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Deliverable 7.1. - Meta-analysis of damage costs related to health, the built environment and the ecosystem

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Summary

This report addresses damage costs related to the negative effects that may occur on human health, the built environment, or the eco-system, when hazardous substances are released from the products they were originally contained in. More specifically, the report focuses on the external cost of damages.

Damages to human health, the built environment and the ecosystem are related to what is known as externalities. Externalities are costs or benefits arising from an economic activity that affect somebody other than the people engaged in the economic activity and are not reflected fully in prices. These effects and damages are external because the affected does not receive any compensation and the polluter does not need to pay without being obliged.

Here, three different models for monetary valuation of externalities have been studied in more detail; that is the EPS system, LIME and ExternE/NewExt/NEEDS. These models all assess costs of impacts to human health and ecosystem production capacity. The EPS system and LIME also address costs related to biodiversity whereas ExternE/NewExt/NEEDS is the model that focuses most on damages to the built environment. The monetary weighting factors presented in the different models are quite similar in size; most often the different models value the same externality within a factor of 10.

A case study was made to show how emissions can be linked to damage costs for the substance lead. The main negative effect caused by emissions of lead was assessed to the IQ decrement. For the case of lead, damage costs are approximately 2,680-5,900 €/emitted kg Pb according to Spadaro & Rabl (2004) and 1.58-2910 €/emitted kg Pb according to Steen (1999b).

Glossary

CBA	cost benefit analysis
DALY	disability adjusted life years
ELU	environmental load unit
NEX	normalised extinction of species
PPP	polluter pays principle
QALY	quality adjusted life years
WTA	willingness to accept
WTP	willingness to pay
YOLL	years of life lost
YLD	years lost due to disability

Table of Contents

1.1 The Project RISKCYCLE

RISKCYCLE is a coordination action (CA) within the 7th Framework programme for research (FP7-ENV-2008-1)[1]. It is aimed to establish and co-ordinate a global network of European and international experts and stakeholders to define together future needs of R&D contributions for innovations in the risk-based management of chemicals and products in a circular economy of global scale. Long-term objectives of the activities are alternative strategies to animal tests and reduced health hazards. The project is organised in eight work packages (WPs):

WP1 – Coordination and management
WP2 – Capacity Building
WP3 – Fate and behaviour of additives
WP4 – Alternative toxicity testing for additives
WP5 – Risk assessment methodologies for additives
WP6 – Life Cycle Assessment
WP7 – Socio-economic aspects
WP8- Global strategy for risk based management

This report is the first deliverable within WP7 of the RISKCYCLE project. The material presented here will also be used in the third deliverable of WP7 where socio-economic effects of chemicals will be studied on a global level.

1.2 Additives in products

Additives are added to materials used in consumer products to give the material certain desired properties, for example to make the materials flexible, flame retarded or able to resist light without degrading. Additives can be more or less loosely bound to the material and can therefore be emitted and cause exposure of humans, the built environment and the ecosystem. Various unwanted effects may occur as a result of exposure to additives.

[1] http://www.wadef.com/projects/riskcycle/

Phthalates and other organic compounds which are used as additives have been detected in both indoor and outdoor environments with high concentrations measured indoors, indicating release from products with indoor applications such as electronic appliances, building materials and textiles (Marklund et al., 2005; Bergh et al., 2011). Building products can be especially problematic with regard to emissions of additives since they have long residence times and are used in large quantities in the society.

If products are recycled, an additional problem may arise. When recycling materials, the additives in the original product can be transferred into the recovered materials. The additive composition of the recycled material therefore becomes unpredictable and material, health and safety problems that are not foreseen may arise as a consequence.

Damages to human health, the built environment and the ecosystem due to exposure to hazardous substances can give rise to external costs for the society as a result of for example premature death or loss of species. External costs are costs arising from an economic activity that affect somebody other than the people engaged in the economic activity and are not reflected fully in prices. Here, these costs will be studied in more detail.

1.3 Linking hazardous substances to external costs

To illustrate the concept of external (or damage) cost, we use an example of substances being emitted to air. The steps leading to the evaluation of an emission's damage cost are the following (SPECTRUM, 2004):

1 *Emissions and inventories* are in the case of air pollution related to the assessment of the level of pollutants released from various sources. That is to say emission specification of the relevant technologies and pollutants.

