, normalisation.

5.1 Characterisation

Some of the flaws of the overall impact assessment as described in this report are related to the characterization step, which includes a partial model of effect routes. The midpoint and endpoint modelling and weighting build on the characterization according to the ILCD recommended set of impact assessment methods. An important prerequisite for the weighting is that the weighting methods should be compatible with the ILCD recommended characterization into mid- and endpoint impact categories as is now being developed. The integrated modelling and weighting according to NEEDS builds, implicitly, on more detailed distribution, fate and effect models. These models differ from the models recommended in the ILCD, in draft now. However, their status outside the LCA community is well established, also in the policy domain. Therefore we include them as one of the three approaches to weighting in the combined weighting method.

General remarks on the draft ILCD recommended characterisation set

At the time of writing, the set of ILCD recommended characterisation factors was in development. In this report, a preliminary set of characterisation factors has been used, version 3.1 and 3.2, d.d. 01 February 2010[34]. During the development of weighting scheme this set of characterisation factors appeared to be not fully elaborated, especially regarding the midpoint to endpoint modelling, land use effects and water depletion. As a consequence, the results of the subsequent weighting of characterised impact scores should be considered as preliminary. When applying the Combined Method, the calculations should be updated to ensure use of the latest factors. Also, the currently missing items should be included if available by then. Such further extensions can be easily made using the excel sheets provided.

[34] ILCD_LCIA_method_documentation_01Feb2010_v.3_1.xls
ILCD_LCIA_method_documentation_01Feb2010_v.3_2.xls

The following items of the ILCD recommended set of characterisation factors need further attention:

- Missing impact categories: characterisation data are missing for the midpoint and endpoint categories: land use and water depletion.
- Endpoint modelling: the characterisation models for the endpoint impact categories for ecosystem health seem to be not completely elaborated. There is no consistent set of endpoint indicators. In this weighting project a rough provisional conversion is applied in order to be able to aggregate the scores. This rough provisional conversion might be the explanation of some of the oddities in the preliminary results.
- Resource depletion: There seems to be only one overall impact category for resource depletion, named "Resource depletion, mineral, fossils and renewables". While a distinction of at least two impact categories namely "depletion of fossil resources" and "depletion of mineral resources" (elements) was expected. At present no characterisation factors seem to be available for resource depletion regarding renewables.

Striking is the very large contribution of C-14 and hydrogen-3 emissions to the total environmental impact score for both midpoint and endpoint indicators. It is not clear whether this outcome is realistic or whether it points to an underlying deficiency in the characterisation model or the data.

Some further aspects should be considered when using the ILCD characterisation factors in weighting, draft now or final later. A main point is the time reference implicit in these models. For example, climate change scores are based on GWPs, which reckon fully with effect mechanisms on a specified time scale, and then set later contributions to zero. By contrast, fate modelling for the toxicity scores is based on an infinite time horizon. In this respect, some, but not all integrated approaches have a more well-defined treatment of time, with quite some disagreement based on the more detailed analysis. Especially, effects of climate change as set up in the contexts of IPCC specify end points explicitly in time. This allows for an explicit discounting procedure. There is a well established discourse with literature on this subject, with some convergence resulting, as in terms of ‘Weitzman discounting’. Without time specification, reckoning with differing time horizons in evaluation is hardly possible. With different time frames in the modelling domains, the evaluation becomes even more complex.

Further differences relate to background concentrations. These are taken into account in climate change and ozone depletion but perhaps not in characterisation of the other impact categories like in toxicity factors and eutrophication. Hence, the evaluation of assumed effects (midpoint weighting) or the further modelling of effects (endpoint weighting) can hardly be consistent in this respect.

Next, multimedia models have been developed in relation to toxicity categories, but not in other characterisation models. The mechanisms lacking in modelling can hardly be reckoned with in evaluation. Finally, the scale levels of characterisation models differ between impact categories, making a conceptualisation of expected effects (midpoint weighting) and a quantification of modelled effects (endpoint weighting) a task not easily done consistently.

General remarks on integrated modelling and evaluation

The integrated modelling and weighting method according to NEEDS implicitly builds on detailed characterisation models. However, the models are different from the models recommended in ILCD. Moreover, the different intermediate results of characterisation and weighting are not reported separately. For this reason, it is not possible to discuss these different steps in detail. The following weaknesses of the integrated modelling and weighting can be identified:

- characterisation models differing from those recommended in ILCD characterisation set,
- missing impact categories: damage of ecotoxicity, direct land use, water depletion,
- limited scope of interventions: compared to the ILCD set of characterisation factors, the number of substance-compartment-emissions for which effects are modelled is very limited.

The flaws in modelling of midpoint and endpoint effects in the LCA based methods have been resolved for some aspects in integrated modelling. Economists' climate models are perhaps more consistent in treatment of time. Their toxicity models and acidification models may be more explicit and detailed in terms of regional and locational specification. Therefore, they may better reckon with differences in climate and in population density. However, the modelling specifications for many integrated models are poor, and mostly do not cover what is modelled in ILCD impact categories.

5.2 Normalisation

With the normalisation step, the characterised LCIA results are multiplied with "normalisation factors" that represent the overall inventory of a reference (e.g., a whole country or an average citizen), obtaining dimensionless, normalised LCIA results. Normalised LCIA results reflect only the contribution of the analysed system to the total impact indicator but not the relative severity/relevance of the impact to others. Therefore, the normalised LCIA results must not be directly summed. However, they can provide insights into the relative importance of an impact in a given impact category.

Normalisation of characterised impact scores is a necessary step in the weighting procedure in case panel weighting is used.

The normalisation factors are based on the intervention profiles for the world in the year 2000 (Wegener Sleeswijk et al, 2008). The normalisation factor of an impact category is the summed product of the characterisation factors and interventions. So the interventions of Wegener Sleeswijk et al. (2008) can be used together with the ILCD recommended set of characterisation factors to derive normalisation factors for the ILCD recommended impact categories. However, the following flaws can be identified in the calculation of the normalisation factors:

- Missing impact categories: world data on land use for different land use types and water depletion are missing. At present also the characterisation models for land use and water depletion are missing. Gathering of interventions for these missing impact categories is only possible if these characterisation models are elaborated and the types of interventions that are going to be accessed are clear.
- Missing interventions: the number of resource extractions that is gathered in Wegener Sleeswijk et al., 2008 is rather limited (the extraction of 4 fossil fuels and about 10 elements). Ideally, the intervention profile to derive the normalisation factor should be as complete as possible. Particularly, when the depletion of fossil fuels and elements are considered as separate impact categories, the normalisation factor for depletion of elements needs further attention and more world consumption data for elements should be gathered.

Endpoint weighting based on monetized valuation, like ReCiPe damage cost (Heijungs, 2007) and NEEDS (Preiss et al., 2008) is performed on not normalized impact category scores. However, to combine the weighting methods into the meta weighting tool, the monetized scores also should be normalised. On this basis, the contributions to the *total problem* of each intervention can be expressed in a fully equivalent way. The normalised damage cost is expressed relative to the damage cost of the total of interventions of the world in year 2000. The midpoint weights are normalised based on exactly the same interventions set.

5.3 Weighting

The strengths and weaknesses of the three main methods are surveyed in this section, based on the operationally available methods.

5.3.1 Midpoint modelling and weighting: EPA, BEES, NOGEPA

Weaknesses

- Coverage of weighting factors for the recommended ILCD midpoints is reasonable, however in NOGEPA no weighting factors are available for resource and water depletion, radiation, land use; in EPA/BEES no weighting factor is available for radiation, but a superfluous factor is available for indoor air quality.
- The geographical reference of the methods differs and is not clear. NOGEPA refers to the Dutch normalisation and effects domain. EPA and BEES probably refer to the US situation; this is not clear.
- To complete the weighting set in accordance to the recommended ILCD impact categories the missing weighting factors have been estimated by 'methods transfer'.

Strengths

- Coverage of weighting factors for the recommended ILCD midpoints is reasonable.
- BEES, EPA and NOGEPA generate comparable results.
- *Panel* weighting sets of endpoint and midpoint provide comparable results.

5.3.2 Endpoint modelling and weighting: Ecoindicator99, LIME, ReCiPe damage cost

The modelling from midpoint to endpoint is not fully elaborated in the recommended ILCD characterisation set (version, 01 February 2010). The rough provisional conversion of factors, which was necessary to derive comparable impact category indicator scores on endpoint level, surely obscures the preliminary results. Thus, a sound evaluation of the weighting on endpoint level will not be possible until the modelling from midpoint to endpoint will be described explicitly with problems surveyed, and until inconsistencies will be solved. So the conclusions given below should be considered in this context.

