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Using monetary values of environmental impacts to support energy choices - three case studies

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Summary

Environmental damage costs are increasingly used for decision-making in environmental and sustainability issues. It may concern choices between different types of technology, investment decisions, sustainability reporting, development of economic instruments or permits. Monetary values of environmental damages are easy to use without understanding the many ways they can be determined and the many perspectives they may represent.

This report includes three case studies made as a part of a project with the overall goal to develop and harmonize methodology to communicate environmental damage cost data. The case studies were carried out at AkzoNobel, Essity and Volvo Group with the aim to find out which metadata (data about data) that are most important to know in choices between energy options based on environmental damage cost.

The results from the case studies show a number of metadata that are important. In the Volvo case, the total environmental damage cost of the alternatives is dependent on how to value abiotic resources, which in turn, is strongly dependent on whose values that are included, the time perspective and how to calculate a present value of future values. For the Essity case it turned out to be important which emissions were included for the production of softwood pulp. In the AkzoNobel case, the sensitivity analysis showed that the main environmental damage costs were due to the health effects of climate change. The case studies demonstrate the importance to include all significant emissions and resources, and not just those who are easy to quantify.

The EPS 2015dx method (Environmental Priority Strategies) was used to calculate the monetary values of emissions and use of natural resources. Emissions and use of natural resources were determined with a life cycle perspective and standard life cycle assessment (LCA) methodology. The participating organizations have a long experience of working with LCA and applied life cycle thinking.

This report also includes interviews with representatives from each case study organizations highlighting the importance of monetary valuation together with lessons learned from the project and ways forward.

Project organizations

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Project information

This report is a publication from the research project Development of methodology to communicate environmental damage cost data, funded by Swedish Energy Agency.

Project title
Development of methodology to communicate environmental damage cost data. (In Swedish: Utveckling av metodik att kommunicera miljöskadekostnadsdata.)

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Aim
The aim of the project was to develop and harmonize a methodology to communicate environmental damage cost data, by a) conducting case studies of energy decisions with sensitivity analyses, to determine which parameters that are most important, and by b) participation in international harmonization to develop a common language to communicate monetary values of environmental impacts.

Project leader
Bengt Steen, Chalmers University of Technology

Coordination of the project
The project has been coordinated by Swedish Life Cycle Center, a national center of excellence for the advance of applied life cycle thinking in industry and other parts of society.

Project management team
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About Swedish Life Cycle Center
Swedish Life Cycle Center is a joint collaboration platform for universities, industries, research institutes and government agencies for the competence building and exchange of experience to move the life cycle field forward. Current partners are Chalmers University of Technology (host of the center), KTH Royal Institute of Technology, Swedish University of Agricultural Sciences, Swedish Environmental Protection Agency, AkzoNobel Special Chemicals, Essity, NCC Sverige, Sandvik, SKF, Vattenfall, Volvo Cars, Volvo Group, IVL Swedish Environmental Research Institute and RISE Research Institutes of Sweden. For more information about Swedish Life Cycle Center, please visit www.lifecyclecenter.se.

1. Introduction

Organizations are increasingly using monetary values for environmental impacts in reporting, in the choice of priority to environmental issues, in permit discussions etc. Monetary measures are easy to uncritically apply without understanding the many ways by which they may be calculated and the many perspectives they may represent.

Since 1990 the "polluter pays principle" for emissions and the "get the prices right" principle for products has been guiding policy for UN, EU, USA and others. Consequently, organizations face a financial risk in that external costs of environmental impacts from emissions and use of natural resources will be internalized and paid by the organization. There are several initiatives among governments, international organizations and NGOs that show that this development is proceeding:

- An initiative, from the G8+5 meeting in Potsdam 2007, called TEEB, The Economics of Ecosystems and Biodiversity, where a scientific foundation for making economic assessments of ecosystem services and biodiversity is presently being developed.
- In 2012 a TEEB for business started. It was later renamed "The Natural Capital Coalition". The Natural Capital Coalition is a global, multi stakeholder platform for supporting the development of methods for natural and social capital valuation in business.
- World Economic Forum wrote in a report 2014 on new growth models that "Natural resources will have prices that rise with scarcity and rising demand. Negative externalities will be priced or constrained by efficient regulatory policies".
- EU has several directives, where economic assessment of environmental impacts is used: e.g. for estimating Road Infrastructure Charging on Heavy Goods Vehicles (Directive 1999/62/EC as modified by Directive 2006/38/EC and by Directive 2011/76/EU), for the selection of best available technology (the IED directive) and the NEC directive (2001/81/EC). Moreover, the German Umweltbundesamt has published recommendations for which values that should be used in Germany for estimation of external costs for CO2, NOx, SO2, NMVOC, NH3, PM2.5, PM10 and coarse particles.
- In USA, the Natural Resource Damage Assessment (NRDA) Process is a legal process, where economic and scientific studies assess the injuries to natural resources and the loss of services.
- Companies like AkzoNobel and PUMA, publish their external environmental costs in their annual reporting.
- 2014, UNECE, United Nations Economic Commission for Europe, published a report with the title "Conference of European Statisticians Recommendations on Measuring Sustainable Development", where they recommend using several perspectives in measuring sustainable development: "here and now", "elsewhere" and "later". They focus on different types of capital: human, natural, social and economic.

The driving force in integrating environmental costs and benefits into the ordinary economy comes from governments, and quantitative estimates vary between governments and over time, but companies must adjust to them. Understanding the nature of monetary estimates for environmental impacts of emissions and use of natural resources is therefore crucial for regulatory bodies and companies.

This report describes three case studies made as part of a project with the overall goal to develop and harmonize methodology to communicate environmental damage cost data. The idea with the case studies is to find out which data and metadata that is most needed to support a choice of energy supply or a driveline. In other words: to which metadata is the outcome (=recommended choice) most sensitive? The case studies result in recommendations of which alternative to choose, but they are focused on the need for metadata not on the decisions as such, why recommendations for choices must be interpreted carefully.

2. Terminology

Some terms which are used in the report and which are not common language are explained below.

Elementary flows: Outputs and inputs to the product systems, such as emissions and natural resources.