2 *Dispersion modelling of the emissions* concerns how air pollutants disperse in the ambient atmosphere. This step is also called environmental fate analysis, especially when it involves more complex pathways. The pollutants dispersed to the atmosphere are in general modelled using dispersion models.

3 *Exposure calculation to the emission calculations involving impact of emissions on humans and ecosystem of the emissions* means the impact calcula-

tion of the dose from the increased concentration. The dose calculation is followed by calculation of impacts (damage in physical units).

4 *Impact assessment*: assesses the impact caused by exposure to a dose of a certain substance, using dose-response functions, where the dose-response relations are based on epidemiological studies.

5 *External cost of damage* is cost economic valuation of these impacts i.e. external costs and their value (ExternE, 2010). Evaluation of impacts on both the humans and the ecosystem is based on valuation studies, in order to monetize the external effects.

1.4 Purpose of this report

This report addresses damage costs related to the negative effects that may occur on human health, the built environment, or the eco-system, when hazardous substances are released from the products they were originally contained in. Such damage costs constitute one important set of the socio-economic aspects related to hazardous chemicals in products.

This study focuses on the fifth bullet point of the list in Section 1.3, the external cost of damages. Existing models for assessing damage costs for environmental pollutants will be presented, such as the EPS model, ExternE and Lime. In addition, an example of how emissions of a substance can be linked to damage costs is presented for the substance lead.

2 Valuating damage costs – a general background

2.1 Externalities

Damages to human health, the built environment and the ecosystem are related to what is known as externalities. Externalities are costs or benefits arising from an economic activity that affect somebody other than the people engaged in the economic activity and are not reflected fully in prices. These effects and damages are external because the affected does not receive any compensation and the polluter does not need to pay without being obliged.

Externalities may be positive or negative. A positive externality may be the result of actions by an individual or a group benefiting others such as technological spillover, which for instance can be generated by foreign direct investments in a developing country. The positive externality may also lead to higher social benefit, being the profit of an activity to an entire society, including not only the benefit to those members of the society directly involved in the activity, but also the benefits to all other members. In the case of positive externalities, the social benefit is larger than the private benefit whereas the opposite applies for negative externalities. Negative externalities arise when an action by an individual or a group implies harmful effects on others such as air pollution effects on health, forest growth or fish reproduction. When negative externalities are generated they should be internalized into the market economy. By internalizing the externalities (i.e. by including the costs of the externality) environmental costs such as air pollution effects on human health and acidification are allocated to the pollution sources and included in the economics of the activities causing the problem (e.g. industry, traffic, agriculture or energy production).

According to economic theory the problem of externalities would not occur if property rights were properly defined for both private and public goods. In the case of public goods, this procedure would be impossible or rather impractical such as in the case of the European air, waters and ecosystems if the public goods were not defined. Therefore, one of the challenges of environmental economics is to develop methods in order to define and value public goods as well as to compare cost to mitigate the externalities with the benefits enjoyed in their absence or reduction;

and to develop tools to minimise the externalities and their implied impacts on health and the environment.

External costs have to be considered and included in the price in order to give the product their real cost. The external costs are in accordance with the polluter pays principle (PPP) that was adopted by OECD in 1972 and the EU environmental policy. The PPP state that the polluter should bear the cost of policy measures and also ensure that the environment is in an acceptable state. The polluters bear the full financial responsibility for pollution reduction. The idea of PPP is the same as a Pigovian tax, meaning internalising the external diseconomy (Sternhufvud et al., 2006).

2.2 Monetary valuation of externalities

In order for physical measures of impacts to be commonly measurable, they must be valued in monetary units. The monetary valuation of different effects is not a straightforward procedure since many of the effects have no market value. The total value is often composed of both use values and non-use values. The *use value* is the value derived from actual use of a good or service. This use value includes direct, non-direct and option values. The direct use value is the value attributed to direct utilization of ecosystem services. Non-direct-use values or "functional" values relate to the ecological functions performed e.g. by forests, such as the protection of soils and the regulation of watersheds. Option value is the value that people place on having the option to enjoy something in the future, although they may not currently use it. The *non-use values*, also referred to as passive use values, are values that are not associated with actual use, or even the option to use a good or service. The non-use values include both bequest and existence value. Bequest value is the value that people place on knowing that future generations will have the option to enjoy something. Existence value is the value that people place on simply knowing that something exists, even if they will never see it or use it. (Kolstad, 1999).