Weaknesses

- ReCiPe damage cost is completely dominated by damage cost to ecosystems due to ionizing radiation and GHG emissions. This very deviating result has not been corroborated well enough to yet accept this as a deliberate and well founded outcome.

Strengths

- All endpoint weighting sets completely cover the ILCD endpoints, i.e. weighting factors for the Areas of Protection human health, ecosystem health and resources.
- Endpoint weighting sets of Ecoindicator99 and LIME give similar results. This is not unexpected because the weighting factors for the three endpoint impact categories are not far apart.
- *Panel* weighting sets of endpoint and midpoint weighting give comparable results. This is in contrast to the ReCiPe damage cost. For the panel weighting procedure, the endpoint impact scores are first normalised and then aggregated. Due to this normalisation step, inconsistencies of units between impact category scores are not a problem. Note that the endpoint impact categories within an AoP (e.g. ecosystem health) are aggregated without further explicit weighting.

5.3.3 Integrated modelling and evaluation: NEEDS, with Tol and Weitzman for climate effects

Weaknesses:

- No clear distinction and reporting of intermediate results between characterisation of interventions into impact category scores and valuation of these impact category scores.
- Different methods/costs are used to valuate different endpoints (human health, ecosystem health (i.e. eutrophication and acidification), climate change, radiation. These involve conceptually different options, like willingness-to-pay and reduction costs. Weighting across endpoints then is not consistent, not in terms of decision support where choices on allowable cost are involved. This point has been resolved as much as possible by using willingness-to-pay as the only base method in economic valuation.
- Availability of data may be an issue.

Strengths:

- With Impact Pathway analysis, detailed modelling of interventions into damage cost is possible on country level, using country specific characterisation factors and weighting factors. However, in this weighting project EU average factors are used.

- With climate models, the extensive research on climate effects can be incorporated, as reviewed and integrated by Tol.

Explicit treatment of time horizon in evaluation, as based on discounting of future effects and uncertainties of willingness to pay, is part of the discussion, which is more hidden and less consistent in LCA discussions.

5.4 Strengths & Weaknesses of the Combined Method

Strengths

- A combined method makes possible to get a quick scan of impact assessment results for an intervention profile, using the different choices in the weighting step in a combined manner.
- It enables a sensitivity analysis on choices between weighting methods, e.g. NOGEPA vs EPA vs Ecoindicator99 vs ReCipe damage vs NEEDS.
- It enables a sensitivity analysis on choices also within a specific weighting method, e.g. within EPA, changing the weighting factors between impact categories.

Weaknesses

- An aggregate weighting method loses the reference to one clear method.

5.5 Combined Weighting Method: an overview

The combined method is a combination of the main weighting approaches with a substantial coverage. Seven separate weighting sets are described, belonging to 3 different approaches: midpoint modelling and evaluation, endpoint modelling and evaluation, and integrated modelling and evaluation.

For the “integrated modelling and evaluation” method only one weighting set is available. This set is already a combination of economic valuation methods for different endpoints using different literature sources (Tol for climate, Weitzman for resource depletion and NEEDS for all other).

For the other weighting methods different operational weighting sets are available, like BEES 1&2 and NOGEPA for midpoint weighting and Ecoindicator99, ReCiPe and LIME for endpoint weighting.

In order to aggregate these different weighting sets into one set a meta-weighting tool is used via a combined method. The meta-weighting tool makes possible to present results for a selected separate weighting set or for a combination of weighted scores by (again: weighted) aggregation. The meta weighting tool aims to be a comprehensive weighting tool that combines the most important weighting approaches available at present.

Although NEEDS is not compatible with the ILCD recommended Impact Assessement methods[35], the NEEDS impact assessment is still incorporated, because in its future updates, the ILCD and NEEDS characterisation models and weighting sets might converge.

Furthermore, the results in the case application of the EU15 are much alike. However, for countries with different economic development and structure, and in specific LCA case studies with very specific emissions the results between different weighting methods might markedly diverge. The use of the Combined Method seems a solution where different views on pros and cons of the three main weighting approaches can be accommodated.

As an example, we propose the set of meta-weights presented in table 1-1. These have been discussed with the experts in the expert consultation.

Table 5-1: Proposed selection of weighting sets in the meta weighting tool

type of weighting approach	operational weighting sets	selection	meta weighting set

[35] European Commission - Joint Research Centre - Institute for Environment and Sustainability. International Reference Life Cycle Data System (ILCD) Handbook - Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context. Publications Office of the European Union; in publication, 2011. Will be available online at http://lct.jrc.ec.europa.eu/assessment/projects

midpoint modelling and evaluation	BEES	25	0.250
	EPA	25	0.250
	NOGEPA	25	0.250
endpoint modelling and evaluation	Ecoindicator99	2	0.020
	LIME	2	0.020
	ReCiPe damage cost	1	0.010
integrated modelling and evaluation	NEEDS	20	0.200
		100	***1.000***

The choices made are not well founded and defendable in a general sense, as overarching weighting concepts are not well developed. There are a number of relevant considerations which support the choices that have been made. As others may make such choices differently, the Combined Method has been implemented in a flexible tool, freely available for all users. The main considerations in the choices made are rather practical. Only the midpoint methods cover all main effect mechanisms and are conceptually clear. The Endpoint weighting is based on an internally inconsistent characterisation model, while the Integrated Weighting may have advantages in some details but hardly covers all relevant environmental interventions. Should all methods reach maturity and become more compatible in their modeling, there would probably be a convergence in weighting results as well. Of course, weighting remains an essential subjective and a political issue, open to discussion and development.

6 Panel procedure of the Panel 1 type for setting midpoint weights

6.1 Goals of the panel procedure

The first goal is to combine different midpoint scores of complex systems into an overall score. As any complex system involves activities at a global scale level, the interventions and following midpoint impact modelling involve the full world as well. A regional differentiation of effects is optionally possible, with additional weighting issues involved, like North-South differentiations.

The second goal is to arrive at broadly accepted results, as broadly accepted as reasonably possible. Diverging views will, and should, always remain, as the weights always represent one moment in time, by one specific group involved in the panel.

6.2 Tasks of the panel

The task of the panel is two-fold. The first task is to estimate subjectively the causal chains from the midpoint effects as modelled in the impact categories to the effects which are ultimately relevant in evaluation. Climate change is not relevant in itself but in its consequences on nature, human welfare, and human health in particular.

The second task is to evaluate the different effects as modelled subjectively, in the heads of the panel members. This requires handling of disparate, partly conflicting and overlapping information, which cannot be formalised.

Therefore, the two tasks may be distinguished analytically, but will always be executed in a combined way, without the explicit modelling step in between.

6.3 Composition of the panel

The different goals and tasks have different requirements on the composition of the panel. To be authoritative and broadly accepted, the persons involved should be confident on their judgements.

To be knowledgeable on the modelling issues, they are to be able to grasp the broad and overlapping and conflicting information involved in estimating midpoint-endpoint causal chains. This leads to experienced scientists as panel members, with some specialisation between them as nobody oversees all domain of empirical knowledge involved.

A third requirement is that ‘those concerned’ are involved. Major issues at stake involve the business community, consumers, politicians and civic society at large. Getting in partisan views will easily lead to a stalemate in the panel procedure. Not getting them in means losing potentially relevant insights. Getting in partisan views and arriving at a most consensus oriented result through adequate procedures seems the best possible solution.

6.4 What is to be evaluated

What is to be evaluated is all effects resulting from the midpoint effects as involved in the impact category modelling. These effects may best relate to the total of environmental interventions in a reference year, preferably the same as used for the normalisation step in weighting. When using data for a specific country, local effects may be specified more adequately. However, several impact categories are global in their mechanisms, like climate change and toxic effects of long lasting substances like heavy metals. These global effects then would have to be reduced to the country level.

6.5 Restrictions to be accepted

The panel members have to accept the midpoint characterisation factors ‘as are’, and have to understand the modelling on which they are based. That is a substantial task. For example, global warming potentials are based on the addition of one unit of global warming influencing substance, with climate forcing effects specified and integrated over a time period of usually 20, 50 or 100 years, and expressed as equivalent to the reference substance carbon dioxide.

6.6 Steps

The steps to go through relate to the communication processes involved in getting the relevant information to all panel members. The main task is to sketch the different effect routes not from a scientific point of view, but from a concerned point of view: what are important routes and effects resulting. Presentations and discussions by specialists are a key first step. The setting of weights is a second step, to be made in several rounds, to recognise and redress the confusions which will come up unavoidably.

6.7 Procedural safeguards

The first procedural safeguard is to see where confusion arises. This can be done by having the setting of weight done individually, with discussion of the outliers. Outliers may be based on wrong perceptions, to be corrected, or on idiosyncratic views, to be accepted. Only discussion can clarify such issues, requiring several rounds of weights setting.

