Integration of environment and economy in product development gives opportunity for innovations

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Summary

The project Integration of environment and economy in product development gives opportunity for innovations (IMP) has intended to strengthen the long-term competitiveness of the manufacturing industry through a pro-active risk management considering environmental and sustainability aspects, by developing methodologies for calculating the economic value of reduced environmental impacts from products, early in the product development phase.

The project activities have included: strengthening of the scientific basis regarding economic values; contribution to an ISO standard; and testing of methodologies in case studies and dissemination.

The case studies, carried out at AkzoNobel, SCA and Volvo Group, have shown different ways in applying a monetary value on environmental impacts, and in particular how these can assist decision-makers in their choice of for example materials. Different scenarios can provide useful input into this process.

The project has been coordinated by Swedish Life Cycle Center. Maria Lindblad, IVL Swedish Environmental Research Institute, has been the project leader.

Swedish Life Cycle Center   ivl SVENSKA MILJÖINSTITUTET   CHALMERS   AkzoNobel   SCA Care of Life   VOLVO

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1. Introduction

The project Integration of environment and economy in product development gives opportunity for innovations (IMP) has intended to strengthen the long-term competitiveness of the manufacturing industry through a pro-active risk management considering environmental and sustainability aspects, and to stimulate to significant eco-innovation and not merely to incremental changes.

A Life Cycle Assessment (LCA) describes the use of natural resources and emissions of a product or service in quantitative terms throughout its life cycle (Baumann and Tillman 2004: chapter 1). Monetization of the LCA results means that an economic value is assigned to the different impacts that are covered within an LCA. This implies that a price is placed on the effects of different environmental damages.

The IMP project has aimed to contribute to more efficient product development by further developing, testing and establishing the Environmental Priority Strategy methodology (EPS) which makes environmental costs more visible early in the product development phase. It has also aimed at facilitating a change from a reactive to a proactive product development strategy with regards to environment and sustainability. In addition, it has aimed to contribute to the innovation process by making environmental and sustainability data more readily available.

Within IMP, the EPS methodology for calculating the economic value of reduced environmental impacts from products has been further developed. Activities within IMP have aimed at: strengthening of the scientific basis regarding economic values; contributing to an ISO standard; and testing of methodologies in case studies. The case studies have been carried out at the Volvo Group: *The Effect on Environmental Damage Costs and Eco-Efficiency of introducing Recycling of Sand in Volvo Group's Engine Plant in Skövde*, and *Environmental Cost and Eco-Effectivity Assessment of Copper and Aluminium High Power Cables*; at AkzoNobel: *4D P&L (4 Dimensional Profit & Loss Accounting)*, and at SCA: *Pilot weighting method for product development and innovations.*

The results from the IMP project have been disseminated via; Swedish Life Cycle Center; IVL Swedish Environmental Research Institute, the working group ´Get the prices right´; contributions to an ISO standard; workshops; conferences, and; publications in peer-reviewed journals. The project has been coordinated by Swedish Life Cycle Center.

Project title:

Integration of environment and economy in product development gives opportunity for innovations

Project leaders:

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2. Background

Business has long been a matter between seller and buyer. Transactions between them are based on the value a product or service has for the seller and buyer. But most products and services also create values and costs for third parties, so called externalities. Some of these externalities arise from changes in the environment.

Historically, there has been a difference between societal value creation and corporate value creation (KPMG 2014: 10). However, this is rapidly changing due to a number of megaforces, such as population growth, urbanization, digital connectivity, climate change and resource scarcity, which creates a new landscape for businesses to navigate in.

Already in 1972 the OECD Council adopted the Polluter Pays Principle (PPP), implying that "the polluters should bear the expenses of carrying out environmental protection measures decided by public authorities to ensure that the environment is in an acceptable state. In other words, the cost of these measures should be reflected in the cost of goods and services which cause pollution in production and/or consumption" (Sterner and Coria 2003, 2012: 118). At the Rio-conference in 1992 there was an international, political consensus about the "polluter pays principle" as it was written into the UN Declaration on Environment and Development, through principle 16. When EU, some years ago, launched their Integrated Product Policy initiative, the principle was transformed to "get the prices right", i.e. the price should include environmental costs. As a result, there are nowadays more precise requirements in the EU for including environmental costs in the energy and transport sectors (European Commission 2016). "Getting the prices right" is about correcting market failures and would imply emitters to bear the costs of the effects they have on the society (Fischer et al. 2012).

This new landscape implies that externalities are internalized, bringing both new opportunities and new risks to businesses and their revenues (KPMG 2014: 6, 11). Risks may include decreased earnings due to for example resource scarcity pushing prices to a higher level, while opportunities may include both increased revenues or decreased costs by proactivity on new markets or better control over the own value chain (KPMG 2014: 18).

A company often generates both positive and negative externalities through their operations, where a positive externality is "an economic, social or environmental benefit that a company creates for society for which it is not directly or fully rewarded in the price of its goods and services" and a negative externality is "an economic, social or environmental cost that a company inflicts on society for which it does not directly pay a price" (KPMG 2014: 7). Their internalization refers to the process of taking into account positive and negative externalities into the business model, meaning a business could either be rewarded or pay for their externalities (Ibid 2014: 7). Often, negative externalities are more directly internalized than positive ones (KPMG 2014: 18).

The increasing internalization of externalities brings a need for companies to better understand their externalities to be proactive and create value (KPMG 2014: 4, 6). The proactive companies are more likely to preserve their corporate value, although some internalization is announced and some unexpected (Ibid 2014: 50). By increasing positive externalities and decreasing negative externalities it is possible to grow revenues, including by cutting costs and reducing risks (KPMG 2014: 11). This brings a need to understand the externalities and to measure them (Ibid 2014: 4, 6).

Environmental impacts from products have so far been seen as negative features, which have been subject to minimization. However, innovation and product development is about value creation in a wider sense. In order to make this happen in an efficient way, there is a need to be able to describe the value of environmental change.

There are a number of published studies and projects quantifying environmental costs for emissions and resource extraction, many originally developed for use in connection with cost-benefit studies (Needs Project 2013, Ahlroth 2009; 2.-0 LCA Consultants 2013). In the 1990s, a research group, that later formed Swedish Life Cycle Center, started to use environmental damage costs for weighting of Life Cycle Data in the context of comparing the environmental impact of different product designs (Steen 1999).

There are several modern estimates of the environmental costs of climate-changing emissions (Stern 2006; Tol 2009), and there is ongoing research to value ecosystem services and estimate the value of natural capital of minerals (Steen and Borg 2002; de Groot et al. 2012). There is however no global consensus on one single methodology for integrating environmental costs into product development.

2.1 Why monetary valuation?

Defining the monetary value of environmental external costs requires subjective methodological choices. However, the decision to monetize the external costs is also a subjective methodological choice. As indicated above, monetization can help in decision-making by creating a common language that is used both for the environmental assessment as well as the economic aspects of an investment or technology update. The familiar nomenclature can help businesses better understand the magnitude of the impact. It becomes easier to relate different impacts to each other (KPMG 2014: 44), to the economic value of the products, and also to the economic costs of reducing the impacts.

Although the external costs are currently paid by the society, they might be internalized in the future through regulation and/or environmental taxes. The monetization thus helps the company estimate the financial risks associated with the environmental externalities. Assigning an economic value to environmental impacts can also assist environmental coordinators etc. in companies in making a persuading case for environmental improvements in internal communication and decision processes.

Despite these benefits, the idea of monetization has been met with scepticism and criticism in several environmental contexts, such as the global LCA community. The international standard for LCA, for example, stipulates that monetization or any other weighting across impact categories shall not be used in an LCA that aims to compare competing products, if the study is intended to be disclosed to the public (ISO 2006: 23).