Good: Good, service or quality, subject to monetary valuation.

Environmental good: Good obtained from the environment including human health.

Human health: Health in the meaning of working capacity. Health impacts are measured by YOLL (years of lost life expectancy), DALY (disability adjusted life years or person-years with specific diseases). Health in a wider meaning, as defined by WHO, may be seen as the overall goal of sustainable development. Here it is limited to mean “human capacity to contribute to sustainable development”.

Metadata: Data about data, i.e. when, where and how data was determined.

3. Methodology

To find out which metadata that are most important to know in choices between energy options based on environmental societal costs, we have made three case studies:

1. Choice between natural gas and steam from waste incineration for an industrial process.
2. Benchmarking site specific production of softwood pulp with average.
3. Comparison between different truck drivelines: conventional, gas and electric.

For each case, we have calculated the monetary values of environmental impacts and used the method EPS 2015dx (Steen 2016). The reason for using the EPS method is that its metadata were known when this project started, and it was required by the early draft version of ISO 14008 standard at that time.

EPS stands for Environmental Priority Strategies.

The EPS system was developed to value impacts on environment and human health from a long-term resource perspective. It can be described shortly as valuing changes in the natural capital including human health.

The characteristics of the EPS impact valuation method, which are required to be reported in the ISO FDIS 14008 standards, is summarized in table 3.1. FDIS means final draft international standard, which implies that only editorial changes are allowed before its final publication. The final publication of ISO 14008 is planned to January 2019.

Table 3.1: Characteristics of the EPS impact valuation method, part 1.

Feature, required to be reported by ISO 14008	EPS 2015dx feature
The reason, goal and intended use and audience of the valuation study.	Broad use for ranking alternative options.
The environmental impact(s) valued, and the direction of the impact (positive or negative).	Depletion of abiotic resources (85 goods), decrease of biodiversity, decreased yield from ecosystem services (4 goods), decreased access to water (2 goods) and decreased human health (18 goods).
The spatial validity of the monetary value(s).	Global.
The temporal validity of the monetary value(s).	A decade. Or other updating periods.
The human population affected by the environmental impact.	Global as long as the impact prevails.
The percentage of the affected human population whose preferences are reflected in the monetary value(s).	17% (OECD).
The indicator(s) by which the environmental impact(s) are measured.	For resources, ecosystem services and water: mass provided or capacity to provide. Biodiversity: share of threatened species. Human health: disability adjusted life years (DALY).
The unit(s) and amount(s) of environmental impact(s) that the monetary value(s) of the study is for.	Kg resources, service provided or water available. The indicator for biodiversity is dimensionless (part of the total). The unit for human health impacts is person-years.
The obtained monetary value(s), its base year, currency, reference unit of value and time-period, with indication of uncertainty.	For examples of obtained values, see table 3.2. Their base year is 2015, unit of value € and time-period, when relevant, 1 year.
The monetary valuation method(s) applied including the type of monetary transactions involved.	Resources: costs for sustainable restoration. Ecosystem services, and water availability: market prices of goods provided. Biodiversity: prevention costs.

Table 3.1: Characteristics of the EPS impact valuation method, part 2.

Feature, required to be reported by ISO 14008	EPS 2015dx feature
The justification for the choice of valuation method(s).	In the long run concentrated elements and minerals may be regarded as stocks needed for a resilient and sustainable technology. If depleted, restoration is needed, sooner or later, but the loss of value is immediate. The choice of using market prices for ecosystem services is made because they are readily available, and that the "business as usual" scenario is commonly used for evaluating impact costs. Bio-diversity is hardly possible to value at present. The only way to do so is to use estimate what it costs to prevent its decline applying politically decided.
The elements of Total Economic Value captured by the monetary value(s).	All, but most non-use values are estimated as use values, assuming equality between people and generations.
The equity-weighting applied, indicating the applied elasticity of marginal utility and its justification, also if a zero elasticity is applied (i.e. no equity-weighting).	No equity weighting is applied. All values are made for an OECD context.
The discounting scheme applied and justification for using that scheme, determining parameters of the discount rate in terms of future maximum and minimum annual growth rates, elasticity of marginal utility also if a zero-discount rate is applied; Unless the base year for discounting is the same as for the currency, the base year for discounting shall be reported separately.	0% discounting is used. Peoples valuation of human health are assumed to follow income, either it increases or decreases. There is thus no reason to have a different NPV for future impacts. For resources, there are two reasons to use zero % discounting. One is that value loss is accounted for at the same year as they occur, and no discounting is needed. The second is following the principle that all the value shall be representative for all affected persons. In the long run, most affected person will not have access to natural concentrates like ores, why a dominating majority of the persons affected must produce their concentrates artificially at the same costs as present restoration costs. There may be some technical development that decrease the cost in the future, but a precautionary principle is applied, saying that no technical development may be accounted for until it happens. Due to increased cost, the volume of restored concentrates may decrease but per mass unit, the WTP will be at least as much as it costs. Decreased ecosystem services are accounted for at the same time as they occur.
Aggregation or transfer of data across time, space, persons and impact indicators.	n.a.

Table 3.1: Characteristics of the EPS impact valuation method, part 3.

Feature, required to be reported by ISO 14008	EPS 2015dx feature
Limitations in applicability of the monetary value(s).	The monetary values obtained is not immediately applicable to standard economics.
Data sources and references used, including reference to any more detailed reporting or data repository.	A complete list of data sources and references is found in (Steen 2015), (Steen 2016) and (Steen & Palander, 2016).
The environmental aspects that cause the environmental impacts.	Emission to air of inorganic substances, volatile organic substances, VOC, particulate matter, PM, halogenated organic substances and noise, emission to land of pesticides, emission to water and land use categories.
The environmental baseline before or without the impact.	The baseline is "business as usual".
The transfer functions or calculations made for value transfer.	None applied.
The name and type of the source(s) causing the environmental aspects or the life-cycle stages concerned.	Emission values represent global average emission. Values for specific sources can be assessed, but are optional.
In case of releases: the receiving media or recipient.	Air, fresh water, sea water, soil.
In case of natural resources: the affected medium or media.	Average ores for metals and fossil fuels, water from freshwater sources, land categories according to IUCN red-list statistics.
The spatial and temporal location and extension of the releases or resource flow.	Anywhere on the globe, 2015.
Impact pathways included in the study.	Pathways relevant for climate change, acidification, eutrophication, toxic impacts, human health impacts stratospheric ozone depletion, tropospheric oxidant formation. For details, see Steen (2015).
The impact factors for the environmental aspect with respect to each impact included.	See Steen (2015).
The total aggregated impact value for the environmental aspect if applicable.	Some are given in table 3.3. For a full list, see Steen (2015).