The end result will be based on the aggregation of the weights given by each panel member. This may easily lead to strategic voting behaviour. Especially if stakeholder interests are involved this can be a problem for acceptance of results. But individuals will always tend to try to influence outcomes into their direction. There are several sophisticated approaches to this problem. A simple one is to delete the highest and the lowest scores from the set being used in aggregation of the final weighting set of the panel.

6.8 Checks

The checks involve the analysis of results. If one person continuously shifts his scores between weighting sets, this indicates strategic behaviour. Open discussion is the procedural solution.

If between voting sessions the standard deviation of scores increases, conflicting opinions are emerging. These should actively be investigated by the facilitator and brought into the panel discussions.

If different groups, from business, politics or civic society vote different systematically, there may different causes. One is misunderstanding: that there has not yet been enough communication. The solution is clear. The other may be that there is a bias in the group composition, for example taking NGOs from the climate domain only. Then there is no easy solution. Ultimately, there is no basic reason why such groups would have different values and preferences.

6.9 Balances

In order to have all members express themselves freely, a Chatham procedure or variant thereof is required. The opinions of no individual panel member are to be brought into public, ever.

6.10 Results

There are two basic reasons why there will be a tendency of weights to be closely to each other. First, it seems difficult to assume a wide disparity between impact categories; “none should be negligible”. Second, the averaging procedure implies that outliers of one person tend to be neutralised by others. This might imply that reckoning with the underlying preferences would lead to still higher weights for the already heavy weight impact categories and lower for the already lower.

The results of the panel procedure are to be published as open as possible within the constraints of safeguarding the secrecy of each panel member’s voting.

6.11 External requirements

A procedure as described above requires substantial preparation, in content and in procedures for arriving at a reasonable and broadly acceptable panel composition.

The number of panel members should on the one hand reflect different backgrounds in the community, also in terms of regions involved, and on the other should be small enough to allow for intense discussion in content. The last requirement would set a limit at around 40 members.

The panel procedure itself is time consuming. A minimum of around 4 days seems to be indicated. The procedure requires a substantial staff for facilitating the process and administering it for later publication. The full panel procedure would require a substantial project.

7 Test on real data

In chapter 3 some preliminary results are presented on the impact assessment of emission profiles on three different levels: the world, the EU28 and the Netherlands in the year 2000. The impact assessment is carried out using the ILCD recommended impact assessment factors and the different weighting sets as previously described. These preliminary results give some insight on the contribution to the overall environmental impact score of substance emissions to initial compartments. And, thus, might give an indication of the reliability of the results.

In this chapter, the results of the impact assessment using different weighting sets are demonstrated on a time series of environmental interventions and GDP for the EU.

For the test on real data, the most appropriate available data set should be used. Ideally, such a data set should encompass a broad set of environmental interventions that contribute to a broad set of environmental problems. In order to detect a decoupling between environmental score and GDP, the data set should cover a considerable time span. For the same reason, the time series of interventions should be based on empirical data and should not be estimated using GDP as an extrapolation factor.

Long time series are poor in inventory data, and if they are available, the time series for the environmental part is based on extrapolation from economic data. The time series with empirical basis, like the NAMEAs for Netherlands and Belgium, are too poor in their inventories. EXIOPOL has no time series yet.

In this project, a time series of environmental interventions is used based on the Environmentally weighed Material Consumption indicator (EMC) (Voet *et al.,* 2009; Voet *et al.,* 2005). The data based on the EMC of EU 15 are not ideal but have the advantage of being a very substantial set of (LCA-based of course!) inventory data, while reflecting real developments in the physical part, namely consumption of materials, of the economy over a time span of 10 years. The disadvantage of this time series is that emission profiles are based on static LCA data. The LCI database here is static. This means the process data are not changed over the period 1990-2000. As a result, technological progress in process efficiency will only partly be detected, while end-of-pipe emission reductions will not be detected at all.

7.1 EMC EU15 for 1990-2000

The Environmentally weighed Material Consumption indicator (EMC), was drafted as an overall decoupling indicator in the context of the EU Thematic Strategy on Natural Resources (Voet et al., 2009; Voet et al., 2005). The EMC is calculated by multiplying the material flows that are 'consumed' by a certain economy with a factor of their environmental impact per unit mass (e.g. kg) of consumed material. A double aggregation step is made by adding over materials to approach the total metabolism of a national economy, and by adding over different impact categories to arrive at a total estimate of environmental impacts, where the contribution of the different materials as well as the contribution of the impact categories is still visible.

Two types of information are generated and used to determine the environmental impacts of materials that are consumed by an economy:

- the total cradle-to-grave impact per kg of each material,
- the number of kilograms of each material being consumed.

To specify the environmental impacts of a material, a life-cycle approach is taken. This implies that impacts over the life-cycle, whether they occur within or outside the country, are included. For every considered material, an estimate is made of the emissions to and extractions from the environment throughout its life cycle. This includes not only the emissions and extractions of the material itself, but also those related to energy and auxiliary materials used for its extraction and production, emissions of impurities and pollutants included in the material during use or waste treatment, etc. These emissions and extractions are translated into a limited number of impact categories according to the LCA-methodology, which in turn can be aggregated to one overall impact score.

The number of kilograms of a material being consumed in a national economy is determined by drafting material balances per material. For this, MFA, industrial and agricultural production statistics and trade statistics are used, with some additional information.

Figure 7-1 gives the EMC based on new impacts per kg material and apparent consumption based on the Eurostat statistics. The EMC2009 is based on the following basic information:

1. apparent consumption: Eurostat statistics on MFA accounts & agricultural products balance sheets,
2. impacts per kilogram material are based on:
    a. process data of the Ecoinvent2.0 database (Ecoinvent, 2008) and LCA food database for agricultural animal products (LCAfood, 2008);
    b. ILCD characterization factors[36];
3. Normalisation data: world 2000 emissions and extractions (Wegener Sleeswijk et al., 2008).

[36] 2010 draft version

4. Weighting methods; BEES, EPA (Lippiatt, 2007), NOGEPA (Huppes *et al.*, 2007), Ecoindicator99 (Goedkoop & Spriensma, 1999), LIME (Itsubo *et al.*, 2004), ReCiPe damage (Heijungs, 2008) and NEEDS (Preiss & Klotz, 2008).

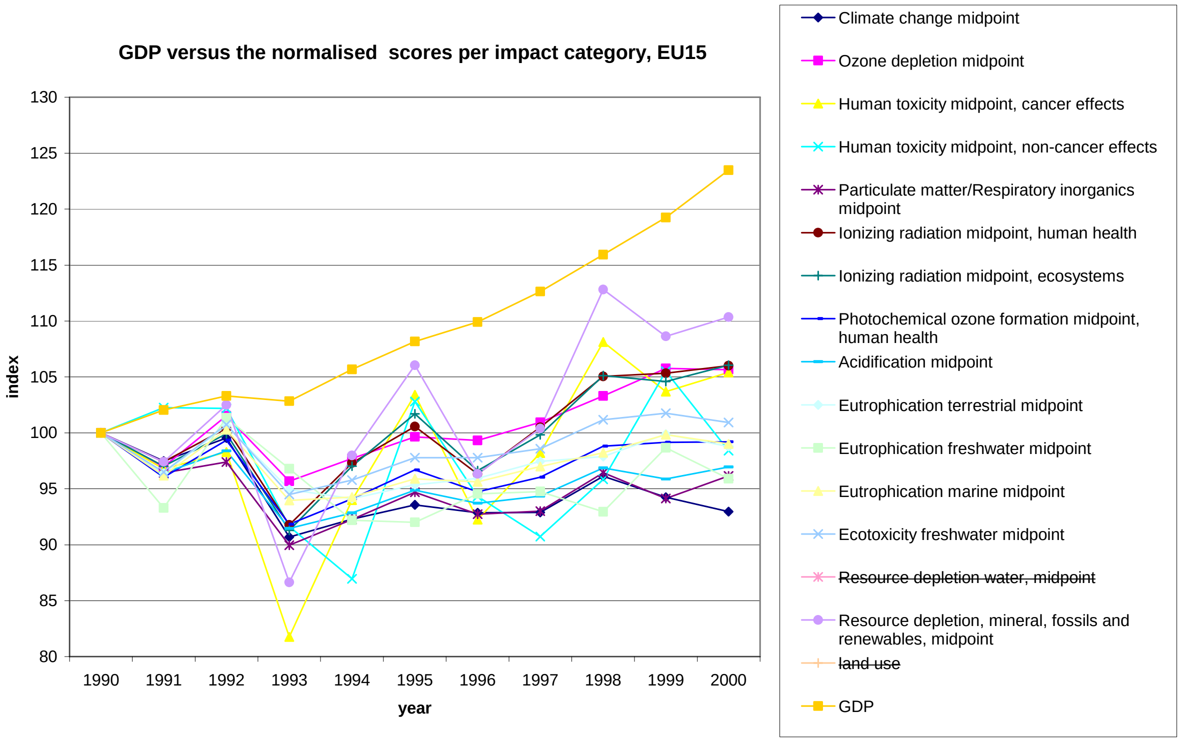


Figure 7-1: GDP and normalised impact scores per midpoint impact category for the EU15 in the year 1990-2000. Intervention profiles for the years are based on EMC (Voet *et al.*, 2009). (striked-through impact categories not available in the 2010 draft version of ILCD characterisation factors)