The most common criticism towards monetization in the LCA community relates to the subjectivity and perceived lack of a scientific basis for monetization. However, many other arguments against monetization have been raised in the context of cost-benefit analysis (CBA). Several of these arguments points to the limitations of CBA itself, and is also relevant for LCA and other methodologies for quantitative environmental systems analysis. Pearce (2001) lists and discusses the following objections in relation to CBA:

Credibility: environmental impacts of an option, and their monetary value, are often highly uncertain. Wynne (1992) distinguishes four types of uncertainty; risk, uncertainty, ignorance and indeterminacy. If the possible outcomes can be defined and their probabilities can be assigned in a meaningful way, one is talking of risks. If the possible outcomes are identifiable, but their probabilities cannot be determined, one is faced with uncertainty. Ignorance refers to when we do not know what we do not know. Finally, indeterminacy is used to describe situations in which the complexity of the system is so large and so little is known about the relevant parameters and their relationships that modelling becomes a matter of hit and miss (Mickwitz 2003). Where ignorance and indeterminacy may be at play, and it will often be the case because of the complexity of social and environmental issues, decision-making will have to rely on other tools in addition to LCA or CBA. An LCA can, in principle, account for risk and, through sensitivity analysis, deal with uncertainty. However, if the full uncertainty is properly accounted for, monetized LCA results might encompass a level of uncertainty that makes them difficult to interpret and use. On the other hand, if the uncertainty is not properly accounted for, the study lacks in credibility.

Moral objections: a CBA or an LCA with monetization reflects utilitarian moral philosophy: it assumes that all types of negative effects can be compensated by positive effects. It can be argued that certain negative effects, e.g., the loss of human life or the extinction of a species, cannot be compensated for by positive effects. Furthermore, individuals that benefit from a policy or project typically do not, in practice, compensate the individuals that lose. As a result, the CBA or LCA should be complemented by an identification of negative (and positive) effects that are difficult to compensate (or off-set) by other effects; and by an analysis of the distribution of positive and negative effects for various groups in society.

The efficiency focus: an objective of monetization is to assess how efficient different options are when they are implemented in the current economic, technological and social context. Consumers and other decision-makers, however, often have additional objectives such as quality of life, fairness, long-term sustainability, etc. A full basis for a decision might require additional analyses to cover these issues.

Flexibility: decision-makers may feel that monetized LCA results, by indicating the most efficient option, usurp the freedom of choice from the decision-makers. Here, it is important to remember that the LCA is a decision-support tool, and that all relevant effects or political considerations may not be encompassed in the LCA.

Participation: CBA has been accused of not involving relevant stakeholders, and the same might be said for LCA.

By presenting one-dimensional results there is a risk that an LCA with monetization closes the door for debate. Stakeholder participation and debates are important to resolve conflicts of interest. Without them, important stakeholder groups might not accept the option selected by the decision-makers. This can be a significant problem for controversial options such as the construction of a waste incinerator or an expansion of the source separation scheme. Since LCA and CBA do not resolve conflicts of interest, they cannot replace the decision-process but only provide input to this process.

Capacity: expertise in both economics and environmental science is necessary to calculate monetized LCA results. A certain level of expertise is also necessary to interpret the results and to participate in a debate that is based on monetized LCA results.

Some of these problems can be alleviated through a few careful measures in the LCA:

- Generating and screening ideas for relevant options;
- Involve decision-makers and stakeholders as partners in the study, for example through an active reference group, to achieve mutual learning and increased acceptability of the final decision;
- Ensure that the methodology and case study are transparently reported, with important methodological choices and uncertainties highlighted; and
- Carry out or recommend complementary analyses to achieve an improved basis for discussion and/or decisions.

Even with these measures taken, it can be argued that monetization is a barrier rather than a path to good decision processes, at least democratic decision processes that involve stakeholders with conflicting interests. This barrier is related to the efficiency of communicating a one-dimensional monetized result. It is easy for the LCA practitioner to present the one-dimensional result, but much more difficult to produce and communicate a transparent presentation of all important methodological choices, assumptions and uncertainties. The difference is even greater for the audience of the study: it is easy to understand the one-dimensional monetized result; understanding the complex issues behind this result can be difficult even when the audience consists of LCA experts with plenty of time to spend. The sheer communication power of the monetized LCA results brings an apparent risk that the audience is tempted to accept these results without understanding what is behind them. This shuts the door for debate and makes the LCA more of a decision-making tool than a decision-support tool.

A decision-making tool that does not invite debate is not well suited for democratic decision processes; however, it can be useful in other contexts, particularly when environmentally relevant decisions have to be made rapidly by decision-makers that are not environmental experts. Such decision-makers can include consumers in a food store, engineers choosing materials for the components of manufactured products, managers making small and medium-sized investment decisions, etc.

The subjective nature of monetization can reduce the usefulness of the one-dimensional monetized result in some applications. Informed consumers or managers might trust the one-dimensional result only to the extent that they share their subjective values or trust the people that calculated the results. In some cases, however, monetization factors can be an efficient way to communicate subjective preferences. If a monetization methodology is consistent with the environmental preferences and perspectives of a company, the application of this methodology in product and process development will help operationalise the values of the company in the products and production processes.

When measures are taken to alleviate the problems of monetization, and when it is used in suitable applications, monetization will still reflect a utilitarian moral philosophy and a focus on efficiency. The choice to monetize environmental impacts remains subjective, because it is based on accepting utilitarian principles and on accepting efficiency as an important criterion for good decisions.

However, the choice to carry through an LCA at all is subjective in similar ways. Utilitarian principles are partly integrated into LCA even without monetization. When an LCA calculates, for example, the total particle emissions of the life cycle, it reflects the assumption that an increase in emissions at one place can be compensated by the reduction of emissions elsewhere, although these emissions will affect the health of different people. The focus on efficiency is also integrated in LCA even without monetization. An LCA does not calculate the total emissions of a system but the emissions per functional unit, which is an indicator of inefficiency.

This project has built on the idea that putting a price on products' total environmental impact will assist in integrating environmental aspects in product development more efficiently. Since the relationship between product design and environmental values is complex and often difficult to understand, standards that support such methodology are required for this approach to be accepted.

2.2 Eco-Efficiency

Measuring Eco-Efficiency can be a way to find out which environmental improvement that is achieved to the lowest cost. The idea is to include the concept of value when there are several alternatives to choose between, in order to not sub-optimize. When there is a limited budget for improvement, it is important that the choice does most good.

Eco-Efficiency can be measured in many ways, and the methodology chosen here is the ratio between the change in the environmental indicator and the change in the value or price indicator. In this way, we get a measure of the environmental load per investment cost and how this changes between different options.

2.3 The EPS Methodology

One common way to present LCA results is by looking at the life cycle impact in different impact categories. This implies looking at how much each resource use or emission contributes to for example acidification, global warming or ozone depletion. Each impact is measured in a standard unit, and all emissions are translated into this unit. One such unit is kg CO_2 equivalents, used for measuring global warming potential. 1 kg CO_2 is worth 1 kg CO_2 equivalents, while other greenhouse gases are worth more or less, depending on if they impact global warming more or less than carbon dioxide.

To show environmental impacts not on the level of impact categories, but aggregated in a single value ("single score"), a weighting of environmental impacts against each other is necessary. How important is for example acidification compared to global warming? This is often helpful for non-LCA practitioners, as it gives one result to consider and not several. There are different weighing methodologies available, and some of them based on monetary values of environmental impacts.

In comparison to the results of impact categories, which are based on scientific models, it is important to understand that "single-score"-methodologies always rely more or less on subjective value choices. Results are therefore dependent on subjective preferences integrated in respective methodology, and should be understood as valid in the context of these preferences only. If weighting is made on impact category indicators that are abstract in character, like "acidification potential" subjective values tend to vary highly in time and among individuals.