The total external environmental cost from a product life cycle can be determined as ∑Ei *Cij*Vj, where Ei is the emission, or resource i, Cij is the characterization factor C for the emission i for the indicator j. C could for example be kg of decreased fish yield in freshwater due to emission of 1 kg of SO2. Vj is the monetary value of an indicator unit. In case of a choice between A and B, it is of interest to know which alternative that has the highest environmental impact costs, i.e. the sign of ∑(EiA-EiB)*Cij*Vj. For this study, we are primarily interested of the how Vj influence the choice, and what influences Vj most. But the consequences for variations in V on ∑(EiA-EiB)*Cij*Vj depends on the two other factors E and C, so one cannot only look at V in isolation. So, for each case study, we have made a sensitivity analysis to find which term Ei *Cij*Vj, that has had the largest contribution to the ∑Ei *Cij*Vj. We also varied the input values to V, e.g. the value YOLL, the year of lost life expectancy, to see if ranking was changed, i.e the sign of ∑(EiA-EiB)*Cij*Vj.

∑Cij*Vj for different elementary flows as determined by the EPS 2015dx method are shown in table 3.3.

Table 3.2: Monetary values of some environmental goods subject to environmental impacts.

Good	Unit	Monetary value (€/ unit)	Uncertainty factor
Crop growth capacity	kg	0.22	2
Fruit & vegetables prod. capacity	kg	0.39	2
Wood growth capacity	kg	0.04	1.4
Fish&meat production capacity	kg	2.1	2.1
Drinking water production capacity	kg	0.002	2
Irrigation water production capacity	kg	0.001	2

Table 3.3: Global averages of environmental damage costs for some elementary flows according to EPS 2015dx (Steen 2016).

Elementary flow Unit cost, €	Unit	Cost, €
CO2 to air	kg	0,135
NOx (as NO2) to air	kg	0,25
SO2 to air	kg	0,12
VOC to air	kg	17
PM2.5 to air	kg	122
PM (undefined) to air	kg	7.35
Natural gas from ground	kg	0.277
Coal from ground	kg	0.161
Oil from ground	kg	0.47
Cr ore from ground	kg Cr	59.5
Cu ore from ground	kg Cu	90.9
Fe ore from ground	kg Fe	0.847
Ni or from ground	kg Ni	107

4. Case studies - choices of energyware

Purpose with case studies

The aim of the case studies was to find out which data and metadata for environmental damage costs that was most needed to support a choice of energy supply. Three case studies were carried out within the project.

Participating companies – case studies

Case 1: AkzoNobel – Choice between natural gas from waste incineration for an industrial process.
Case 2: Volvo Group - Benchmarking site specific production of pulp against average.
Case 3: Essity – Comparison between different truck drivelines; conventional, gas and electric.

The method EPS 2015x (Steen 2016) has been used for each case, to calculate the monetary values of environmental impacts. For more information about the methodology behind the case studies, see section Methodology above.

4.a Case study - AkzoNobel

Choice between natural gas and steam from waste incineration for an industrial process

The global coating and chemical company AkzoNobel is participating in this project, contributing with an energy related case study. It includes two options; either keep the current energy situation, using natural gas, or invest in renewable energy (described further below).

The aim of the case study is to investigate dominant parameters regarding environmental costs in the choice situation between the *zero alternative* (do nothing) and the *investment alternative*. It is also to identify how robust the results are when changing data for the dominating parameters.

Description of the energy system

Increasing the rate of renewable energy used in AkzoNobel´s value chains is an important part of their strategy. In this case study, the focus is put on the own operations. One of AkzoNobel´s sites is purchasing natural gas as fuel for its combined heat and power plant (CHP). The electricity and steam produced is further supplied both externally and internally. This is the current situation and shall be considered as the *zero alternative.*

The other option is *the investment alternative*. The natural gas fuel to the CHP is substantially decreased and replaced partly by wood from buildings that cannot be reused and partly from market wind and biomass power. The volume of residual wood supplied to the CHP is substantial with an expected volume of several hundred thousand tons per year. The amount of electricity and steam produced is considered to be the same for both options. Below figures (4.1 and 4.2) display schematic overviews of the energy systems.

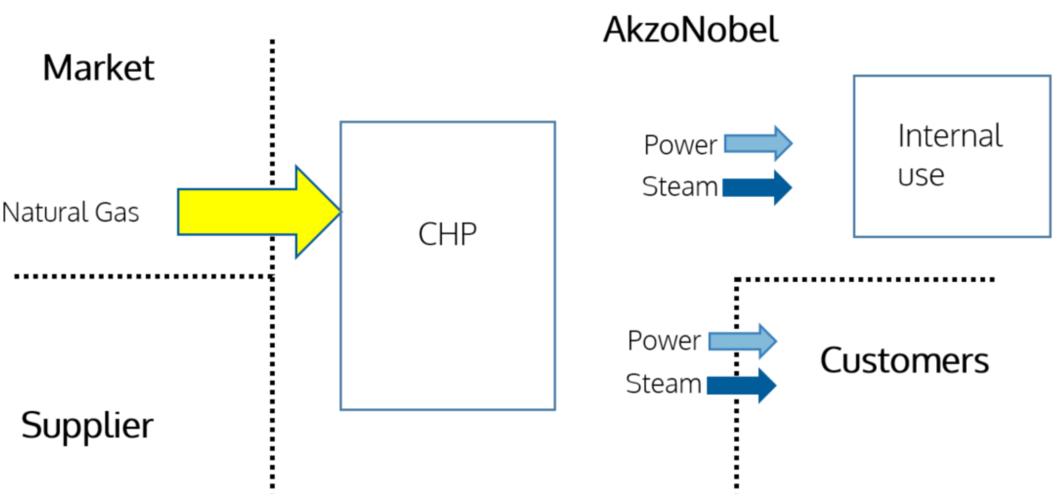

Figure 4.1: Energy system - Zero alternative.