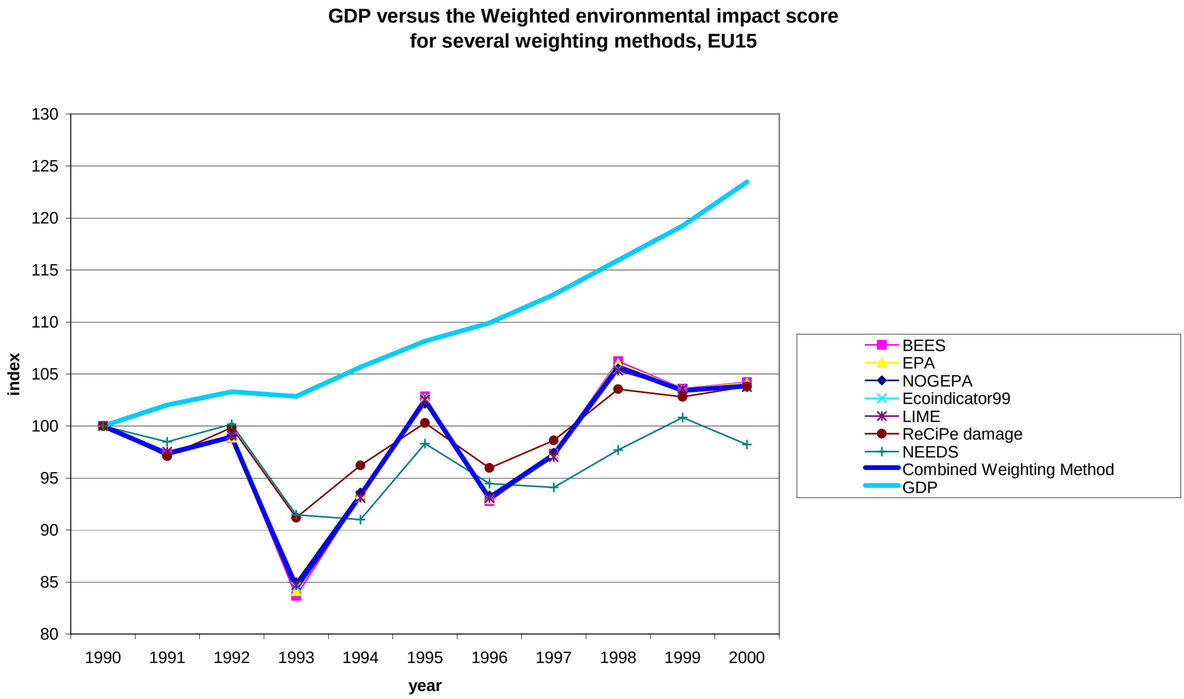


Figure 7-2: GDP and environmental impact scores for the EU15 in the year 1990-2000, using the different weighting methods available. Intervention profiles for the years are based on EMC (Voet *et al*., 2009 Voet *et al*., 2005), as in figure 7-1.

7.2 Description of the results and conclusions

Figure 7-1 presents the change of GDP together with the change in environmental impact score for the EU15 over the period 1990-2000. The environmental impact score is plotted for the combined weighting method, using the proposed setting, and the separate weighting sets.

For the choice in ranking of the weighting methods in the meta weighting tool the most practical point to note is that all methods converge. There are slight differences only, probably because in all weighting methods the substances CO_2, NO_2 and SO_x have a large contribution in the overall impact score. This simplifies substantially the discussions on which weighting set or combination of weighting sets to use.

Figure 7-1 displays a gradual increase of GDP whilst the environmental impact score remains more or less the same or only slightly decreases. Therefore, according to this time series there is only a relative decoupling. Note, however, that in the EMC the intervention profiles of the LCI database on materials is static. This means the process data are not changed over the period 1990-2000. As a result, technological progress in process efficiency will only partly be detected, while end-of-pipe emission reductions will not be detected at all.

8 Conclusions and remarks

In this project, seven operational weighting sets have been selected and have been applied to the intervention profiles of the EU28, the World and the Netherlands, not on time series. Three sets are available for the weighting applied on midpoint level. Three sets are available for the weighting applied on endpoint level. One set is available for the integrated modelling and weighting, applied on intervention level.

All weighting sets applied on midpoint level refer to interactive panel weighting, i.e. EPA, BEES, and NOGEPA. Two weighting sets applied on endpoint level refer to panel weighting, i.e. Ecoindicator99 and LIME. One weighting set, ReCiPe damage, refers to weighting on endpoint level using damage cost based on willingness-to-pay (WtP) valuation, which is itself based on panels but usually not interactive panels. The weighting set in the integrated modelling and weighting refers to different costs. These are damage cost (as WtP) for human health and climate change; market prices for crop damages due to acidification and eutrophication; restoration costs for biodiversity (WtP) and for damages to buildings (market prices).

The weighting sets on midpoint and endpoint level have been made fully compatible with the midpoint and endpoint indicators proposed in the ILCD recommended set of impact assessment factors. The weighting set of integrated modelling and weighting is not based on separately distinguishable characterization models and midpoint to endpoint modelling. This weighting set is not consistent with the ILCD recommended impact assessment factors as available at the time of development of this project.

In the weighting methods, the original weighting sets on midpoint level are not fully compatible with midpoint impact categories as specified by the ILCD recommended impact assessment[37]. Some categories were missing and/or superfluous. For these cases, in this project additional weighting factors are proposed. Note, however, that although in this project weighting sets are made available for all impact categories, the version of the ILCD characterisation factors used was not complete[38]. Characterisation factors were, at that time, missing for land use and water depletion. Development of these missing characterization factors is beyond the scope of this weighting project.

The original weighting sets on endpoint level are fully compatible with the endpoint impact categories as specified by the ILCD recommended impact assessment. However, the dimensions in which these factors differ, thus it is not possible to apply a set of weights to them. If this is done, this leads to odd results. For example, in the case of ReCiPe damage cost, different domains refer both to square meters and

[37] European Commission - Joint Research Centre - Institute for Environment and Sustainability. International Reference Life Cycle Data System (ILCD) Handbook - Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context. Publications Office of the European Union; in publication, 2011. Will be available online at http://lct.jrc.ec.europa.eu/assessment/projects

[38] 2010 draft version

cubic meters. We adapted for these differences by unifying dimensions, though outcomes still seem odd.

The integrated modelling and weighting is partly based on different characterisation models than those proposed by the recommended ILCD impact assessment. The integrated modelling is mostly not transparent in the operational models used and lack the intermediate results calculated for midpoint indicators and from there to endpoint indicators. We tried to use only the damage valuation method, where available. This is in order to remain as consistent as possible with the other two methods, and to allow for application in a policy context. A thorough comparison of the effect modelling between midpoint and endpoint modelling versus integrated modelling is therefore not possible at this moment. However, on the intervention level it is clear that the integrated models only take into account a very limited number of interventions. We expanded the sets as far as possible by ‘methods transfer’, using the other methods to estimate missing values.

All methods have specific advantages and disadvantages, on which diverging views exist. Midpoint approaches have a clear modelling basis with mutually inconsistent elements and they rely on extensive subjective estimates in the combined further-modelling-and weighting step. Endpoint models can have a weak modelling step after the midpoint and then are conceptually similar to the valuation step in the economics oriented integrated modelling and weighting. The integrated modelling approach has some strong points in modelling (e.g. in climate modelling), but is weak in its further modelling. The valuation step of this approach is best specified, based on thoroughly tested but not unquestionable methods.

The seven selected and expanded operational weighting methods have been combined into a single meta-weighting set. This combined weighting set can be varied as to the strength of the individual methods in determining the outcome.

The application to a time series of European data suggests that there is not a wide divergence between the different weighting methods, at least as developed and applied in this report. This means that the choice of specific weighting methods may not have an overarching influence on outcomes and the combined set of meta-weights may reasonably reflect different positions in weighting. Nevertheless, this may also be linked to some of the adaptations and extrapolations across methods made in this project.