To increase the reproducibility of weighting, the EPS, Environmental Priority Strategy, methodology strives to apply subjective weighing of environmental impacts on utilities well-known to everyone, such as food and different human health conditions. This means that the impact models must follow the cause-effect chain past acidification and global warming to the actual consequences for human everyday life. The value of harm (for example lives lost) caused by different environmental impacts is taken from scientific studies, implying that this part of the assessment represents a "shared subjectivity". Compare this to evaluating the cost of CO2 emissions directly.

In the EPS 2000d methodology, the environmental impacts are evaluated, and expressed in terms of "willingness to pay" to hinder the damage on five safeguard subjects: human health, biological diversity, eco-system production, natural resources and aesthetic values. The calculation is based on an average OECD citizen.

The damage from different impacts is expressed in category indicators such as "years of lost life" (YOLL), "crop production capacity" or "oil reserves". These are then related to an economical value, and the entire effect over the life cycle is summed up to get the final result. As a guide for non-LCA practitioners it can be commented that the calculation of environmental impact in terms of cost is a way to both highlight the effect of emissions on current and future generations, but also a way to highlight what cost can be expected due to environmental legislation in the future (EPS 2015a and b).

For resources the overall principle is that the environmental cost of depleting a resource equals to the cost of replacing the resource from earth's average crust or another non-scarce rock. Similarly for fossil resources the cost to produce a bio-based equivalent gives the damage cost for resource depletion. For emissions, it is the added costs of impacts on safeguard subjects: Ecosystem services, access to water, biodiversity, and human health.

3. About the IMP project

The IMP project has been coordinated by Swedish Life Cycle Center, a national center of excellence for the advance of life cycle thinking in industry and other parts of society. In the Center, universities, industries, research institutes and government agencies are working together in research- and administrative projects, working groups and expert groups, and communication activities to develop, implement and share knowledge and experience in the life cycle field. The mission is to improve the environmental performance of products and services as a natural part of sustainable development. Current partners are Chalmers University of Technology (host of the center), KTH Royal Institute of Technology, Swedish University of Agricultural Sciences - Dept. of Energy and Technology, Swedish Environmental Protection Agency, AkzoNobel, NCC Construction, SCA, Sony Mobile Communications, SKF, Vattenfall, Volvo Cars Corporation, Volvo Group, IVL Swedish Environmental Research Institute and SP Technical Research Institute of Sweden.

The EU has within IPP (Integrated Product Policy) aimed to include environmental externalities in products prices, trying to 'Get the prices right'. This has been the focus in one of the working groups within the Center, called "Get the prices right". The working group has worked with the EPS-methodology, and together started the IMP pto investigate further monetization of environmental external costs.

The IMP project, Integration of environment and economy in product development gives opportunity for innovations, was funded by Vinnova Sweden's innovation agency, with in-kind contribution from AkzoNobel, SCA and Volvo Group. The IMP project was operated between November 2013 and November 2016. The project built on the pilot study Externalities in product development give possibilities for innovation (Vinnova ref: 2012-03841), and aims to promote a more effective product development concerning environmental and sustainability aspects.

The IMP project has strengthened the long-term competitiveness of the manufacturing industry through a pro-active risk management considering environmental and sustainability aspects. The IMP project has developed methodologies for calculating the socioeconomic value of reduced environmental impacts from products and to make it available early in the product development phase. A methodology has also been developed for estimating the economic risk for a company associated with its future environmental impacts. This gives businesses the opportunity to take on a more long-term planning in development of new products and services.

Within IMP, the project group has contributed to;

- Continue to developing the EPS methodology for calculating environmental damage costs;
- The EPS methodology implementation, including: case studies, output from case studies, and methodology ISO standardisation;
- Dissemination, including: project management, coordination of the Working Group "Get the prices right", contribution to ISO standardization work, and dissemination.

Within the IMP project, work has been done to initiate development of an international standard on monetary valuation of environmental impacts. An ISO working group began working on a standard in February 2016. The group has held three meetings and a draft standard has been formulated. The standard, if it is accepted by voting of the member countries, will be called ISO 14008 - Monetary valuation of environmental impacts from emissions and use of natural resources. The work has led to another initiative from the UK to start a project on how to use monetary values of social costs in companies. That standard will be called ISO 14007 - Environmental management: Determining environmental costs and benefits. The IMP project group has participated also in this work. Describing the EPS methodology in terms of international standards will increase its credibility.

Three companies have been involved in developing case studies within the project, Volvo Group: *The Effect on Environmental Damage Costs and Eco-Efficiency of introducing Recycling of Sand in Volvo Group's Engine Plant in Skövde*, and *Environmental Cost and Eco-Effectivity Assessment of Copper and Aluminium High Power Cables*; AkzoNobel: *4D P&L (4 Dimensional Profit & Loss Accounting)*, and SCA: *Pilot weighting method for product development and innovations*. Below follow conclusions from the case studies, as well as interviews with their performers, while the case studies can be found in the appendices (1, 2, 3 and 4).

4. The history of the EPS methodology

The story of EPS

The EPS system was developed to meet the requirements of an everyday product development process, where the environmental concern is just one among several others. The development of the EPS system started during 1989 on a request from Volvo and as a co-operation between Volvo, the Swedish Environmental Research Institute (IVL) and the Swedish Federation of Industries. Since then it has been modified several times during projects, which have involved several companies, like in the Swedish Product Ecology Project (Ryding et. al 1995) and the Nordic NEP project (Steen et.al, 1996).

About EPS

EPS is a systematic approach to choose between design options in product and process development. Its basic idea is to make a list of environmental damage costs available to the designer in the same way as ordinary costs are available for materials, processes and parts. The designer may then calculate the total costs over the products life cycle and compare optional designs.

EPS includes an impact assessment (characterisation and weighting) methodology for emissions and use of natural resources, which can be applied in any Life Cycle Assessment (LCA).

The results of the EPS impact assessment methodology are damage costs for emissions and use of natural resources expressed as ELU (Environmental Load Units). One ELU corresponds to one Euro.

For more information:
The maintenance and updating of the EPS system is managed by IVL Environmental Research Institute. For more information see www.ivl.se/eps.

Dissemination

Many methodologies of varying quality have been proposed for green and sustainable development. In order to "market" the EPS methodology in this context, the IMP Project group has initiated and been active in an ISO working group on an international framework standard, ISO 14008 and has cooperated with LCA software companies with more than 10 000 users in order to integrate EPS data on monetary values of emissions and use of natural resources. The group also held an educational course for the Swedish Life Cycle Center network. There have been three ISO meetings and the ISO 14008 standard is now at Committee Draft level (about in the middle of the standardization process). The standard will create a language making it possible to communicate the basis for the EPS methodology and increase its credibility.

The EPS monetary values for emissions and natural resources is now integrated in the LCA softwares GaBi and SimaPro, which are used by partners in Swedish Life Cycle Center.

Bengt Steen & EPS

The latest version of EPS: www.ivl.se/eps

The work with EPS was initiated around 1989. How did the idea develop into what it has become today? Who requested the EPS?
- At Volvo there was a discussion on which material to choose for a front piece in their car model 850. Gunnar Westerlund, at Volvo's material lab, argued that this discussion was very costly and that they needed a methodology to calculate environmental performance of alternative designs. He therefore contacted The Swedish Industrial Board (Industriförbundet) who in turn contacted IVL, where Sven-Olof Ryding and I formed a working group together with Gunnar Westerlund. After a few years, we had developed the first version of EPS. Industriförbundet then contacted the CEOs of the five largest companies in Sweden and got their consent to start a larger project, the so called "Product Ecology Project". Soon, 15 companies were involved, and this paved the ground for CPM, presently Swedish Life Cycle Center, where the EPS system was maintained and developed further.