In order to assess these values, environmental economics uses several methods. These valuation methods may be based on stated preferences or relealed preference. *Stated preference methods* involve asking respondents for their willingness to pay (WTP) such as in the case of contingent valuation and choice experiment methods, as well as asking the respondents for their willingness to accept (WTA). WTP studies are used to determine market price for a non-market good. The current preferences of the survey population state the current price, given their awareness of the subject and the information available. The values mirror the current attitude and preferences, rather than the importance of the environmental impact. The result can be compared to the values of marketed goods (Ahlroth, 2007). Other methods are based on *revealed preferences* that are often based on consumers' or producers' behaviour or actions such as: *The hedonic price method* which is used to estimate the value of environmental effects on properties such as the effect of noise or air pollution on house prices; *The production function method* is used to estimate the value of the environmental effects on production such as the effect of ground-level ozone on the production of wheat or timber.

2.2.1 Valuation of health damage externalities

In the case of health effects other methods than stated or revealed preference ones can be used to estimate the impact of externalities. Two of the most popular methods for valuating human health damages are the Disability Adjusted Life Year (DALY), or the Quality Adjusted Life Year (QALY).

The DALY describes how many years of life that are lost due to premature death and morbidity as the result of a certain disease (WHO, 2011). The DALY is calculated as:

DALY=YOLL+YLD

YOLL stands for Years Of Life Lost which corresponds to the number of deaths caused by a certain disease multiplied by the standard life expectancy at the age at which death occurs. YLD stands for Years Lost due to Disability and is calculated as the number of incident cases multiplied by a disability weighting factor which is in turn is multiplied by the average duration of the case until remission or death. The disability weighting factor describes the severity of the disease on a scale from 0 (perfect health) to 1 (death).

Opposite to the DALY, the QALY describes how many years that would be saved if a certain intervention towards a disease would be implemented. In the QALY, the value of quality of life is assigned from 0 (dead) to 1 (perfect health).

2.2.2 Valuation of ecosystem damage externalities

To value the ecosystem *The standard price method* can be used, which involves costs for reducing pollutants to a level that is sustainable, which is not comparable to the health and welfare values for the ecosystem. However, in the evaluation of acidification impacts on health, biodiversity, based on action and health treated in the CBA, values from other studies have been adapted and used. This procedure is called benefit transfer, meaning benefits estimated in other studies are adapted to new applications, which represent extrapolation. This procedure is often used since making new, locally adapted studies is expensive and time consuming.

2.2.3 Valuation of damage externalities to the built environment

Damages to the built environment due to anthropogenic emissions of pollutants can affect all built structures in the society but it mainly affect buildings, due to their long life. Other objects such as cars tend to be replaced long before effects from pollution damage become significant. The two most important damages to the built environment caused by manmade emissions are considered to be soiling caused by emissions of particles and corrosion due to acid rain (Rabl, 1999).

External costs to the built environment can be expressed as the sum of renovation cost and amenity loss (Rabl, 1999). While renovation costs are direct costs with a defined value, the amenity loss needs to be valued. To do this, contingent valuation can be used. In the case of soiling, Rabl (1999) showed that amenity costs can also be inferred from renovation costs, where the amenity loss is approximately equal to the renovation cost.

3 Comprehensive monetary valuation models

There are various models available for monetary valuation of damages to the built environment, to the ecosystems and to human health. Here, a set of different valuation models are presented. The models presented here are comprehensive models that use an impact approach in order to valuate externalities directed towards a wide variety of endpoints. These models are also accepted by the scientific community in the sense that have been used widely for monetary valuation of externalities.

The EPS system was included in this study since it was one of the first monetary valuation models developed. ExternE and its following models were included on the basis that these models are today used as the standard model for monetary valuation of externalities in Europe. The LIME model has been included as an example of a non-European model.

3.1 The EPS system

The EPS (Environmental Priority Strategies in product design) system was initiated in 1989 by Volvo Automotive Company, IVL Swedish Environmental Research Institute and the Swedish Federation of Industries. The current version was developed at the Center for Environmental Assessment of Product and Material Systems (CPM) (Steen, 1999a and b).

The EPS system was initially developed to be used within the product development process as a tool to help assess the environmental performance of products. The system is based on LCA (Life Cycle Assessment) methodology and uses inventory data (kg of substance X), characterisation factors (impact/kg of substance X) and weighting factors (cost/impact) to calculate the external costs or values of a product. By multiplying the characterisation factor with the weighting factor, an impact index is obtained (cost/kg of substance X) which describes the costs/values related to the emission/use of a kg of a certain substance.