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Annexes

Annex 1 Note of the authors on economic valuation of externalities

The meta-weighting procedure as specified in this report allows for the specification of weights in monetary terms, as one of the weighting methods included is economic valuation, mainly based on willingness-to-pay. When using the outcomes in terms of for example eco-efficiency analysis, the trade-off between environment and economy is not formalized and can be made at a policy level or even at a case level. However, the monetized values are expressed in the same units as the economic scores, allowing for an integrated overall economic score, as is usual in cost-benefit studies. Cost-benefit type of studies are increasingly used in a policy context, both in the EU and in the US. Therefore, there is a special responsibility in this weighting project to use the most relevant figures in valuating environmental externalities.

There is opposition against the use of monetary valuation based on different grounds. One line of reasoning is that the contingent valuation techniques are not valid for guiding long-term policy decision, and derived technology decisions. A recent and thorough statement of this position is for example Ackerman (2009a; 2009b). This position refutes the welfare theoretical building on which much of current economics rests. Such positions have a different starting point. When using the outcomes of current economic valuation, there will hardly be any policy or measure which can be based on the analysis resulting, as the figures just are too low, so a simple analysis makes clear. Ackerman then proposes to leave the contingent valuation domain and turn to a Baumol-type of marginal abatement cost (MAC) approach. Set emission reduction goals, analyze the marginal cost for reaching the goals, and use this figure in applied analysis of policies and technologies. We will not follow this line of reasoning here.

The second line of reasoning, which will here be adopted, follows the main lines of economics but looks into a number of details in the reasoning involved. The monetary figures available, as surveyed in the main weighting report, are based on the combination of effect modeling and effect valuation. We focus here on climate externalities, where this modeling and valuation has a long history involving major scholars from the climate and economics domain. Though there is quite some divergence in detailed positions, the overall outcomes have a high degree of convergence and acceptance. The survey paper by Tol summarizes what the main stream economists have reached as a consensus. These numbers have been developed and used in ExternE [EC, 1995]; NEEDS (see Anthoff, 2007), and are now expanded for example in the ongoing EXIOPOL project. The main reference is the damage due to one ton of CO2 emissions. The value lies around 6 Euro per ton CO2, which corresponds to around 21 Euro per ton carbon. In the US, similarly low values are being discussed, of around 21$ per ton carbon (US DOE 2010). Some economists like Stern (2006) use higher values, reasoning in the main stream economists approach but using a much lower discount rate than is deemed acceptable in the main stream. Tol (2008) gives a survey of studies and applies different discount rates. The discussion on discount rates has been thoroughly surveyed by Portney and Weyant (1999), with convergence on an approach which places a somewhat higher discount rate on the short term and a lower rate for the longer term future. Tol sees Stern as way-out of the reasonable domain of applicable discount rates. We will not step into the line of reasoning on discount rates either.

The core argument for using deviating values from the dominant line as surveyed by Tol is based on the set-up of empirical modeling. This modeling uses the central value of the IPCC climate models. The marginal value of damage due to one ton of carbon emissions is relative to a scenario which links to the central scenario of the IPCC, for limiting climate change to two degrees Celsius by 2050. The risks and uncertainties taken into account are those associated with the central value, not with the risk that the climate outcome may be substantially different. For example, the two degrees change may lead to substantial changes in global weather patterns and may induce a substantial change in thermohaline circulation patterns in the oceans. Such risks are dealt with in most studies.

However, the current attacks on the IPCC model focus on the uncertainties involved in the model itself. There is valid reasoning why the effects of climate changing emissions might be much lower than the central value on which the IPCC reached (now somewhat crumbling) consensus. There also is valid reasoning why the effects of such emissions might be much more extreme, leading to higher temperatures. Most serious positive feedback effects may be those of a climate run-away based on the methane emission from smelting tundra and from oceanic clathrates. The chance on such positive feedback events is quite low. However, the effects involved may be dramatic, possibly leading to climate change which will wipe out a major part of the human population, and to a quite unprecedented loss of biodiversity, not comparable to current already very fast species extinction. How to deal with these a-symmetric uncertainties?

The first step in the analysis is to specify these less probable outcomes, both the less than mid-value outcomes and the higher than mid-value outcomes. One can envisage these outcomes as climate change levels with a probability distribution. The total chance on the sum total of all possible climate outcomes is one, as there will be one future only. That total is the area under the curve in the figure.

The seminal paper by Weitzman (2009) indicates that a fat tail is the situation to consider in climate change, meaning that the sum of probabilities in the right hand tail is substantial. Using the available modeling studies, Weitzman sets the chance of temperature rise of more than 5 degrees Celsius due to a doubling of CO2 concentration relative to preindustrial at 1%. This estimate itself has a high uncertainty (in the sense of unknown probabilities), as the studies used are inherently inadequate for a situation where data for modeling are mostly lacking. That is the fat tail, which graphically looks quite thin, thinner still than in this graph. It cannot reckon yet with unknown feedback mechanisms as this range of temperature change has no known examples in the geological past of the earth.

The second step is to link the range of climate changes resulting to their environmental effects and next also to the further socio-economic effects resulting. That outcome forms the basis for economic valuation. This step is laden with modeling difficulties as also discussed in the central value based models. These problems are less severe with more limited climate change and more severe with larger and faster climate change. Several problems in effect modeling become difficult to handle, like the climate influence on adapted food production, the possibility of economic collapse and broader societal collapse, and the number of death resulting also from such secondary failures. There is no serious modeling of such consequences of climate change available. Choices on discounting them to a net present value in a certain year, (like the year of decision or the year of emission) then is not so relevant. In the realm of nuclear energy analysis a similar discussion has been enriched by an additional factor like the societal risk aversion, which transforms the scores non-linearly, depending on the severity of the (disastrous) effects. These nuclear disasters are insignificant however compared to the effects of severe climate disruption. The methods as had been developed have not been broadly accepted since.

In the current discussion, the paper by Weitzman (2009) gives some clues on relevant orders of magnitude to consider in this situation of fundamental uncertainty. His reasoning is quasi-quantitative. Assume that you would use a valuation method of effects as now applied in the central value based method. Using back of the envelope type of quantification of disasters, it is clear that the disasters would dominate the overall results, even if multiplying them with a very low chance on occurring. The chance times weighted effect score, integrated over all small chances at the right hand side, will be a much larger area than the surface area around the two-degrees change highest probability domain. The small-effect area to the left of the mid-value is insignificant for decision making, though currently dominant in public discussion.

How to deal with this subject of such direct practical importance in decision making? There clearly is not one method to come to an outcome, as empirical modeling is substantially lacking. Also, the evaluative framework dealing with massive loss of human life just is not there, nor is there is sound basis for measuring the welfare of the remaining population. Thinking about the unthinkable, a term coined by Kahn (1962) in discussing nuclear war, has not led to specific outcomes for allowable nuclear war, let alone more generally usable outcomes as in substantial climate change. Risk aversion and precaution give some guidance in a qualitative sense, but not at the level of economic valuation of disasters. The solution we use has the beauty of simplicity, and shows the relative arbitrariness of the choice we make. We stick to the order of magnitude reasoning. The order of magnitude underestimation of current mid-value methods as surveyed by Tol might be set at one or two, or even three orders of magnitude, following Weitzman. We take a modest approach of one order of magnitude and multiply the customary mid-value outcomes by a factor 10, arriving at around 60 Euro per ton carbon. The resulting damage per ton of carbon dioxide then falls in the range of the Stern report but is based on fundamentally different reasoning. Sterns figure of 85$ per ton CO_2 would be slightly higher than the choice we made here.

Concluding: We will use the Weitzman based reasoning and the one order of magnitude scaling up, arriving at ***60 Euro per ton CO_2***, equivalent to ***220 Euro per ton of carbon***.

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Annex 2 External review comments

Comments on ”Technical review of existing weighting approaches in LCIA (Deliverable 1, Final version 27 May 2009)” and “Recommendations on an appropriate weighting approach for measuring the EU-27 overall environmental impact, (Deliverable 2 and 3, Final draft 25 February 2010)”, by Gjalt Huppes and Lauran van Oers, CML, Leiden University.

We received review comments from Rainer Friedrich and colleagues, at IER, Stuttgart, Germany and from Göran Finnveden at Environmental Strategies Research – fms, KTH Royal Institute of Technology, Stockholm, Sweden.

The comments from IER mainly referred to the sections on economic valuation, with a number of details which have been corrected. These were useful additions.