What would you say have been the biggest challenges and barriers for the development of EPS?
-The development of LCA methodology is dependent on academia, where it is more important to have high scientific quality than to deliver useful information when it is needed.

What is your biggest interest of developing and disseminating EPS?
- I want to contribute to making EPS an industrial standard. I think our philosophy on the use and value of EPS is outstanding in terms of broad system thinking. It is based on a good understanding of what sustainability is and how product development is made.

Who are the main users of EPS?
- Volvo and AkzoNobel use it regularly and several other companies have used it in special studies. It is used in education at Chalmers and MIT. EPS data are available in software like GaBi and Simapro and in the EcoInvent database.

What is your vision of the future of EPS? Which challenges does EPS face ahead?
- I am pretty convinced that the EPS principles of monetary valuation of environmental impacts will become a standard approach. It would be nice if we would still be at the stage then, so that wheels do not need to be invented again. Our main challenge is endurance.

How does the work with the ISO standard 14008 help drive the monetary valuation of environmental impacts ahead?
- It creates a language and gives credibility to the numbers, the quantified values, we produce. It offers a platform for dissemination of our results.

5.1 AkzoNobel

About AkzoNobel

AkzoNobel is a global paints and coatings company and produces specialty chemicals. The AkzoNobel headquarter is based in Amsterdam, the Netherlands, but the 45 000 employees are present in about 80 countries (AkzoNobel 2016: d). Ingredients produced by AkzoNobel are found within a wide range of different products (AkzoNobel 2016: b).

In Sweden, 2700 employees are spread out in 12 different cities. The global sustainability branch of AkzoNobel is based in Sweden (AkzoNobel 2016: a).

About the case study

The working group which has been involved in the case study within this project has been led by Klas Hallberg, Manager New Developments in Sustainability at AkzoNobel. The main participants were Karin Andersson Halldén, Caterina Camerani, Max Sonnen and Niek Stapel.

Results and conclusions

Where traditionally the impact of a company was solely measured in terms of the profit generated for its share-holders and its share price on the stock market, today, stakeholders demand increasingly more insight into a business' societal contribution in a broader sense. AkzoNobel has addressed this request by developing the 4 dimensional profit and loss (4D P&L) methodology.

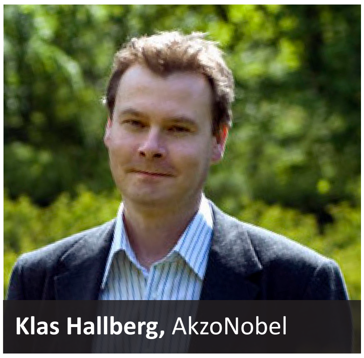
The 4D P&L methodology takes into account not only our own company's costs and profit, but also the value creation (profits) and negative effects (losses) that take place in other links of the value chain, collectively called externalities. It does so in multiple dimensions: financial, environmental, human and social impacts are assessed. This is a totally new way of looking at a product's value chain, because the impact of a company on society at large can be assessed.

To assess the environmental impacts of a life cycle approach is used, together with the EPS in order to set a price on the environmental impacts. A comprehensive overview of all profits and losses throughout the value chain of a product is created by combining the results for each of the 4 capitals.

In this case study, AkzoNobel has taken a book as an example. The results show that per book, the combined overall increase in financial and human capital is more than 10 times greater than the loss of natural capital, and few social risks were identified. By using the model, AkzoNobel can identify where to focus their work in order to minimize the negative externalities, maximize the positive externalities, and decrease their environmental impacts.

Read more about the case study in Appendix 1

Klas Hallberg - AkzoNobel



Read more about the work of AkzoNobel within sustainability at their website (AkzoNobel 2016: c).

What kind of benefits (and barriers) do you see when integrating monetary valued environmental impacts for materials and processes (EPS-values) in your product development process/organization?
- A benefit is that using monetary valuation enables us to speak the same language: monetary terms. But the benefit might also become a barrier, since the management is afraid to mix environmental costs with monetary terms, since they fear that financiers might think that the numbers are actual costs which might occur next quarter, or next year. It is necessary to explain how it works really carefully, but sometimes it is not enough.

What has been the most surprising result for your organization?
- The results are not so surprising for us, we are experienced within the field. My biggest surprise is that people are so positive to use the methodology, and this could be considered a result in itself. It is all about habits. People within our organization are now becoming used to this way of thinking.
- Given our type of business,we use a lot of fossil fuels, and climate impacts are of vital importance for us, which we are already measuring. Would we have another type of business, perhaps we would be more surprised with the results. One could be surprised over the high values of our climate impact, but to a large extent the reason for this is that we are using one methodology, EPS, and follow it stringently, instead of using different parts from different methodologies in order to steer the results.

Have there been any new lessons for your group while carrying out the case studies?
- Early in the process, we realized that in order to go beyond one case, and make it work for all products, it is necessary to integrate the data in an appropriate data processing tool.

What has been the biggest challenge during the work with the case studies?
- It has not such a big challenge for us, since we already have a lot of data. But for those who do not have a lot of data, it will be a big challenge. Perhaps our biggest challenge has been to explain why we should work with monetization of environmental impacts.

Do you have any ambitions to continue this work, and in that case, how?
- Yes, there are several examples. Pulp and Performance Chemicals AB have decided to do this annually. Also, we recently decided to make it on a general level for the whole organization and include it in the Annual Report. It will not be as detailed, and hence less substantiated, and the data we have varies in details in different parts of the organization. We will look at value chains which are representative for the whole organization.

What do you think is needed for more organizations to start to work with an integration of environment and economy through monetization of environmental damage costs?
- The organizations must have a well substantiated information data base regarding their value chains. They must start to measure and follow up their value chains and use a system for it. It is necessary to follow up the value chains, not only the own activities.

Do you have any recommendations to interested organizations about how they could get started with their work with an integration of environment and economy?
- It is necessary to have a few people focusing on this in their work, not just one person because it is necessary to have colleagues to discuss with. This is not easy if you are a small company, but you can collect data. It is also necessary to have the right competence, people who understand environment, but also has a holistic view, as it will be necessary to make simplifications and a well-balanced appreciation about how it could represent the whole organization. It is crucial to know what is important and which information that is available.

-To conclude, this work has functioned very well and it will be exciting to follow how it all develops further on.

5.2 SCA

About SCA

Based in Stockholm, Sweden, SCA is a global company operating in about 100 countries, producing hygiene products such as personal care and tissue, and forest products. It is also the largest private forest owner in Europe. SCA has 44 000 employees (SCA 2016: a).

About the case study

The project team has consisted of members of the Product Sustainability group at SCA, with Ellen Riise as the internal project leader. The whole team of seven persons have participated in general discussions around the internal weighting methodology. Out of that group, the LCA practitioners discussed and brought up suitable case studies to be used in the internal weighting tests. In addition, Madeleine Pehrson and Annica Isebäck from the group have run all additional evaluations where the EPS methodology has been used. These results were reported in a standard format for analysis and comparisons, which have been done by Ellen Riise.

Results and conclusions

SCA has used life cycle assessment (LCA) since the early 1990s. The methodology is used both to calculate the environmental performance of new innovations as well as to measure the improvements over time for product assortments. For many years SCA has had an interest in weighting as a support in complex interpretation of LCAs, and as a guide for strategic targets. In this project SCA has worked with both a development of an internal weighting methodology, and implemented, tested and started to evaluate the EPS methodology. A first step for development of an internal weighting methodology was the selection of environmental impact categories in a structured way. It was done with following basic principles like relevancy and scientific validity, as well as with a basis from a continuous stakeholder dialogue with SCA's stakeholders. The next step was to implement the EPS methodology in the way of working with LCA. Experiences from earlier work with EPS had made it clear that a sound technical solution for importing EPS data into LCA software was critical. With such a solution eventually in place, SCA has compared the internal weighting methodology with EPS values for the compared products. There is an overall agreement with the methodologies, explained by the focus on resource use in both methodologies. However, this focus is more explicit with the EPS methodology, whereas the internal weighting methodology has another priority for some emissions.