The first version of the model was developed in 1991-92. In the EPS system, the impacts are expressed in terms of socio-economic costs (or values) occurring by unit effects of damage to five safeguard subjects: human health, biological diversity, ecosystem production, natural resources and aesthetic values. The latest version vas published in 1999 (Steen, 1999 a and b). Table 1 lists the weighting factors used in the EPS system.

Table 1 Monetary weighting factors in the EPS system (Steen, 1999b)

Safeguard subject	Impact category	Category indicator	Indicator unit	Weighting factor (ELU/ indicator unit)[1]	Uncertainty factor
Human health	Life expectancy	YOLL[2]	Person-years	85000	3
	Severe morbidity	Severe morbidity	Person-years	100000	3
	Morbidity	Morbidity	Person-years	10000	3
	Severe nuisance	Severe nuisance	Person-years	1000	3
	Nuisance	Nuisance	Person-years	100	3
Ecosystem production capacity	Crop growth capacity	Crop	kg	0.15	2
	Wood growth capacity	Wood	kg	0.04	1.4
	Fish and meat production capacity	Fish and meat	kg	1	2
	Soil acidification	Base cat-ion capacity of soil	Mole H^+ - equivalents	0.01	2
	Production capacity for irrigation water	Irrigation water	kg	0.003	4
	Production capacity for drinking water	Drinking water	kg	0.03	6
Biodiversity	Species extinction	NEX[3]	dimensionless	1.10E+11	3

[1] 1 ELU (Environmental Load Unit) corresponds to 1 Euro
[2] YOLL (Years Of Life Lost)
[3] NEX (Normalised EXtinction of species). Normalisation is made with respect to the species extinct during one year on a global basis.

For abiotic stock resources, not listed in the table above, the resource value is set as equal to the production and environmental cost for a renewable alternative. For fossil oil, gas and coal, these alternatives are rapeseed oil, biogas and charcoal, respectively. For metal (metal ores), the production and environmental costs to upgrade low-quality ores (sustainable supplies), such as silicate minerals, to a quality similar to present day ores, using a bioenergy-driven process (near-sustainable process), is used as the resource value.

3.2 LIME

The Life-cycle Impact assessment Method based on Endpoint modelling (LIME) project was a national Japanese project with the aim to develop a database that allows industry to conduct reliable LCA (Itsubo et al., 2004). Within the LIME project, characterisation factors, damage assessments and weighting factors were developed for impacts in the nation of Japan. As for the EPS system, LIME is based on life-cycle methodology.

The monetary valuation in LIME is based on a conjoint (combined) analysis where approximately 500 respondents were asked for their WTP to avoid a unit quantity of damage to four different safeguard objects; human health, social assets, primary production and biodiversity.

The weighting factors developed within LIME are originally given in Japanese Yen, but to allow for easier comparison with the other models presented in this study, the weighting factors have been converted to Euro, see Table 2.

Table 2 Monetary weighting factors used in LIME (Itsubo et al, 2004)

Safeguard object	Unit	Weighting factor (JY/unit)	Weighting factor (Euro[1]/unit)
Human health	1 DALY	9 700 000	97 000
Social assets	10 000 JY	10 000	100
Primary production	1 kg	20.2	0.202
Biodiversity	1 specie loss	4.8E+12	4.8E+10

[1] 1 JY (Japanese Yen) corresponds to approximately 0.01 €

3.3 ExternE, NewExt and NEEDS

The Externalities of Energy (ExternE) project was a project funded by the European Commission with the aim to monetize socio-environmental damages caused by energy conversion (ExternE project, 2010). ExternE uses a step-wise impact pathway procedure to assess damage costs (externalities). The impact pathway method is a bottom-up-approach in which environmental benefits and costs are estimated by following the pathway from source emissions via quality changes of air, soil and water to physical impacts, before being expressed in monetary benefits and costs. The impact pathway approach is acknowledged as the preferred approach when it comes to air pollution and noise costs (Maibach et al., 2008). To monetize the socio-environmental impact, ExternE uses willingness to pay (WTP) and the willingness to accept (WTA) methods.