The comments below are by Göran Finnveden. Most of them have led to adaptation in the report, or in the paper which accompanies the report. Specifically, the references mentioned have been added to the text. They broaden the view but do not lead to other choices, as these methods either are not complete or are not in line with ILCD recommendations. On one quite fundamental point we differ with the views of Finnveden, that is on monetised midpoint evaluation. By nature of midpoint modelling, the effects specified are not those that are amenable to willingness-to-pay types of evaluation. Climate change is a physical phenomenon having further effects on humans, nature and the economy; these further effects can be subject of monetary valuation. Of course it is possible to have midpoints weights and then link one to monetary valuation as a reference and then translate all of them into this monetised score, as midpoint weights. These can be translated back into monetised weights per environmental intervention. This reference value should be an important one, like for CO_2 and climate change. This reference value based monetisation can be applied to all methods. We have indicated this in the text and in this sense we follow Finnveden.

Comments on Deliverable 1

The report is a review of existing weighting methods. I think it is the best review of the topic that has been produced for some time now. I have however a few comments:

a) The review focuses on some methods, however the choice of methods is not really motivated and there are a number of methods published in the scientific literature which are not included. Examples of references that could have been included are Mettier and Hofstetter (2005), Finnveden et al (2006), Huijbregts et al (2006), Soares et al (2006), Zhang et al (2006), and Weidema (2009). The choice of methods leads for example to a lack of monetarised mid-point methods. Also perhaps references should be made to earlier reviews and their conclusions[39].

b) The review is quite uncritical. I think we need to discuss weighting methods more critically. Right now there is almost an “anything goes culture” regarding weighting methods. It is of course difficult to evaluate weighting methods since we don’t know the right answers. But we can evaluate

the scientific parts (are there logical inconsistencies, are best practise use concerned methods, models and data), are there any significant data gaps and

we can evaluate the results and discuss if they are reasonable.

The first part could be discussed in Deliverable 1.

Comments on Deliverable 2 and 3

I think you are doing a great work in calculating the most important environmental impacts and interventions according to the different weighting methods. This gives an excellent input to a discussion on whether the results are reasonable. I think it would be feasible to take one step further in that discussion. For example, as you note the results for Carbon-14 are questionable. Also I think the results for dioxins to fresh water are unreasonable[40]. Also, I believe that the results for Climate change are too low for many (or all) weighting methods[41]. The economic effects from climate change are according to the Stern report huge and possibly underestimated since later research points at larger impacts at current emission levels than included in the Stern-report. Climate change is also described as the biggest global health threat in the 21st century (Costello et al, 2009). Thus climate change should probably be weighted orders of magnitude higher than for example dioxins to fresh water and carbon-14.

[39] We will have a slightly more extended discussion in the paper

[40] The results for dioxin have been adapted. In the emission registration the emission of dioxin to water is given in gram instead of kilogram. So in the calculations the emission was a factor 1000 to high. This mistake has been adapted.

[41] The damage costs for GHG emissions in NEEDS have been increased with a factor 10.
Weighting factors for the midpoint weighting have not been adapted, although this would be possible.
Weighting factors for the endpoint weighting have not been adapted. In the endpoint method the weighting factors are given for the Areas of Protection “human health” and “ecosystem health”. Both AoPs are affected by GHG emissions. To change the relative contribution of GHG effects compared to other effects, not the weighting factors but the midpoint to endpoint modelling should be adapted. This midpoint to endpoint modelling is part of the characterisation and not of the weighting across impact categories. This weighting project was supposed to build on the ILCD recommended set of characterisation factors. Changes in the midpoint to endpoint modelling was outside the scope of this weighting project.

Also the weighting factors for particles in some of the weighting methods seem way to low. We know that particles kill quite a number of people each year. I don't think the impacts of some of the other hazardous compounds are anyway near that.

A general comment is that I lack a critical discussion about advantages and disadvantages of panel approaches. There are different types of biases as for example discussed by Mettier and Hofstetter (2005) which needs to be handled. A major problem, as I see it, is that panels tend to give weights within an order of magnitude (and often less, e.g. a factor of 3-4) between the things they are to be valued regardless of what the things are. This means that if the "true value" (if there would be a true value) would be several orders of magnitude, most panels would not be able to handle that. This is especially so if the AHP approach is used where a factor of 9 is the maximum difference between two things that are to be weighted against each other. I see this as a major problem and one of the reasons we may get strange results some times[42].

Another related bias that is typical of panel approaches is that the summed weight of a number of things to be weighted typically is higher than if it had been weighted by itself. Thus if you ask a panel to weigh eutrophication and then divide it by three (as you do here), the weights will most probably be lower than if you had asked a panel to weigh the three different subcategories directly. This is a problem when you calculate the different weights in your report.

In the reports I thus lack a discussion of different biases in panel approaches and a discussion on how you will try to handle them in your method.

In deliverable 2 you only include seven methods. Thus several of the methods included in the review did not make it to the second phase. What were your criteria for choosing the methods? Why were these methods selected?[43] Also several potentially relevant methods were excluded also from the review and thus not included here.

[42] We have added a remark in this vein in the main text of the report.

[43] In deliverable 1 it is concluded that some of the methods are methodologically wrong because they actually do not have an explicit weighting across impact categories. Another important criterion is that the weighting should be applied on the ILCD recommended set of impact categories. An exception is made for the integrated modelling and weighting. This method does not comply with the recommended ILCD impact assessment. Nevertheless the method is taken into account because the method is often used in political decision making.

The three mid-point panel methods are similar and it is thus not surprising that they give similar results. Because they have approximately the same impact categories, and because panels tend to give weights within a narrow range as mentioned above, it is not surprising that they give similar results. Perhaps the results would have been more interesting if you had included methods that were more different to each other.

I have problems understanding why the different indicators in Table 2.2b have different units, and what the implications of that are, and also the implications of your conversion factors. Maybe this needs more explanation[44].

I am glad that you included the “Integrated modelling and evaluation”. It would be interesting if you would be able to discuss which Human health impacts are included for the different interventions. At least in earlier versions of the Ecosense model, only some effects and some pathways were considered and not necessarily the most important ones. Thus a discussion about data gaps would be useful (if possible).

I like your discussion about discounting. However, the choice you make still leads to a rather heavy discounting of long term effects. I think that you perhaps should have chosen a lower discounting or at least discussed the impacts of choosing other types of discounting.

The choice of using data from Tol leads to a low valuation of climate change. In our work we used data from Tol as minimum values and data from the Stern review as higher values (Ahlroth and Finnveden, 2009). Today, I might have chosen data from Stern as medium values and picked other data as high values. I think your choice of climate change data leads to too low values. At least you should discuss this[45].

As you note, the NEEDS project use a mixture of different types of monetarisation data and that is a problem. Sofia Ahlroth developed WTP-data for eutrophication and acidification that we use in Ahlroth and Finnveden (2009). Perhaps they can be useful-

[44] The different impact category indicators should NOT have different units. However, it seems that in the present version of the ILCD database the characterisation factors are expressed using different units. Before a weighting can be applied these factors should be transformed using the multiplier and divider presented in table 2.2b.

[45] The damage costs of GHG emissions have been increased with a factor 10.

Table 3.1 could use some more explanations concerning the meaning of numbers in bold and in italics[46].

The explanations immediately after Table 3.1 could use some more explanations, for example for which method the different adaptations are made[47].

Why do you assume that weighting factor for radiation should be equal to the weighting factor for indoor air quality?[48]

At some places, for example in the first sentence in section 4.1, you write that Figure x shows something. I think statements like that are problematic because they assume that the results and thus the weighting methods that have been used are correct in some sense. I think that all these statements should be made more conditional, for example, Figure x shows something according to weighting methods x, y and z. I think that would be more correct[49].

In section 4.1 your raise questions concerning C14. I think you should try to answer them as well.[50]

In relation the ReCiPe damage cost you question the results because they are dominated by climate change ecosystems. I wonder why? I don't see any arguments why you can be so sure. On the contrary, these results may be quite reasonable, (I would say depending on the type of health impacts included for climate change)[51].

In section 4.3 you calculate the damage costs in the EU28. This cost is quite low. It is for example low compared to the results from the Stern review. I think this

[46] **Bold** figures are the weighting factors in the original literature. *Italic* figures are derived or adapted figures according to the comments given underneath the table.
[47] Comments underneath the table explain how the factors are derived/adapted. More information may be found in the spreadsheet.
[48] The weighting factor of EPA and BEES for indoor air quality is superfluous. As a first estimate this factor is used for radiation. The average factor more or less corresponds with the factor when all impact categories are weighted equally.
[49] The statements have been made more conditional.
[50] Some possible explanation has been given. However, all data, that is emissions, characterisation factors and weighting factors, may have (large) uncertainties. A thorough analysis of all these data is beyond the scope of this project.
[51] Due to several updates in the ILCD factors this outcome has been changed. The score for ReCiPe damage cost is completely dominated by damages to ecosystems caused by ionizing radiation. This seems to be disputable and may be caused by several flaws in the midpoint to endpoint modelling.

suggest that your damage costs are way to low, probably because to few impacts are considered and the discounting is (too) high.[52]

The meta-weighting is interesting. However the meta-weighting is completely dominated by three methods which are very similar in both approach and results. I think it would have been more interesting if you had combined methods which are different in approach, and therefore probably also in results. It would also be interesting if you would have picked out methods that you by some criteria would consider better than other methods. In the conclusions you suggest that the Combined methods can be a solution where there are pros and cons of different methods. But if the Combined method in practise only include one approach, this does not seem like a solution.