The possibility of further use of the EPS methodology will be evaluated after this pilot, where it is reasonable to believe that the internal implementation will take time. Communications of learnings and results will be an important part of the future monetarization work, and the upcoming international standard will support this work.

Read more about the case study in Appendix 2

Ellen Riise - SCA

Read more about the work of SCA within sustainability at their website (SCA 2016: b).

What kind of benefits (and barriers) do you see when integrating monetary valued environmental impacts for materials and processes (EPS-values) in your product development process/organization?
- We assess environmental and financial impact of our products in separate ways today. The integration of monetary values for environmental impacts gives an opportunity to evaluate the potential financial cost of environmental impacts. This will broaden the environmental assessment beyond direct environmental impact such as GWP (Global Warming Potential), acidification or eutrophication. Monetization has been researched for many years but is still a "new" assessment methodology for many people working with other financial tools. The internal implementation from the current pilot to integration will take time.

What has been the most surprising result for your organization?
- We perform environmental assessments with LCA of new innovations we have today a system for weighting the results of environmental impact categories. It turns out that the difference between products is about the same when comparing the difference between EPS values and the weighted environmental impacts.

Have there been any new lessons for your group while carrying out the case studies?
- Not so much of new lessons, but interesting to learn that our idea of resource efficiency at least has a corresponding methodology that seems to indicate in the same direction as we have chosen by our internal weighting methodology.

What has been the biggest challenge during the work with the case studies?
- Our pilot is focusing on integrating EPS in our LCA tool. It has been a practical issue, because the case study was depending on the update of EPS values in our software for LCA. Once the values were in place, and we had a template for the result interpretation out of the software, it has been very easy to run LCAs with an EPS result for many different products.

Do you have any ambitions to continue this work, and in that case, how?
- Our first step was to run the pilot. We will now evaluate the result and propose next steps for internal evaluation.

What do you think is needed for more organizations to start to work with an integration of environment and economy through monetization of environmental damage costs?
- Firstly, the companies need to anchor the purpose and value of adding the monetization of environmental and social aspects. Secondly, it is a very good foundation to have a good way of working with Life Cycle Management. You need good procedures, tools and data for handling environmental and social aspects in an efficient and credible way. Communication of learnings and result will be an important part of the monetization work.

Do you have any recommendations to interested organizations about how they could get started with their work with an integration of environment and economy?
- It is important to work based on life cycle management, with corresponding good knowledge about the processes and products. It is necessary to be able to analyze and find hot spots along the value chain such as different life cycle stages, environmental impacts, and down to single processes since the important outcome is to find where to work to reduce the environmental impacts.

5.3 Volvo Group

About Volvo Group

With 100 000 employees, production in 18 countries and markets in 190 countries, the Volvo Group is a large, global manufacturer of trucks, buses, construction equipment and marine and industrial engines. The Volvo Group headquarter is located in Gothenburg, Sweden (Volvo Group 2016).

About the case studies

Volvo Group made two case studies within the IMP project.

1. The Effect on Environmental Damage Costs and Eco-Efficiency of introducing Recycling of Sand in Volvo Group's Engine Plant in Skövde: The case study was initiated by Maria Böös, Director CSR and Public Affairs at Volvo Group Operations. Lisbeth Dahllöf collaborated with Johan Ålander, a manufacturing technology specialist at Volvo Group Trucks Operations at the foundry in Skövde where he is planning investments. Other information around the hypothetical case was given by the references in the report. The LCA study was performed by Lisbeth Dahllöf and the report was reviewed by Mia Romare, Bengt Steen and Johan Ålander.

2. Environmental Cost and Eco-Effectivity Assessment of Copper and Aluminium High Power Cables: All involved people in the study are from Volvo Group trucks advanced technology and research. Mattias Dalesjö, Senior technology specialist, is responsible for the development of the aluminium cable project on which the case study is based and has contributed with data for the LCA. Marasami G, system engineer, is also part of the development project and has provided data for the eco-efficiency calculation. Mia Romare and Lisbeth Dahllöf have been involved in the LCA modelling and report.

VOLVO

Results and conclusions

1. The Effect on Environmental Damage Costs and Eco-Efficiency of introducing Recycling of Sand in Volvo Group's Engine Plant in Skövde

This study investigates how the information of environmental damage costs can be calculated and presented for investment in a production facility.

Volvo Group Trucks Operations, Powertrain Production in Skövde needs large amounts of sand for their foundries. They have a new and an old foundry. The old one has no recycling of the used sand and it becomes more and more difficult to get new sand, because of the specification and the unwillingness to start new sandpits due to environmental reasons. Also Volvo has high costs for deposition of the used sand although it is used for filling of ground for industrial areas, and thus avoiding the landfill fee.

Recycling of the sand would reduce the need for virgin sand. There is technique for this that is mechanical which was hypothetically calculated with in this report. There are also other possibilities to reduce the need of virgin sand, such as using synthetic bauxite (a common ore) sand or natural clay. Both solutions are, however, expensive.

The environmental damage costs for the current situation and a hypothetical future with recycling were calculated and compared. It serves as an example of how environmental damage costs would be changed in comparison with hypothetical investment costs. The damage cost/kg of the natural sand had been calculated earlier. A theoretical calculation was also made for the case if the foundry is using bauxite sand and considers recycling. 96 % of the environmental costs for the hypothetical case of natural sand recycling would be due to the sand itself and not the transports involved.

The hypothetical introduction of recycling of the natural sand is eco-efficient, thus both environmental damage costs and direct costs decrease, given a payoff time that is shorter than the probable usage time for the investment and that current sand price stays the same. It is however probable that the sand price increases, which makes the recycling option even more eco-efficient.

Bauxite sand does not give an

environmental benefit compared to natural sand even if it would be used afterwards in the aluminium industry. To use bauxite sand or other minerals with a content of a useful resource but not reusing them after the foundry, would however cause very high environmental costs as illustrated in this study in a case where the bauxite sand is not reused in the aluminium industry.

For bauxite sand, the cost for CO2 emissions are mainly from sand making. For calculations of risk in investments it is recommended to subtract the CO2 emissions where the society has internalized the costs (tax or fees) and in this case the truck transports in Sweden and Norway pay CO2 tax. However, still the natural sand would have the highest risk, because its dominance in the environmental damage costs result. It can thus be the fossil energy use causing CO2 emissions in synthetic sand production that has the highest internalization risk.

If the energy use in the world would come from sustainable sources, then the CO2 emission problem in this study would be solved and if the sand can be made from rock without scarce minerals, nearly all the environmental risk would have disappeared. In the meantime it is recommended to invest in energy and sand efficiency.

To summarize, with the recycling rate assumption in this study, it is a risk not to invest in recycling of natural sand, since it is a limited resource and the synthetic alternatives are expensive and environmentally impacting with current production technology.

2. Environmental Cost and Eco-Effectivity Assessment of Copper and Aluminium High Power Cables

Volvo Group made life cycle assessments of two different high power cable alternatives: copper based cables and aluminium based cables.

The results indicate that the environmental cost of the copper cable is significantly higher than that of the aluminium cable. This is due to the fact that copper is much more scarce than aluminium in the earth's crust, and thus the cost of using it in a sustainable way is much higher.