A follow-up project to ExternE, the New Element for the Assessment of External Costs from Energy Technologies (NewExt), was developed with the main objective to improve the assessment of externalities developed in the ExternE project (Preiss & Klotz, 2007). New methodological elements for integration were developed into the existing EU external costs. In the NewExt, emissions to water and soil are also assessed in addition to atmospheric emissions already included in the first generation assessments. Human exposure to heavy metals and some important organic substance can also be assessed using NewExt.

The New Energy Externalities Development for Sustainability (NEEDS) project is in turn a follow up to the NewExt project. The objective of the NEEDS project was to evaluate costs and benefits, both direct and external, of energy policies and future energy systems based on the methodologies developed in ExternE (NEEDS project, no date). In Table 3 below, the monetary values of human health impacts, impacts to ecosystem production capacity as well as impacts to the built environment developed within the ExternE, NewExt and NEEDS projects are presented.

Table 3 Monetary values used in NEEDS (Preiss & Klotz, 2007)

Safeguard object	Endpoint	Unit	Monetary value [$Euro_{2000}$]/unit
Human health	Medication use / bronchodilator use	Case	1
	Minor restricted activity days (MRAD)	Case	38
	Lower respiratory symptoms (adult)	Case	38
	Lower respiratory symptoms (child)	Case	38
	Cough days	Case	38
	Acute respiratory symptoms	Case	38
	Consultation with primary care physician (asthma)	Case	53
	Consultation with primary care physician (upper respiratory diease and allerigic rhinitis)	Case	75
	Restricted activity days (RAD)	Day	130
	Work loss days (WLD)	Day	295
	Respiratory hospital admission	Case	2000
	Cardiac hospital admissions	Case	2000
	Life expectancy reduction	$YOLL_{Chronic}$	40 000
	Increased mortality risk	$YOLL_{Acute}$	60 000
	New cases of chronic bronchitis	Case	200 000
	Fatal cancer due to radio nuclides	Case	1 120 000
	Non-fatal cancer due to radionuclides	Case	481 050
	Hereditary defect due to radionuclides	Case	1 500 000
	Value of prevented fatality	Case	1 500 000
Ecosystem production capacity	Sunflower growth capacity	kg	0.237
	Wheat growth capacity	kg	0.137
	Potato growth capacity	kg	0.113
	Rice growth capacity	kg	0.200
	Rye growth capacity	kg	0.099
	Oats growth capacity	kg	0.132
	Tobacco growth capacity	kg	2.895
	Barley growth capacity	kg	0.093
	Sugar beet growth capacity	kg	0.064
Built environment	Galvanised steel	m^2	14-45
	Limestone	m^2	245
	Mortar	m^2	27
	Natural stone	m^2	245
	Paint	m^2	11
	Rendering	m^2	27
	Sandstone	m^2	245
	Zinc	m^2	22

The methodology developed within ExternE has also been used the project EXIOPOL - A new environmental accounting framework using externality data and input-output tools for policy analysis, which aims at estimating external costs of key environmental impacts for Europe for the evaluation of future policies.

4 Lead – An example of linking emissions to damage costs

To be able to link emissions of a substance to damage costs, it is necessary to have knowledge about the exposure and the impacts that the emissions of a certain amount that a substance can cause. The relation between exposure and impacts is often described using dose-response functions. The dose-response functions are then transformed into characterisation factors that describe how much impact that is caused by the emission of a certain amount of a substance. Monetary weighting factors that describe the costs of a certain impact, such as one incidence of cancer, are then used in combination with the characterisation factors to obtain damage costs for the emissions of a certain substance. Below, an example of how emissions can be linked to damage costs for the substance lead is presented.

Lead (Pb) is used for many applications, for example in electronic goods such as cathode ray tube (CRT) televisions and as a stabilizer in PVC. Pb is one of the oldest known and most studied occupational and environmental toxins. Despite the many studies, there is still debate regarding the toxic effects caused by Pb (Gidlow, 2004).

In studies of acute effects in humans caused by exposure to Pb, nephrotoxic effects as well as gastrointestinal effects have been observed (Tukker et al., 2005). Encephalopathy can affect both children and adults. Acute encephalopathy has been shown to increase the incidence of neurological and cognitive impairments.

Chronic exposure to Pb has been shown to cause anaemia, neurotoxic effects, such as reduced cognitive performance and reduced peripheral nerve conduction velocity, and nephrotoxicity. Children are more sensitive to exposure to Pb than adults, especially during the first two years of life (Spadaro & Rabl, 2004). For children, exposure to lead can cause growth retardation, affect the neuropsychological development and to cause encephalopathy (Gidlow, 2004). Adverse reproductive effects due to lead exposure have been observed for both men and women. Exposure of pregnant women to low concentrations of lead is associated with miscarriages and low birth weights (Tukker et al., 2005).