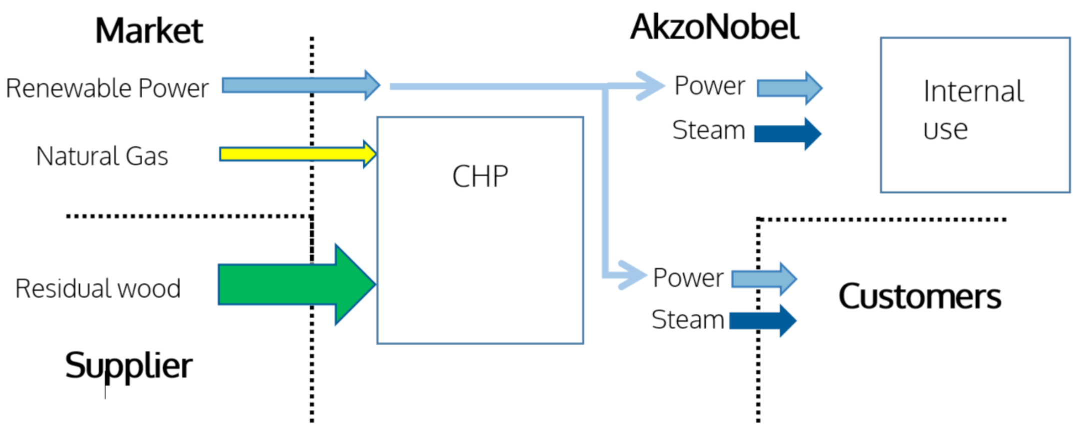

Figure 4.2: Energy system - Investment alternative.

Emissions and resource consumption

The environmental impact of the current system is in line with what can be expected when producing electricity and steam from natural gas. On the upstream side, natural gas is the main resource extracted and also oil and coal are used to extract the gas. In addition, some leakage of methane in the production and distribution chain of natural gas can be expected. The emission at the CHP plant is dominated by carbon dioxide.

When considering the *investment alternative*, the amount of natural gas is decreased substantially but it is still a vital part of the environmental impact of this alternative. As described above, the natural gas is partly replaced by wind and biomass-based power. The majority of the natural gas is however replaced by residual waste from buildings. The quality of the wood is low and it is most valuable as a fuel in the incineration plant. Although low quality wood and quite low calorific value, the wood comes with environmental impact mainly from transportation activities and wood incineration. In the CHP plant there is a significant reduction of carbon dioxide emission compared to the *zero alternative*. Other emissions are however increasing such as carbon oxide, nitrous oxides, sulphur dioxide and particulate matter.

Total environmental damage costs and ranking of alternatives

The functional unit, reference of results, is in this case study 1 kWh delivered electricity. The environmental costs for the two options are displayed below, including the major contributors to the result. The *zero alternative* acts as a reference with a total index of 100.

Table 4.1 below shows the environmental damage costs for the two options, the *zero alternative* and the *investment alternative*. It can be seen that the *investment alternative* reduces the environmental costs by about 74 %.

This is almost solely due to decreased impact from natural gas (reduced use) and consequently lower carbon dioxide emissions. A few elements contributing more than 0.1% are added to the list.

There are also some emissions having lower contribution in the zero alternative (e.g. carbon oxide, nitrous oxides, sulphur dioxide) but have contributions below 0.1%. An interesting observation can be made as both coal and oil uses are higher in the investment alternative. This can be explained by a low use of coal and oil to extract natural gas in the particulate case. This observation shall not be misinterpreted as the figures are small and there exist uncertainties in the datasets.

Sensitivity analysis

The damage cost of carbon dioxide is mainly caused by health effects on humans, and the damage cost of depletion of natural gas resources caused by sustainable replacement cost. As the investment alternative uses less natural gas and emits less carbon dioxide, the priorities are not influenced by the values of YOLL versus natural gas. For example, if the nickel replacement cost for the investment alternative increases about 35 times, there will be a shift in priorities. This is however not likely. The priority found is thus very robust.

Table 4.1: Overview of environmental damage costs for the two options, using the EPS2015d method.

	Damage cost (index)	
Element/resource/emission	Zero alternative	Investment alternative
Fossil oil	0.5	0.9
Fossil coal	0.1	0.4
Natural gas	56.1	10.4
Iron	0.3	0.9
Copper	0.1	0.1
Nickel	0.6	2.3
Chromium	0.1	0.3
Carbon dioxide	41.6	9.5
Particulate matter	0.4	0.6
Others	0.2	0.4
Total	**100.0**	**25.8**

4.b Case study - Essity

Production of softwood pulp

In the European pilot project for Product Environmental Footprint (PEF), organized by the European Commission, a large number of industry sectors have participated in the work of creating Product Environmental Footprint Category Rules (PEFCR) for the different product categories. These rules shall be used in addition to the PEF guidance to establish environmental footprints of products. For possible communication, the footprints are in the future expected to be normalized and weighted. However, for the time being, there are no policy directions outlined for the use of environmental footprints.

One of the main ideas of the footprints is to find the so called hot spots of the different products' life cycles, i.e. both which parts of the life cycle and which impact categories that contributes most to the footprint. As a basis for establishing the category rules, various screening studies have been performed by the industry sectors in the pilot. For the paper industry, the screening studies showed that pulp production and pulp data contribute highly to the outcome for intermediate paper, and new data collections were done for pulp production. However, forestry data is lacking, and in old datasets there is a lack of VOC data. The VOC emissions are mainly monoterpenes, which influences ozone levels and reacts to form secondary organic aerosols, SOA. SOA has significant health effects on humans in that they decrease the lung capacity and cause premature deaths. Although the VOC emission is natural, the amount varies with the needle surface, which in turn varies with tree age and density and is influenced by forest management practice.