The lower weight of the aluminium cable is beneficial in the use phase, but this has a much smaller impact on the environmental cost than change of material. If the efficiency of the copper recycling can be improved, the losses will decrease, and the total impact over the life cycle due to the material can be decreased.

It is important to note that the results indicate the long term issues and environmental cost of the different cable alternatives. When choosing, also short term considerations must be made, where the use phase might be more important. As the choice of aluminium is beneficial both in the long term, as well as for the energy consumption in the use phase, it can be recommended as the alternative with least environmental cost.

As the results are presented in monetized terms, the environmental gains of the change of cable material can be weighed against the investment cost. This can help decision-makers evaluate how sizable the gain is in terms that are already familiar within decision-making.

Main conclusions and recommendations:

- The copper alternative holds the highest environmental cost.
- In this case a good choice of sustainable material is more important in the long run than the potential weight reduction for the environmental performance.
- Recycling is critical in order to minimize the total life cycle cost. Proper collection, separation and processing to secure quality is essential.
- It is clear that the difference between internal and extern cost is very large in the case of the copper cable input material. This indicates a risk that the price of this cable alternative might increase. End of life value might also increase accordingly.
- The eco efficiency assessment shows that the change from copper to aluminium is an investment that will decrease the environmental cost with 1-10ELU per invested € depending on if the end of life if included.

Read more about the case studies in Appendices 3 and 4

Lisbeth Dahllöf and Mia Romare - Volvo Group

Lisbeth Dahllöf,Volvo Group

Lisbeth Dahllöf,Volvo Group

Read more about the work of Volvo Group within sustainability at their website (Volvo Group 2016: b).

What kind of benefits (and barriers) do you see when integrating monetary valued environmental impacts for materials and processes (EPS-values) in your product development process/organization?
- A benefit we can see is that by integrating monetary values, environmental aspects will be taken into consideration more when it comes to decision making. This because they now can be evaluated on the same basis.

- A barrier is that the environmental damage costs are not allowed to be included in the normal balance sheet, thus the costs are not tangible in the short perspective.

- The time perspective is also a real barrier. Abiotic resource depletion has a high environmental cost, but it is not a visible problem for businesses today. Because of this the results can be hard for decision makers to take into consideration. Many unborn generations have to be considered in order to work with sustainable development, which is not common in economic decisions today.

What has been the most surprising result for your organization?
- Surprising for the foundry was that the sand resource has a high environmental damage costs. There had been a high focus on CO2 emissions and the direct costs for alternative synthetic sand, not the environmental impact of the synthetic sand.

- The results from the comparison of the aluminium and copper cables showed the predicted results, where aluminium is more environmentally beneficial. The surprise was that the difference was very large.

Have there been any new lessons for your group while carrying out the case studies?
- Yes, definitely! In the LCA team we got to test the effect of GaBi's economic allocation on EPS, increasing our knowledge on how LCA method assumptions impact the EPS results. We also learned a lot about the updated EPS and how our results changed when using it.

- We also learned good ways to use economical valuation to calculate eco efficiency. Eco-efficiency can be defined in different ways, and we found one that could help us as a company to optimize our environmental investments. Additionally, we got the change to argue for the benefits of using EPS, with its long term sustainability focus.

What has been the biggest challenge during the work with the case studies?
- The big question to understand was; when can we use EPS. The answer ended up being that we can use it to look at future risks.

- When looking at EPS as a measure of future risk it is important to subtract the already implemented environmental cost, in order to only see future risks. Understanding, clarifying and conveying this presented a challenge, for example in the case of CO2 tax or in the case of emissions without EPS index.

- It is also interesting that plants struggle with environmental goals for emissions that may not cause proven environmental damage for that concentration level (EPS index=0). In that case EPS does not add any extra information, since the limits are from a precautionary standpoint. It was a challenge to differentiate these types of cases from cases where EPS is applicable.

Do you have any ambitions to continue this work, and in that case, how?
- Yes, we would like it to become a common practice. We already have EPS in the product development but the monetary values are not used. The indices are only used as relative umbers, not as monetary values, which we would like to include.

- We hope we can find other case studies and so that we can continue to do calculations for environmental costs as a part of investment evaluations.

What do you think is needed for more organizations to start to work with an integration of environment and economy through monetization of environmental damage costs?
- It requires that the companies set aside specific time and resources for this accounting-process. It is important that the company not only does it to confirm the investment they already have decided to do, because they see the damage cost as “not real money”. It needs to be considered as a risk in the same way as other risks.

- EPS can be used as a communication tool, but also as a part of development and business decision making. In a real integration the environmental damage cost should be known as early as the direct cost, and of course it should be minimized.

- Policies (internal and external) and long-term perspective is also desirable in companies, as well as a will to include long term risks.

Do you have any recommendations to interested organizations about how they could get started with their work with an integration of environment and economy?
- It requires that the companies set aside specific time and resources for this accounting-process. It is important that the company not only does it to confirm the investment they already have decided to do, because they see the damage cost as “not real money”. It needs to be considered as a risk in the same way as other risks.

6. Results and conclusions

The case studies have showed different approaches and examples of how companies can use the EPS methodology for integration of economically valued environment impacts in product development. EPS can be used to compare two scenarios with each other and to choose between design options in product and process development.

In AkzoNobels case study on a book, they worked with a model to assess the impact of the product life cycle on society at large, using a 4 dimensional profit and loss accounting methodology. The model assesses financial, environmental, human and social impacts. The model has been developed by AkzoNobel as a response to the society's demands on companies to address and explain how they work with externalities. The four dimensions are assessed using different methodologies, where a life cycle approach has been used when assessing the environmental impacts of a product. Using the EPS has subsequently allowed AkzoNobel to set a price on their environmental impacts in the study.

In the case study, AkzoNobel has identified that, per book, the combined overall increase in financial and human capital is more than 10 times greater than the loss of natural capital, and few social risks were identified. AkzoNobel believes that the loss in natural capital can be (further) reduced by using their technology and value chain cooperation.

In the SCA case study, SCA compared the EPS results with an internal weighing method they have used for several years. SCAs weighing method mirrored the concern they had experienced from their stakeholders and society on their releases and use of natural resources. The comparison showed similar ranking of their alternative product life cycles, but differed in terms of the weight it gave to single emissions and resources. The difference may be explained by the difference between local aspects in permit contexts (SCA's internal method) and global or regional resource aspects in sustainability assessment (EPS). In permit contexts, for instance for water emissions, safety marginal are often used, resulting in zero impacts. The SCA internal method therefore gave significant weight to water emissions that was given no weight in the EPS method as it as global averages gave no or negligible impacts. The SCA case study clearly showed that not all environmental management of a company can be handled through product policy. The permit process and the environmental concern on the product levels are complimentary.

The integration of monetary values for environmental impacts gave an opportunity to evaluate the potential financial cost of environmental impacts. The possibility of further use of the EPS methodology at SCA will be evaluated after this pilot, where it is reasonable to believe that the internal implementation will take time.

The Volvo Group made two case studies within the IMP Project: *The Effect on Environmental Damage Costs and Eco-Efficiency of introducing Recycling of Sand in Volvo Group's Engine Plant in Skövde*, and *Environmental Cost and Eco-Effectivity Assessment of Copper and Aluminium High Power Cables*. The study on recycling of sand, investigated how the information of environmental damage costs can be calculated and presented for investment in a production facility. The results showed that with the recycling rate assumption in this study, it is a risk for future costs if they do not invest in recycling of natural sand, since sand is a limited resource and the synthetic alternatives are expensive and impacting with current production technology. The study shows an example of how one can work to handle future risks. It shows different scenarios and their associated costs, and can assist decision-makers in taking decisions based on these scenarios.