According to Spadaro & Rabl (2004), damage costs of IQ decrement is likely the dominant part of the total damage costs of Pb. The dose-response function has been quite well characterised for Pb, for example by Schwartz (1994) in a meta-analysis, who found that the IQ decrement is 0.026 IQ points for a 1 µg/l increase of Pb in blood. Spadaro & Rabl identified two possible ways of linking blood levels of lead to exposure. One of the methods connects incremental exposure of Pb in air to increases of Pb in blood levels, while the other method relates blood levels to ingested dose of Pb.

Combining the dose-response function with the exposure/blood level relations, Spadaro & Rabl (2004) derived two possible characterisation factors of 0.268 and 0.59 IQ points decrement per kg emitted Pb. Damage costs for loss of an IQ point have for example been derived by Lutter (2000), Grosse et al. (2002), Muir & Zegarac (2001), see

Table 4. The range of damage costs for the loss of one IQ point was estimated to 3,000-15,000 €/IQ point. Using an average of 10,000 €/IQ point in combination with the two characterisation factors given above, as in the study by Spadaro & Rabl (2004), gives a damage cost of 2,680-5,900 €/emitted kg Pb.

Damage costs for emission of lead were also derived in the EPS system (Steen, 1999b). Damages caused by emissions of Pb were estimated with IQ decrement. In the EPS system the loss of IQ points is classified as severe nuisance which is measured in YOLL (person-years). A Swedish case and a global case were derived. The Swedish case was based on Swedish emission data and epidemiological data from 1990. Based on the Swedish case, a characterisation factor of $1.58*10^{-4}$ person-years/emitted kg Pb is obtained. For the global case, global emissions for 1983 estimated by UNEP (2005) and epidemiological data from USA were used. These data yield a characterisation factor of 0.291 person-years/emitted kg Pb. According to the EPS system, the cost for severe nuisance is 10,000 €/person-year. This gives a damage cost of 1.58-2910 €/emitted kg Pb. The Swedish value is considerably lower than the damage costs derived by Spadaro & Rabl (2004), while the global estimation is very close to Spadaro & Rabl’s estimations.

Table 4 Characterisation factors for damages caused by emissions of Pb

Endpoint	Unit	Characterisation factor	Reference
Severe nuisance	Person-years/kg	0.000158	Steen, 1999b
Severe nuisance	Person-years/kg	0.291	Steen, 1999b
IQ decrement	IQ points/kg	0.268	Spadaro & Rabl, 2004
IQ decrement	IQ points/kg	0.59	Spadaro & Rabl, 2004

Table 5 Monetary characterisation factors

Endpoint	Unit	Characterisation factor	Reference
Severe nuisance	ELU/Person-year	10 000	Steen, 1999b
Loss of one IQ point	€/IQ point	3 000	Lutter, 2000
Loss of one IQ point	€/IQ point	8 600	GREENSENSE project, 2004 cited in Spadaro & Rabl, 2004
Loss of one IQ point	€/IQ point	10 000	Spadaro & Rabl, 2004
Loss of one IQ point	€/IQ point	14 500	Grosse et al., 2002
Loss of one IQ point	€/IQ point	15 000	Muir and Zegarac, 2001

5 Discussion and conclusion

Table 6 below summarises monetary weighting factors for the different models. As can be seen, monetary weighting factors for a wide range of endpoint have been developed within these three models. All of the three models studied here present weighting factors for human health and ecosystem production capacity, while the EPS system and LIME are the only ones that valuate damages to biodiversity. ExternE (here meaning ExternE, NewExt and NEEDS) is the only model that valuates damages towards the built environment.

Amongst the models studied here, ExternE is the model that presents weighting factors for the largest number of endpoints, see

Table 6 below. Take human health as an example, for this safeguard object there are weighting factors available for a large variety of different endpoints, ranging from costs for the use of medications to costs for death and morbidity. LIME on the other hand has developed weighting factors for a very limited number of endpoints, only three weighting factors.

Looking at the valuation of damages towards the different safeguard objects, it can be seen that loss of species is the endpoint with the highest external cost, followed by damages to human health. The external costs caused by damages to ecosystem production capacity are the lowest amongst the studied safeguard objects.