We have at present no site-specific data on pulp production but assume that the main variation between pulp mills lies in the energy set up, i.e. energy use and choice of fuels.

Table 4:2 Emissions and resource use when producing 1 ton of softwood pulp.

Emission/resource	Kg/ton
Dust (unspecified)	0.31
CO2 (fossil)	71.7
CO2 (biomass)	2532
CO	1.11
SOx (as SO2)	0.26
NOx	1.57
TRS (as S)*	0.048
VOC	6.38
Natural gas	7.49
Fuel oil	12.55

Emissions and resource consumption

For softwood pulp, average emissions and resource use for production of 1 ton of pulp are shown in table 4:2. All data except VOC data are from the PEF project.

VOC data are estimated from measurements made by Rantala et al. (2015) in central Finland. Our calculations are explained below:

- The forest was dominated by Pine (Pinus silvestris. L.) and about 50 years old. expanding 200 meters at all direction from the measuring place.
- Average emission was measured by agradient method.
- Average emission during three years was 20 ng/m2, s = 6.3 kg/ha, yr.
- Average growth rate is estimated to5m3sk/yr*0.83 =4.15 m3fub/yr.
- Average emission of monoterpenes = 6.3/4.15 = 1.52 kg/m3fub wood.
- Weighted average use of wood per ton of softwood pulp = 4.2 m3.
- Average emission of monoterpenes per ton of softwood pulp = 4.2*1.52 = 6.38 kg.

Total environmental damage cost

The total environmental damage cost for emissions and resources when producing 1 ton of softwood pulp are 34.8 € if only emissions and resources assessed by the EU PEF project is included. If VOC is included the total environmental cost is 143 €.

The damage cost for VOC emissions widely exceeds other costs, but it is not clear what part of that cost that should be allocated to the production of 1 ton of softwood pulp. A natural forest also emits a large amount of VOC. If a managed forest emits more, or less than a pristine forest is unclear, but the magnitude of the damage costs indicate that more research is needed on this issue.

Sensitivity analysis

VOC contributes most to the environmental damage costs. The use of fossil fuel may differ significantly between different production sites. While CO2 and use of fossil fuel is a global issue, VOC impacts may be regional and vary depending on forest types and population density.

VOC emissions seem to be proportional to leaf area. Leaf area index, LAI (m2 leaf area per m2 ground area) vary from 12.5 to 8.5 for 15yr trees to 102yr trees (Pokorny 2012). This means that managed forests, where harvesting is done of about 80 years old trees, may be emitting more VOC than natural forests, where trees may be several hundred years.

The damage cost for VOC depends on the atmospheric transformation to secondary particles, their residence time and resulting population exposure. Therefore, data on where the emission occur, impact models, including dose-respond factors (e.g. YOLL/(µg/m3), are valuable.

For the whole assessment of environmental damage costs for production of 1 ton of softwood pulp, it is essential to include VOC emissions.

4.c Case study - Volvo Group

Comparison between different truck drivelines: conventional, gas and electric

Volvo Group contributes to this project with a case study assessing distribution trucks with different drivelines: diesel, gas and electric.

The aim of including the EPS score in this assessment is to broaden the view from global warming, which is also included, by adding a more long-term view. This can help in identifying sustainability risks when introducing new drivelines.

Description of the products and life cycles

The study includes the following cases, varying both in driveline set up and fuels, see table 4.3. The case consists of several variants of a distribution truck. Three driveline setups are included, each with several fuel alternatives. The fuels represent both fossil and bio-based options.

The study aims at being a high-level analysis of environmental impacts when changing fuels, it is assumed that the diesel driveline is sufficiently similar to an ethanol one so that ethanol can be included as fuel in the diesel driveline case. All cases include the material mining and processing, production impact from the Volvo plants and part suppliers, use phase emissions and fuel production emissions, maintenance as well as end of life handling of the trucks.

The end of life handling includes an allocation of the recovered material to the next product system based on quality and value of the scrap. This is done in the form of a credit in the end of life stage.

Table 4:3: Drivelines for which environmental damage costs have been assessed.

Vehicle set up	Driveline setup	Fuel
Distribution truck	Diesel driveline	Diesel 7% FAME
		HVO Palm oil
		HVO Beef Tallow
		Ethanol sugar beat
		Ethanol wheat
	Gas driveline (modified diesel driveline, updated EATS, engine and tank)	Natural gas
		Swedish biogas
	Electric driveline	EU-27 wind el
		EU-27 el mix
		SE marginal el (coal)
		SE wind el

Emissions and resource consumption

As a base for the assessment the total emissions and resource use from each case were collected. For such a complex product as a distribution truck, the inventory is quite extensive.

Significant emissions include the CO2 emissions when driving with diesel or natural gas. When it comes to resource use there is a use of fossil resources in the driving with diesel and natural gas, but there is also resource use in the form of materials.

Significant material flows vary between the drivelines. Platinum group metals in the exhaust after treatment systems of the diesel and gas drivelines are important due to their scarcity. Silver, gold and copper are also relatively scarce resources that are used at an increasing rate when including more electronic components. Due to this they become increasingly relevant for the damage cost as we move towards electrified vehicles, while the importance of platinum group metals decreases.

Total environmental damage costs and ranking of alternatives

Using the global warming results to improve the environmental performance of products has been done for a relatively long time. Adding the total environmental damage cost to the assessment in the form of EPS gives increasing insight into mainly material issues. CO2 emissions and fossil resources use remain an important impact, but other issues emerge as well.

This can clearly be seen in the comparison of the GWP results and the EPS score. For GWP the main concern for most cases is the use phase. Even in the electrified case using low-carbon electricity the use phase is the most impactful stage.

When adding the environmental damage score to the assessment, however, it is clear that we have a long-term sustainability issue in the materials as well. Due to this the recycling becomes increasingly important, as can be seen in figure 4:3 which highlights the total EPS score depending on the level of recycling. The recycling cases are:

- No recycling.
- Recycling with all steel and aluminium ending up with an average scrap quality.
- High recycling with sorting allowing for higher quality output.