Regarding the case study on copper and aluminium high power cables, the results indicate that the environmental cost of the copper cable is significantly higher than that of the aluminium cable. This is due to the fact that copper is much scarcer than aluminium in the earth's crust, and thus the environmental cost (and in the long run economic cost) of using it in a sustainable way is much higher. As the results are presented in monetized terms, the environmental gains of the change of cable material can be weighed against the investment cost. This can help decision-makers evaluate how sizable the gain is in terms that are already familiar within decision-making. EPS could in this case assist in determining the best long-term decision, but also for the short-term.

To conclude, the IMP project has been able to meet the aims decided in the beginning of the project. By updating the EPS methodology, and further on testing the methodology in the case studies, the IMP project has contributed to the aim of achieving a more efficient product development by making environmental costs more visible early in the product development phase. Using EPS in the case studies enabled a showcase of how companies can work with the methodology, and has hence contributed to facilitating a change from a reactive to a proactive product development strategy regarding environment and sustainability.

The update and further development of the EPS has contributed to making environmental and sustainability data more readily available, which can be used in an innovation process.

Within IMP, the project group has contributed to;

- Continuing to developing a methodology for calculating environmental damage costs and for estimating degree of internalisation;
- Methodology implementation, including: case studies, output from case studies, and methodology standardisation;
- Dissemination, including: project management, coordination of the Working Group ´Get the prices right´, contribution to ISO standardization work, and dissemination.

7. Lessons learned and way forward

Monetization can help in decision making by creating a common language that is used both for the environmental assessment as well as for the economic aspects of an investment or technology update. Monetary valuation can also help us better understand the magnitude of the impact. Another potential benefit of discussing the environmental impact in terms of money is that we better understand if the price we pay includes the external cost, a cost that is paid by society. The external costs, externalities, are a potential business risk as they may become internal due to for example regulations and taxes. The case studies in this project have shown how companies can use monetary valuation to handle these risks, by using the EPS methodology.

Communications of learnings and results will be an important part of the future monetarization work, and the upcoming international standard will support this work.

7.1 ISO standard and the future of EPS

Valuing environmental impacts in monetary terms is a complex issue, and users of the EPS methodology seldom have the time to understand all models and data. Therefore, credibility is crucial so that new users will be reluctant to start using it, and learn gradually about its different features.

Our strategy will be to fulfil the work within ISOs environmental management committee and to maintain the EPS impact assessment data, so that it always represents latest knowledge on environmental issues.

One of the lessons learned in the project is how much work that is needed to implement and disseminate a new methodology that has been developed. Even if we spent much time in the planning of the project and during the project work to implementation and dissemination, the world is big and lots of efforts remain.

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Appendix 1: Appendix 1: AkzoNobel, *4D P&L*

(4 Dimensional Profit & Loss Accounting)

Paper books are part of the sustainable city

Now – and in the future. We have done the math.

AkzoNobel

Financial Capital

Natural Capital

Human Capital

Social Capital

4 Dimensional profit and loss accounting

Did you know AkzoNobel helped in creating your favorite book?
Most book readers are aware of the role of the author, editor and publisher in producing the books you find in the book store. But have you ever considered the physical journey your favorite novel has taken before it ends up in your hands?

The physical journey of a book includes the manufacturing of materials such as paper and ink, packaging materials, transport to and from the printing house, the book seller and your local shop. Once read, the book may be resold a number of times, until it is ultimately recycled or processed as waste. This journey is called a book's value chain. As a leading global paints and coatings company and a major producer of specialty chemicals, AkzoNobel is positioned right at the beginning of this value chain. Thanks to our bleaching technology, the pages of the book become white.

Why AkzoNobel is committed to creating the book of the future
Our company goal is to create everyday essentials to make people's lives more liveable and inspiring. Books are of great value to society, and AkzoNobel is proud to play such an essential role in their production. Further, we believe that economic growth cannot be sustained if the underlying natural and social capital which wealth creation depends upon is depleted. This is why we are committed to create the book of the future by continuously innovating our processes. How we do this, will be explained in later sections.

4 Dimensional profit and loss accounting
In the course of doing business, companies create societal value in many ways. Not only do they provide their customers with products and services that they need, they also contribute to the economy by purchasing products and services from upstream suppliers. Further, they generate jobs and income for their employees and pay taxes to the government.

Unfortunately, business activities exert negative effects as well. On people and communities, but most importantly on environment and nature.

As a result, society is critical of companies. Where traditionally the impact of a company was solely measured in terms of the profit generated for its shareholders and its share price on the stock market, today, stakeholders demand increasingly more insight into a business' societal contribution in a broader sense. AkzoNobel has addressed this request by developing the 4 dimensional profit and loss (4D P&L) methodology.

The 4D P&L methodology takes into account not only our own company's costs and profit, but also the value creation (profits) and negative effects (losses) that take place in other links of the value chain, collectively called externalities. It does so in multiple dimensions: financial, environmental, human and social impacts are assessed. This is a totally new way of looking at a product's value chain, because the impact of a company on society at large can be assessed.

Overview of the value chain of the book

The 4D P&L methodology is a totally new way of looking at a product's value chain, because the impact of a company on society at large can be assessed.

Each of the four pillars of the 4D P&L framework is assessed with a separate methodology. The methodologies for natural and social capital were adopted from external approaches, whereas the ones for financial and human capital were newly established. The resulting framework of repeatedly and robustly tested methodologies, is now publicly available. We will in this leaflet explain our 4D P&L framework, our methodology and the results of our case study on the book in greater detail.

Books and value creation
In 2015 we launched a 4D P&L accounting study, which specifically focused on the production of books. In order to identify possible improvements and ultimately increase business value, we assessed the book's full value chain (see infographics):

1. Paper production
2. Authoring and publishing
3. Distribution and sales
4. Transport to customer and recycling

For each link in the chain both direct and indirect impacts were taken into account, such as the environmental burden and financial gains of raw material production and electricity use.

Conclusions on our book case study:
Per book, the combined overall increase in financial and human capital (€ 21.74) is more than 10 times greater than the loss of natural capital (-€ 1.87). Few social risks have been identified. This is an encouraging result: we believe that the loss in natural capital can be (further) reduced by using our AkzoNobel technology and value chain cooperation.

Thanks to this extensive assessment we can continue to engage with value chain partners and tackle key issues that help us to reduce the negatives and build on the positives in order to improve the overall sustainability of the book's value chain.

In the next pages we will explain in great detail the methodology and results per capital, our key findings and insights, and the conclusion.

Paper production
Paper production includes the manufacturing of wood pulp and (bleaching) chemicals, paper drying, cutting, transport and storage.

Authoring and publishing
A book is written by an author, edited and published. This step includes book printing and binding, transport and storage.

Distribution and sales
The book is distributed to book stores, where it is sold. Marketing and advertisement are included in this step.

Transport to customer and recycling
The customer visits the store and takes the book home. After one or more readings, potentially some re-sells, the book is processed as waste or recycled as paper.

Natural Capital Protocol
The natural capital evaluation of this study is used as a pilot study to test the Natural Capital Protocol.

4 Dimensional profits and losses in the value chain of the book

The 4D P&L accounting study, focusing on the production of books, was launched in 2015. In order to identify possible improvements and ultimately increase business value, we assessed the book's full value chain, from forestry, via pulp and paper production, all the way to customer home transport of a book and recycling of the book.

It was further assumed that a total number 100,000 copies of the book would be sold in European book stores, for a price of € 20 per book. The book production was assumed to take place in Europe, using 50% recycled paper and 50% virgin paper manufactured in Brazil. The results were calculated per book.

About this study
The study results as discussed below are generic industry results and are based on generic data which have been collected from public sources. It does not reflect AkzoNobel's specific customers. AkzoNobel is not a producer of books or paper; we produce chemicals that are used in pulp and paper production. By sharing the results of the study we intend to contribute to an even more sustainable value chain.