In

Table 6, it can be seen that the monetary weighting factors in the different models are quite similar. In most cases, the three methods valuate the different externalities within a factor of 10 when looking at the same endpoint. Take for example lowered life expectancy, which has been valuated to 40 000 €/YOLL by ExternE, 85 000 €/YOLL by the EPS system and 97 000 €/DALY according to LIME. The monetary weighting factor per DALY is higher than the ones per YOLL, which can be explained by the fact that the DALY includes both premature death and morbidity while the YOLL only includes premature death. Taking the differences in unit into account

Looking at ecosystem production capacity, all three models value the loss of production quite similarly. For example, the EPS system values the loss of crops to 0.15 €/kg while the ExternE system values it to 0.064-2.895 €/kg depending on the specific crop. The LIME system only mentions loss of primary production which it values to 0.202 €/kg.

Values for biodiversity is only given by the EPS system and LIME, which value the loss of one specie to 1×10^{11} and 4.8×10^{10} €/specie respectively. For the built environment, the ExternE model is the one to give values. Looking at these numbers, it can be seen that damages to stone materials is the most expensive while damages to paint in the most inexpensive damage.

Table 6 Summary of monetary weighting factors for all studied models

Safeguard object	Endpoint	Unit	EPS (Euro/unit)	LIME (Euro/unit)	ExternE [Euro$_{2000}$]/unit
Human health	Life expectancy	YOLL	85 000		
	Severe morbidity	YOLL	100 000		
	Morbidity	YOLL	10 000		
	Severe nuisance	YOLL	1000		
	Nuisance	YOLL	100		
	Human health	DALY		97 000	
	Medication use / bronchodilator use	Case			1
	Minor restricted activity days (MRAD)	Case			38
	Lower respiratory symptoms (adult)	Case			38
	Lower respiratory symptoms (child)	Case			38
	Cough days	Case			38
	Acute respiratory symptoms	Case			38
	Consultation with primary care physician (asthma)	Case			53
	Consultation with primary care physician (upper respiratory diease and allerigic rhinitis)	Case			75
	Restricted activity days (RAD)	Day			130
	Work loss days (WLD)	Day			295
	Respiratory hospital admission	Case			2000
	Cardiac hospital admissions	Case			2000
	Life expectancy reduction	$YOLL_{Chronic}$			40 000
	Increased mortality risk	$YOLL_{Acute}$			60 000
	New cases of chronic bronchitis	Case			200 000
	Fatal cancer due to radio nuclides	Case			1 120 000
	Non-fatal cancer due to radionuclides	Case			481 050
	Hereditary defect due to radionuclides	Case			1 500 000
	Value of prevented fatality	Case			1 500 000

Safeguard object	Endpoint	Unit	EPS (Euro/unit)	LIME (Euro/unit)	ExternE [Euro$_{2000}$]/unit
Ecosystem production capacity	Crop growth capacity	kg	0.15		
	Wood growth capacity	kg	0.04		
	Fish and meat production capacity	kg	1		
	Soil acidification	Mole H^+ - equivalents	0.01		
	Production capacity for irrigation water	kg	0.003		
	Production capacity for drinking water	kg	0.03		
	Primary production	kg		0.202	
	Sunflower growth capacity	kg			0.237
	Wheat growth capacity	kg			0.137
	Potato growth capacity	kg			0.113
	Rice growth capacity	kg			0.200
	Rye growth capacity	kg			0.099
	Oats growth capacity	kg			0.132
	Tobacco growth capacity	kg			2.895
	Barley growth capacity	kg			0.093
	Sugar beet growth capacity	kg			0.064
Safeguard object	**Endpoint**	**Unit**	**EPS (Euro/unit)**	**LIME (Euro/unit)**	**ExternE [Euro$_{2000}$]/unit**
Biodiversity	Species extinction	Per specie	1.10E+11		
	Species extinction	Per specie		4.8E+10	
Safeguard object	**Endpoint**	**Unit**	**EPS (Euro/unit)**	**LIME (Euro/unit)**	**ExternE [Euro$_{2000}$]/unit**
Built environment	Galvanised steel	m^2			14-45
	Limestone	m^2			245
	Mortar	m^2			27
	Natural stone	m^2			245
	Paint	m^2			11
	Rendering	m^2			27
	Sandstone	m^2			245
	Zinc	m^2			22

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