The different recycling cases imply that a varying amount of impact can be allocated to the next product system (as this depends on the quality), in turn giving different amounts of “credit” in the EOL of the truck product system. In the results the credit is included in the material result, as to show the total impact of the material over the product life cycle.

The results indicate the importance of well developed recycling chains. When adding a large amount of electronic components, like in the electrified case even the best-case recycling is too underdeveloped to mitigate resource extraction.

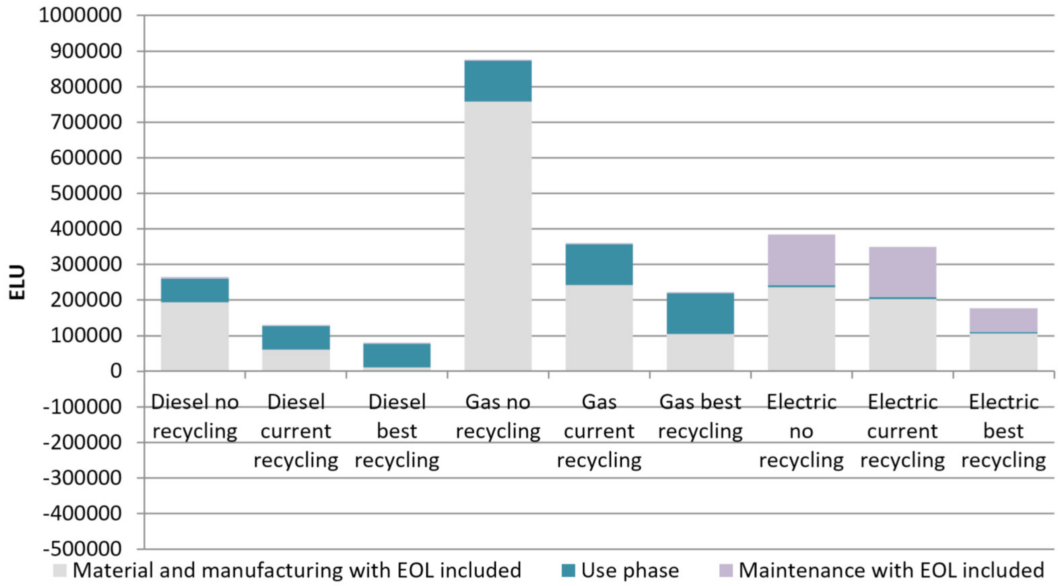

Figure 4.3: Damage cost in € for different driveline life cycles.

Fig 4.3. Damage cost in ELU (€) for different drivelines and recycling scenarios. Although the electrified version greatly improves the climate change results, there is more work to be done to handle the increased use of scarce materials, which the EPS result highlights. The impact of maintenance is increased for the electrified case due to the replacement of the battery. The fuel choices are diesel, natural gas and Swedish electricity mix respectively.

Based on these results the study adds perspective to the question of developing transport solutions that are move environmentally beneficial. Focusing only on the use phase has led us far, since the CO2 emissions and fossil resource use are important factors, but now we must also prioritize the scarce materials being used to an increasing degree.

Sensitivity analysis

With increasing focus on material resources, the question of how to allocate material use between products and systems becomes impactful to the results.

In this study datasets from Thinkstep and Ecoinvent where used in the assessment, and they use economic allocation. This implies that materials mined together with other materials are subject to allocation. In practice this gives rise to flows of materials that are not connected to the product, but that are related to the allocation of the materials.

The focus on materials additionally highlights the importance of accurate value scores for these flows. A high valuation of the material resources impacts the results of the cases where:

1. Scarce materials are used and/or
2. There is poor recycling.

5. Lessons learned and ways forward

Voices from case study organizations

Johan Widheden is Senior Sustainability Specialist at AkzoNobel. We asked Johan a few questions to find out how the project and monetary valuation can contribute in the future.

Johan Widheden, AkzoNobel

How will AkzoNobel continue its work on monetary valuation of environmental impacts?
- We will continue to support the development of EPS and use it in our own 3 and 4 dimensional profit and loss accounting. This accounting methodology includes Financial, Social, Human and Environmental capital, where the environmental capital is calculated partly based on an LCA valuation using EPS. We have used this methodology to get an overview of the sustainability risks of our different markets, but also our sites and raw materials.

Another example is the use of a price on climate impact (carbon pricing) in our investments. Within every project for investing in increased production or building a new factory, a sustainability assessment is included. This assessment is based on an LCA and puts a price on climate impact of the LCA, to be included in the appropriation request, i.e. the request for financing to our executive committee.

How is your work with EPS developing your internal sustainability work?
- Putting a price on environmental impact brings knowledge and valuable discussions on future risks, and finance also gets involved in the discussions. It has also brought about a discussion on the importance of different environmental impacts. EPS values climate change fairly high, which is no surprise, but it also highlights scarce resources (especially mineral resources) and the use of these resources came as a surprise to us since they are not explicitly used in our value chains.

What is added to your sustainability analysis?
- A weighting of different environmental aspects that reflects science, but also societal costs. It therefore provides a good representation of future risks to our value chains.

Are you planning to include EPS in your future work?
- Absolutely!

Read about AkzoNobel's 3 & 4 dimensional profit and loss accounting

Voices from case study organizations

Per Hanarp is Fuel Specialist at Volvo Group Trucks Technology and prepared the case study on transport fuels diesel and gas. We asked Per a few questions to find out how the project and monetary valuation can contribute in the future.

Per Hanarp, Volvo Group Trucks Technology

What has been the greatest value for your organization from this project?
– We have done a detailed LCA evaluation of a distribution truck using diesel or gas. Both GHG and EPS impact categories were included to illustrate the different environmental concerns in road transport. It was presented in a final seminar to 30+ Volvo Group employees.

How will Volvo Group Trucks Technology continue its work on monetary valuation of environmental impacts?
– When putting a new product on the market we always do an LCA. We normally include EPS as impact category in our LCAs.

Have there been any new lessons for your organization while carrying out the case study?
– Yes, we learned that the precious PGM materials in emissions aftertreatment has a big impact on resource depletion issues. "Design for recycling" and proper recycling schemes are necessary for long-term sustainability. As vehicles are becoming more complex with more electric components, this will be an increasingly important issue.