At the end of section 6.3 you state that there probably will be a convergence in weighting results. I am not so sure about that. There would probably be a convergence in characterisation results, but if the weighting truly reflects different values, I can’t see why there should be a convergence.

In section 7 under the heading Tasks of the panel, you state that the first task of the panel is to estimate the causal chains from the midpoint to the effects. I think this may need some consideration. One of the advantages of midpoint modelling and midpoint valuation is that uncertain effects can be included in the valuation. In endpoint valuation only the effects that can be modelled can be included. This means that effects that are to uncertain to model can not be included in endpoint evaluation thus leading to a potential underestimation of the effects. In midpoint modelling such effects can however be included. The importance of such uncertain or even unknown effects will depend on how risk-aversive the panellist is. Different persons may thus want to evaluate different things in the casual chains. A risk-aversive panellist may want to evaluate things early in the casual chain given high values to uncertain or even unknown effects, whereas a not so risk-aversive person may want to give less weight to uncertain effects and thus want o evaluate things later in the casual chain. Different panellists should therefore have the freedom to handle the casual chains in different ways and decide which effects are relevant. For example, I think a lot of people would think climate change is relevant. This question is of course also linked to our views of science and the possibilities of science to predict environmental effects. Such views are part of the world-views and values that influences the weights but also the choice of valuation method (Finnveden, 1997)

[52] This has been adapted from 230 billion euro to 650 billion euro. This increase is the result of adapted damage costs for GHG emissions (factor 10 increase of original NEEDS costs) and extrapolation of missing damage costs in NEEDS based on ILCD characterisation factors.

Concerning the composition of the panel, I think this also may need some further consideration. The choice of panellist is one of the value choices that has to made when developing panel valuation methods (Finnveden, 1997). Your conclusion is that the panellist should be experienced scientists. Others may argue that when it comes to value choices, scientists can not be given a special role. Especially if the aim is to ”arrive at broadly accepted results”, some may argues that the choice of panellist can lead to biased results.

The question What is to be evaluated may need some more consideration both in terms of what technically can be related to the interventions, but also in relation to what the panellists can grasp. One question is for example if it is the effects a certain year or the effects of the interventions a certain year that are to evaluated. Probably it is the latter. But that needs to be carefully explained to the panellists. For example in the case if climate change, they should not consider the current impacts, that is irrelevant, instead they should consider the effects of this years emissions, far into the future.

The procedure you are suggesting will probably lead to small differences between the different impact categories (within a factor of ten probably within a factor 2-3). I think this is problematic. It can not be ruled out that the true values (if there are any true values) could be much larger. It is therefore unfortunate that the methodological setup will not be able to catch large differences in the weights.

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Annex 3 Spreadsheet "Combined Weighting Method"

This spreadsheet contains basic data and results of the calculation of the environmental impact score of the EU28 in the year 2000. Results are calculated using different weighting schemes for midpoint, endpoint indicators and impact pathway approach indicators. The impacts estimated are based on the total of interventions (emissions and extractions) in the EU28 in 2000, taken from Wegener Sleeswijk et al., 2008. Characterisation of these interventions is carried out using the ILCD recommended characterisation factors (draft 2010 version). Normalisation factors are based on the total of interventions (emissions and extractions) in the world in 2000, taken from Wegener Sleeswijk et al., 2008.

The following weighting schemes are applied

- midpoint weighting: EPA, BEES, NOGEPA, equal weighting.
- endpoint weighting: Ecoindicator99, LIME, ReCiPe damage cost, equal weighting
- impact pathway approach: EXIOPOL/NEEDS/ExternE

There is a 'small' version and an 'extended' version of the spreadsheet. Both spreadsheets contain the same assumptions and generate the same results. However, the extended version also presents intermediate results of different weighting methods. The spreadsheets can be downloaded from the CML website:

http://www.leidenuniv.nl/cml/ssp/download/IES_weighting_D2_methods_applied_on_EU28_world_NL_2000+timeserie_small_version_NEW_version_ILCD.zip

http://www.leidenuniv.nl/cml/ssp/download/IES_weighting_D2_methods_applied_on_EU28_world_NL_2000+timeserie_extended_version_NEW_version_ILCD.zip

How to use the spreadsheet

Most users of the spreadsheet will probably use the worksheets 3-7 and 9-10.

The worksheets 3-7 refer to the "meta weighting tool" and allows you to make a mix of the described weighting methods and present the resulting scores and contributions.

The worksheet 9 and 10 allows you to change the weighting factors of the different midpoint and endpoint weighting methods. The blue marked cells are the weighting factors actually used on the recommended ILCD characterisation set. Please note that some of the factors are derived factors from the original weighting set.

Watch out! If changes are made in the weighting factors the file should be saved using a different name in order to prevent loss of the original weighting sets and assumptions for derived weighting factors.

Meta weighting set selection

In this spreadsheet one can adjust a user defined application of type of weighting methods: midpoint, endpoint and/or integrated modelling and weighting.

CNW imp sc (meta w.tool)(EU)

This worksheet will give the characterised, normalised and weighted impact scores for the intervention profile of the EU28 in the year 2000. The weighting across the impact category scores is based on the meta weighting tool as selected from the weighting methods in the worksheet "meta weighting set selection". The worksheets CNW imp sc (meta w.tool)(W) and CNW imp sc (meta w.tool)(NL) will give the same information for resp. the world and the Netherlands.

CNW scores sorted (meta w.tool)

This worksheet presents the contribution of substance-compartment-intervention to impact scores of EU28, the world and the Netherlands in the year 2000 (%) for the meta weighting tool as selected from the weighting methods in the worksheet "meta weighting set selection".

The third worksheet "meta weighting set selection" allows you to indicate in which amount you want to take into account the specific weighting methods in the meta weighting tool (see example table A-1).

Selection of weighting approach in the meta weighting set			
type of weighting approach	**operational weighting sets**	**selection**	**contribution of method in the meta weighting set**
midpoint modelling and evaluation	BEES	1	0.333
	EPA	1	0.333
	NOGEPA	1	0.333
endpoint modelling and evaluation	Ecoindicator99	0	0.000
	LIME	0	0.000
	ReCiPe damage cost	0	0.000

integrated modelling and evaluation	NEEDS	0	0.000
		3	

In the example given above the three midpoint weighting sets are selected. All sets are selected with an equal weight (that is all methods are selected with a factor 1). This means that the characterised and normalised impact scores for the different impact categories will be weighted with an assembled weighting set, based on the weighting set of BEES, EPA and NOGEPA, all with equal contribution. In other words in the example the average weighting set of the midpoint weighting sets is applied on the impact category scores.

Of course it is also possible to select just one weighting set, or more weighting sets or several weighting sets using different selection factors (see example table A-2).

Selection of weighting approach in the meta weighting set			
type of weighting approach	**operational weighting sets**	**selection**	**contribution of method in the meta weighting set**
midpoint modelling and evaluation	BEES	2	0.250
	EPA	1	0.125
	NOGEPA	3	0.375
endpoint modelling and evaluation	Ecoindicator99	1	0.125
	LIME	1	0.125
	ReCiPe damage cost	0	0.000
integrated modelling and evaluation	NEEDS	0	0.000
		8	

The remaining of the spreadsheet contains the basic data and intermediate results of the different weighting methods. A description of the content of the worksheets is given below.