Read more

Voices from case study organizations

Ellen Riise is Senior Environmental Specialist at Essity and was a member of the project team. She took part in project meetings as well as in internal discussions within her organization. We asked Ellen a few questions to find out how the project and monetary valuation can contribute in the future.

Ellen Riise, Essity

What has been the greatest value for your organization from this project?
- The discussions during our project meetings and to follow the other case studies. These discussions together with following the ongoing standardization work, have contributed to an important competence build-up in the area.

How will Essity continue its work on monetary valuation of environmental impacts?
- The possibility to use of the EPS method will be further evaluated after this project. Weighting of results from life cycle calculations is an issue that is developing in general (EUs Product Environmental Footprint, ISO on LCA), and EPS is an interesting method.

Have there been any new lessons for your organization while carrying out the case study?
- Communications of learnings and results will be an important part of the future work. It is reasonable to believe that the internal implementation will take time, however, the upcoming international standard will support this work.

Read more

6. Discussion and conclusions

The overall aim of the project was to find which metadata (data about data), which are most important to know to be able to understand what a monetary value for an emission or resource represents. This is of course dependent on the application context, and one may reflect on how representative our cases are for other application contexts. Some facts indicate that they are reasonably representative: they include climate gases, natural resources and particles (primary and secondary). These elementary flows result in the highest damage costs and their damage costs depend on several methodological conditions.

The results from the case studies show that the monetary valuation is particularly sensitive to:
1. What emissions and resources are included
2. What environmental impacts and impact mechanisms are included
3. Whose values are used
4. What is assumed about the future

The case studies clearly show that it is essential to include a comprehensive list of emissions and use of natural resources. What comprehensive means, can be discussed, but in this case, it means those elementary flows that significantly contribute to the overall damage cost.

The ISO standard on monetary valuation of environmental impacts and related aspects (ISO 14008) exists now in a final draft, which includes requirements to report all the metadata found to be important in our case studies.

Through the standard and this work, transparent databases can be developed that facilitate for decision makers to use monetary values of environmental impacts.

7. Meet the team

Bengt Steen, Chalmers University of Technology

Why is monteray valuation important?
- *Sustainable development requires housekeeping of resources. Economics is the science of resource management and to be able to include our natural capital in economics, we need monetary measures of natural resources.*

Can you mention one important learning from the project to bring back to your organization?
- *How important human influences on the natural VOC emissions from forests may be.*

What will happen in the future? Did the project give you any new ideas for future research?
- *I will continue to work on the communication aspect. The standard ISO 14008 on monetary valuation of environmental impacts and others that has followed offers a good platform for communication.*

Bengt Steen
Title: Professor Emeritus
Organization: Chalmers University of Technology
Role in the project: Project leader

Mia Romare, IVL Swedish Environmental Research Institute

Why is monteray valuation important?
- *Communication of environmental impacts is always difficult, but monetary valuation of the damage gives an opportunity to communicate the results in a format that is more accessible to non-LCA practitioners. We are more used to talking about money and value, and in that way the results can easier be put into perspective, and potentially also included in decision making.*

Can you mention one important learning from the project to bring back to your organization?
- *What I've found when presenting this project is that EPS gives deepened insight into a larger number of environmental issues than the commonly discussed climate change. This has also been received well and EPS has been discussed as a compass to avoid future environmental issues arising while we are trying to improve the climate change impact.*

Mia Romare
Title: Project Manager
Organization: IVL Swedish Environmental Research Institute
Role in the project: Performed and evaluated AB Volvo's case study

Jacob Lindberg, IVL Swedish Environmental Research Institute

Why is monteray valuation important?
– Monetary valuation allows you to clearly illustrate the economic effects of environmental impacts, effects that has, so far, been invisible. Being able to demonstrate these effects is extremely important for our entire societal economy since these invisible costs are deemed to be significant.

Jacob Lindberg
Title: Project Leader
Organization: IVL Swedish Environmental Research Institute
Role in the project: Project member, carried out AkzoNobel´s case study

Ellen Riise, Essity

Can you mention one important learning from the project to bring back to your organization?
– The general discussions during our project meetings as well as following the other case studies and on-going standardization work have contributed to important competence build-up for me. And the fact that you sometimes get surprising results just tells you that there are always new things to learn.

Ellen Riise
Title: Senior Environmental Specialist
Organization: Essity
Role in the project: Project member, being part of project meetings as well as in internal discussions within Essity

Klas Hallberg, AkzoNobel

Why is monteray valuation important?
– *Monetaziation of environmantal impacts are very imporatant in order to speak the same language as decision makers. And it is an eye opener for future costs that a company is not considering today.*

Klas Hallberg
Title: Manager New Developments in Sustainability
Organization: AkzoNobel
Role in the project: Project member and representative for AkzoNobel's case study

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Tomas Rydberg, IVL Swedish Environmental Research Institute

What will happen in the future? Did the project give you any new ideas for future research?
– *We plan to implement EPS in a database based on the ISO 14008 structure. It would then be the first implementation of the standard that we develop within the project.*

Tomas Rydberg
Title: Assistant Director in the area of Sustainable Production, LCA and Environmental Management
Organization: IVL Swedish Environmental Research Institute
Role in the project: Project member

Anna Wikström, Swedish Life Cycle Center

Why is monteray valuation important?
– In order to tackle our common global ecological challenges and to steer our world in a more sustainable direction, externalities need to be valued and made visible and be taken into decision making. It is our duty towards future generations, but also important for tomorrow's responsible business.

Did the project give you any new ideas for future research?
– Yes, the project has given a lot of new ideas for future research and applications! There is a need for further development in the field and applications to new unexplored areas. We are on our way and are looking forward to continuing joining forces to develop the area.

Anna Wikström
Title: Project Manager
Organization: Swedish Life Cycle Center at Chalmers University of Technology
Role in the project: Project member, responsible for communication, the survey and coordination within Swedish Life Cycle Center

8. Impact, dissemination and further reading

Impact

Towards an international harmonization of a common language and framework for monetary valuation of environmental impacts

The project has contributed to an international standard for monetary valuation of environmental impacts; ISO 14008 - Monetary valuation of environment impacts and related environmental aspects.

The standard specifies requirements and recommendations for determination and reporting environmental impact costs. Monetary values of environmental damages are easy to use without understanding the many ways they can be determined and the many perspectives they may represent. The idea with the standard is to create a common language to facilitate communication of environmental damage costs. The users of monetary values of environmental damage costs, e.g. external costs of NOx, shall be able to understand which costs that are included and how they are included. The producers of monetary values will have access to a structured process and a harmonized way of reporting.

The project has developed inputs to and contributed to the standard text. In three case studies, we have determined which metadata for the monetary values that has the largest influence. We have also made an inquiry to see if potential users understand the metadata proposed. Based on the ISO standard new databases and software may be developed to facilitate studies with environmental and ecological economics. The new ISO standard is planned to be finalized and published in the beginning of 2019. The standard was initiated by Swedish Life Cycle Center's working group Get the prices right, through SIS (Swedish Standards Institute) in 2015.

Dissemination

The project has been presented on several occasions and conferences, such as:

SETAC Annual meeting in Rome, May 13-16, 2018 by project member Tomas Rydberg (IVL Swedish Environmental Research Institute). Poster presentation. (Steen et. al. 2018)

Read more
Link to poster

LCM 2017 (8th International Conference on Life Cycle Management) in Luxembourg, September 3-6, 2018. (Steen et al. 2018)

Link to poster

Further reading and related activities on monetary valuation of environmental impacts

EPS Environmental Priority Strategies
Read more

Report: Integration of environmental economy in product development gives opportunity for innovations.
Rebecka Hallén Jorquera, Maria Lindblad, Bengt Steen, Ellen Riise, Lisbeth Dahllöf, Klas Hallberg. 2016. Swedish Life Cycle Center report no 2016:6.
Read it here

Swedish Life Cycle Center's working group Get the prices right
Read more

About ISO 14008 - Monetary valuation of environmental impacts and related environmental aspects
Read more

News post by Swedish Life Cycle Center about ISO 14008 and interview with convener Bengt Steen: "Monetary valuation of environmental impact – awarded with leadership congratulations".
Read more

News post by SIS Swedish Standards Institute about ISO 14008: "The cost of environmental impact"
Read more

9. References

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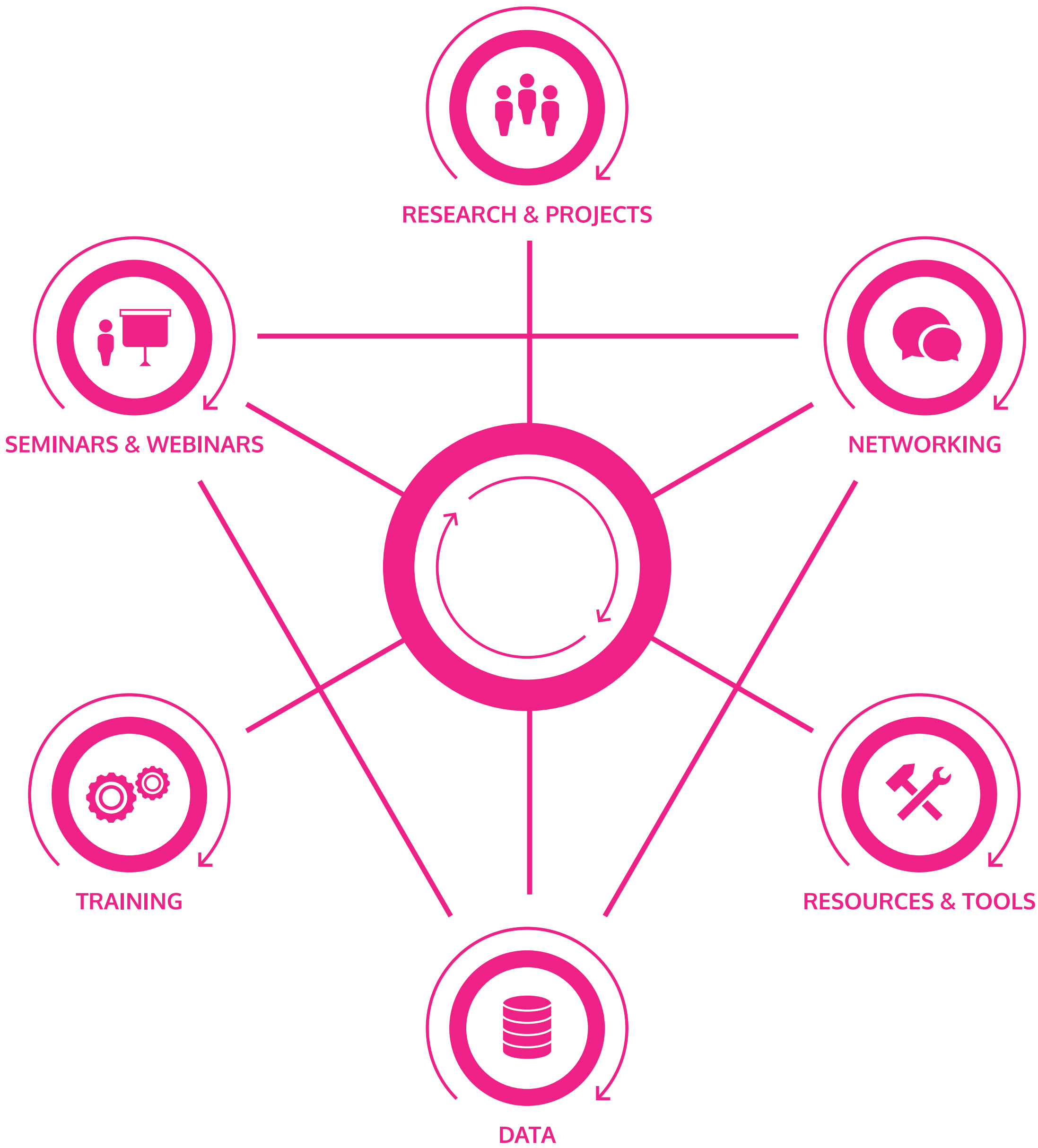

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