Content

		tab sheet	description
meta weighting tool	selection of weighting methods	meta weighting set selection	adjust user defined application of type of weighting methods: midpoint, endpoint and/or integrated modelling and weighting
	results (meta weighting tool)	CNW imp sc (meta w.tool)(EU)	impact scores for EU28, based on a selection of the weighting methods (meta weighting tool)
		CNW imp sc (meta w.tool)(W)	idem, the world
		CNW imp sc (meta w.tool)(NL)	idem the Netherlands
		CNW scores sorted (ALL)	contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%) for each weighting method and the meta weighting tool
weighting factors	averages	average weighting factors	sets of average weighting factors for midpont and endpoint modelling and weighting
	midpoint methods	Weigh midp (BEES,NOGEPA)	original and adjusted weighting factors for midpoint modelling and weighting: EPA, BEES, NOGEPA
	endpoint methods	Weigh endp (ECO99,LIME,ReCiPe)	original and adjusted weighting factors for endpoint modelling and weighting: Ecoindicator99, LIME and ReCiPe damage cost
Impact assessment factors	characterisation factors	recommended CF ILCD (sort)	ILCD recommended characterisation factors for midpoint and endpoint modelling (value containing cells of original set)
	normalisation factors	norm. factors (world 2000)	normalisation factors for midpoint and endpoint impact categories; sumproduct of intervention profile world2000 and characterisation factors
interventions	emissions and extractions world, EU, NL	intervention profiles	totals of emissions and extractions in the year 2000 for the regions: world, EU28 and the Netherlands
results midpoint methods	results (BEES)	CNW impact factors (BEES)	impact factors, based on characterisation, normalisation and BEES weighting factors
		CNW impact scores (BEES)(EU)	impact scores, sumproduct of CNW factors and intervention profile EU28
		CNW impact scores (BEES)(W)	idem, the world
		CNW impact scores (BEES)(NL)	idem, the Netherlands
		CNW scores sorted (BEES)	contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)
	results (EPA)	CNW impact factors (EPA)	impact factors, based on characterisation, normalisation and EPA weighting factors
		CNW impact scores (EPA)(EU)	impact scores, sumproduct of CNW factors and intervention profile EU28
		CNW impact scores (EPA)(W)	idem, the world
		CNW impact scores (EPA)(NL)	idem, the Netherlands
		CNW scores sorted (EPA)	contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)
	results (NOGEPA)	CNW impact factors (NOGEPA)	impact factors, based on characterisation, normalisation and NOGEPA weighting factors
		CNW impact scores (NOGEPA)(EU)	impact scores, sumproduct of CNW factors and intervention profile EU28
		CNW impact scores (NOGEPA)(W)	idem, the world

		CNW impact scores (NOGEPA)(NL)	idem, the Netherlands
		CNW scores sorted (NOGEPA)	contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)
	results (average)	CNW impact factor (mid average)	impact factors, based on characterisation, normalisation and the average of the weighting factors of BEES, EPA and NOGEPA
		CNW impact sc (mid average)(EU)	impact scores, sumproduct of CNW factors and intervention profile EU28
		CNW impact sc (mid average)(W)	idem, the world
		CNW impact sc (mid average)(NL)	idem, the Netherlands
		CNW scores sorted (mid average)	contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)
	results (equal)	CNW impact factors (mid equal)	impact factors, based on characterisation, normalisation and equal weighting of the midpoint indicator scores (so no weighting set is applied)
		CNW impact sc (mid equal)(EU)	impact scores, sumproduct of CNW factors and intervention profile EU28
		CNW impact sc (mid equal)(W)	idem, the world
		CNW impact sc (mid equal)(NL)	idem, the Netherlands
		CNW scores sorted (mid equal)	contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)
	results (overview)	midp weight contribution subst	overview, contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)
		midp weight impact scores	overview, impact scores, sumproduct of CNW factors and intervention profile EU28
		Chart midp weight impact scores	chart, impact scores
results endpoint methods	results (ECO99)	CNW impact factors (Eco99)	impact factors, based on characterisation, normalisation and Ecoindicator99 weighting factors
		CNW impact scores (Eco99)(EU)	impact scores, sumproduct of CNW factors and intervention profile EU28
		CNW impact scores (Eco99)(W)	idem, the world
		CNW impact scores (Eco99)(NL)	idem, the Netherlands
		CNW scores sorted (Eco99)	contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)
	results (LIME)	CNW impact factors (LIME)	impact factors, based on characterisation, normalisation and LIME weighting factors
		CNW impact scores (LIME)(EU)	impact scores, sumproduct of CNW factors and intervention profile EU28
		CNW impact scores (LIME)(W)	idem, the world
		CNW impact scores (LIME)(NL)	idem, the Netherlands
		CNW scores sorted (LIME)	contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)
	results (ReCiPe dam)	CNW impact factors (ReCiPe dam)	impact factors, based on characterisation, normalisation and ReCiPe damage cost
		CNW imp sc (ReCiPe dam)(EU)	impact scores, sumproduct of CNW factors and intervention profile EU28
		CNW imp sc (ReCiPe dam)(W)	idem, the world
		CNW imp sc (ReCiPe dam)(NL)	idem, the Netherlands
		CNW scores sorted (ReCiPe dam)	contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)
	results (end equal)	CNW impact factors (end equal)	impact factors, based on characterisation, normalisation and equal weighting of the endpoint indicator scores (so no weighting set is applied)

		CNW impact sc (end equal)(EU)	impact scores, sumproduct of CNW factors and intervention profile EU28
		CNW impact sc (end equal)(W)	idem, the world
		CNW impact sc (end equal)(NL)	idem, the Netherlands
		CNW scores sorted (end equal)	contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)
	results (overview)	endp weight contribution subst	overview, contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)
		endp weight impact scores(EU)	overview, impact scores, sumproduct of CNW factors and intervention profile EU28
		endp weight impact scores(W)	idem, the world
		endp weight impact scores(NL)	idem, the Netherlands
		chart endp weight impact scores	chart, impact scores
		chart endp weight imp sc(contr)	chart, impact scores, broken down into contributions of endpoints
results integrated method	results (NEEDS+Weitzman)		
	missing factors: NOT extrapolated	CW factors(NEEDS_n.ext,GHG_MDC)	valuation factors, based NEEDS and Weitzman (resources), GHG: **Marginal Damage Cost**
		CW scores (NEEDS_n.ext,GHG_MDC)	scores, sumproduct of CW factors and intervention profile EU28
		CW factors(NEEDS_n.ext,GHG_MAC)	valuation factors, based NEEDS and Weitzman (resources), GHG: **Marginal Avoidance Cost**
		CW scores (NEEDS_n.ext,GHG_MAC)	scores, sumproduct of CW factors and intervention profile EU28
		sorted (NEEDS,n.ext)	contribution of substance-compartment-intervention to impact score of EU28 in 2000 (%)
		NEEDS weighted imp scores (EU)	overview, impact scores, sumproduct of CNW factors and intervention profile EU28
		NEEDS weighted imp scores (W)	idem, the world
		NEEDS weighted imp scores (NL)	idem, the Netherlands
		Chart NEEDS	
	missing factors: extrapolated	CW factors(NEEDS_ext,GHG_ MDC)	valuation factors, based NEEDS and Weitzman (resources), GHG: **Marginal Damage Cost**
		CW scores(NEEDS_ext,GHG_MDC)	scores, sumproduct of CW factors and intervention profile EU28
remarks		Remarks	some remarks on data processing and questions related to the ILCD characterisation factors
references		References	references to literature and databases
original data sets		recommended CF ILCD (orig)	ILCD recommended characterisation factors for midpoint and endpoint modelling (original set)
		norm.ref. interventions (orig)	totals of emissions and extractions in the year 2000 for the regions: world, EU28 and the Netherlands (original set)
		NEEDS global warming	NEEDS, damage and avoidance cost for GHG
		Weitzman resources	damage cost for resource depletion based on Weitzman (1999)

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Abstract

In this project, seven operational weighting sets have been selected and have been applied to the intervention profiles of the EU28, the World and the Netherlands, not on time series. Three sets are available for the weighting applied on midpoint level. Three sets are available for the weighting applied on endpoint level. One set is available for the integrated modelling and weighting, applied on intervention level.

All weighting sets applied on midpoint level refer to interactive panel weighting, i.e. EPA, BEES, and NOGEPA. Two weighting sets applied on endpoint level refer to panel weighting, i.e. Ecoindicator99 and LIME. One weighting set, ReCiPe damage, refers to weighting on endpoint level using damage cost based on willingness-to-pay (WtP) valuation, which is itself based on panels but usually not interactive panels. The weighting set in the integrated modelling and weighting refers to different costs. These are damage cost (as WtP) for human health and climate change; market prices for crop damages due to acidification and eutrophication; restoration costs for biodiversity (WtP) and for damages to buildings (market prices).

The seven selected and expanded operational weighting methods have been combined into a single meta-weighting set. This combined weighting set can be varied as to the strength of the individual methods in determining the outcome.

The application to a time series of European data suggests that there is not a wide divergence between the different weighting methods, at least as developed and applied in this report. This means that the choice of specific weighting methods may not have an overarching influence on outcomes and the combined set of meta-weights may reasonably reflect different positions in weighting. Nevertheless, this may also be linked to some of the adaptations and extrapolations across methods made in this project.

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