Natural Capital Protocol
The natural capital evaluation of this study is used as a pilot study to test the Natural Capital Protocol. This is a standardized framework for businesses to measure and value their direct and indirect impacts and dependencies on natural capital, developed by the Natural Capital Coalition.

References: Financial capital creation along the value chain (Ecomatters, 2016). www.ecomatters.nl/financial-capital

Financial Capital

Concept: Companies create financial value in many different ways: they generate wages for their employees, tax revenue for the government, interest for their investors and profit that is shared with their shareholders. The sum of these financial gains we call 'financial capital', which we define as:

Value added = Profit after tax + Taxes + Interest + Depreciation + Lease rentals + Staff compensation

Calculating financial capital throughout the book's value chain:
Financial capital involves the flow of financial value along the value chain. To illustrate this, imagine what happens when a book is sold at a local book store. The financial revenue generated by the sell is partly used by the store owner to pay employee wages, rent, heating, etc. Another part of the revenue is reallocated by the store owner to the book distributor by means of book cost price. The distributor, in turn, reallocates a part of his/her revenue to the book publisher, and so on. Ideally, this reallocation leads to a net profit at every link of the value chain.

We have calculated the financial capital throughout the value chain, based on an average retail price of € 20 per book. The data used in this study is based on public cost data for various inputs to the value chain and verified by a number of publishers.

Financial capital of a book:

Financial Capital		
Value chain phase	**Value created**	**% of total**
1) Paper production	€ 0.85	4%
2) Authoring and publishing	€ 8.15	39%
3) Distribution and sales	€ 11.00	52%
4) Transport to customer and recycling	€ 0.96	5%
Total book	**€ 20.96**	**100%**

1) Paper production
Paper is produced in large quantities and has a relatively low market value. As a result, a mere 4% (€ 0.85) of the financial capital of a book is allocated to the first production phase of the value chain.

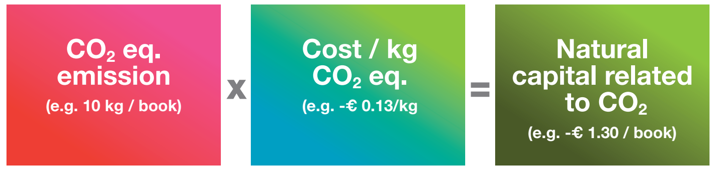
2) Authoring and publishing
Much more financial value is allocated to the second link of the value chain; the authoring and publishing of a book creates on average about 39% (€ 8.15) of financial capital. Most financial value flows to the publisher, who reallocates it by means of advertising and payment of employee wages, and the author, who receives a few euros per book.

3) Distribution and sales
The bulk 52% (€ 11) of the financial capital is allocated to distribution and sales activities. This capital constitutes mainly the sales margin of the bookshop owner, which is used to pay the wages of the sales people, the rent and other indirect expenses such as electricity and advertising.

4) Transport to customer and recycling
The final 5% (€ 0.96) of the financial capital is allocated to the final link of the book's value chain: transport to customer and recycling. We assume that all customers travel by car. The financial value for this link of the value chain is therefore related to the use of a car to drive up and down to the book store. We realize that the financial capital created from reading a book is potentially very high; for example where it concerns study books that are essential to the readers' education, which in turn leads to higher paid jobs. However, we did not include this in our assessment.

Conclusions:
The sum of the average book retail price of € 20 and the estimated € 0.96 for customer transport to and from the book store, adds up to a positive financial capital creation of € 21. This profit is mainly allocated to the more labor intensive links in the book value, such as authoring, publishing and sales.

Reference: Environmental Priority Strategy (EPS) system (Chalmers University of Technology, Bengt Steen, 2015). www.ivl.se/eps



(A) Shows schematically the way which natural capital is calculated.

Natural Capital

Concept: Business activities have an impact on environment and nature: they lead to, among others, fossil fuel consumption, greenhouse gases emission (collectively expressed as carbon dioxide equivalents, CO_2 eq.) and waste production. We have quantified environmental burden and natural cost associated with our business activities and have attached a monetary value that these negative impacts create. This results in what we call our 'natural capital', which we define as:

Cost to nature = impact on nature x monetary value of the impact

Calculating natural capital throughout the book's value chain:
Over the last decades, the research discipline involved in Life Cycle Assessment (LCA) has assessed the environmental impact of a wide variety of (business) activities. Today, these data are available in various Life Cycle Inventory (LCI) databases. Using a multitude of generic activities (e.g. the impact of driving a car for 1 km or heating a bookshop for one year), we have modelled the full life cycle of a book in specialized LCA software. The monetary value, which subsequently is attached to the quantified environmental impacts, is in accordance with the price for impact as established in the Environmental Priority Strategy (EPS), a methodology developed by Chalmers University of Technology. The monetary values in the EPS are based on either real or hypothetical market values, and reflect the cost of either environmental remediation or resource replacement. The impact on nature is based on the actual emissions and resource extraction. Schematically, the way in which natural capital is calculated see graph (A) above.

Natural capital of a book:

Natural Capital		
Value chain phase	**Value created**	**% of total**
1) Paper production	-€ 0.93	50%
2) Authoring and publishing	-€ 0.53	28%
3) Distribution and sales	-€ 0.07	4%
4) Transport to customer and recycling	-€ 0.34	18%
Total book	**-€ 1.87**	**100%**

1) Paper production
As most of the materials required for the production of books are manufactured in the first link of the value chain, it is not surprising that the activities in this link are the most resource consuming. Indeed, our calculations show that about 50% (-€ 0.93) of the natural capital loss is allocated to the production of paper.

2) Authoring and publishing
About 28% (-€ 0.53) of natural capital is allocated to activities in the second phase of the book production authoring and publishing. As the writing process itself, conducted by the author, has a negligible impact on environment, this loss of natural capital is mainly related to the energy and resource use in book printing.

3) Distribution and sales
With 4% (-€ 0.07), the smallest loss of natural capital is allocated to distribution and sales. The losses include the environmental burden of book transport, storage and sales, in which the heating of book stores was identified to have the largest contribution. As the number of books sold on an annual basis is very high, the natural capital loss allocated to distribution and sales per book is much lower than that allocated to paper production.

4) Transport to customer and recycling
The final 18% (-€ 0.34) of the natural capital is lost in the final link of the book's value chain: transport to customer and recycling. This environmental burden is mainly associated with consumers' car usage driving to and from the book store. Although it is assumed that books are recycled as paper in the end, the financial credit for this end-of-life phase is allocated to new products produced from recycled material (e.g. newspapers) and is not included in this calculation. We have included paper recycling in the first link of the value chain, by assuming that 50% of the material input consists of recycled paper.

Conclusions:
The production of a book leads to a net natural capital loss of -€ 1.87 per book, which is mainly allocated to resource consuming activities such as paper production, book printing and customer transport to and from the book store.

Reference: Human capital creation along the value chain (Ecomatters, 2016). www.ecomatters.nl/human-capital

Human Capital

Concept: The third dimension in which we aim to create value is in ‘human capital’. The human capital metric is related to the knowledge and skill development (or degradation) of employees, and takes into account positive or negative impact on future salary development. Human capital is defined as:

Expected value of future earnings
= current wage
x inflation corrected wage development
x time till retirement
x fraction of compensation related to work

Calculating human capital throughout the book’s value chain:
The human capital is calculated per country for a specific industry sector. It is based on employees’ wages, which is calculated as a part of the financial capital, and the expected value of future earnings.

The data used for the assessment of human capital was acquired from various statistics bureaus around the world and include wage levels for various industry sectors which were tracked for over a decade and corrected for inflation. Negative wage developments were observed in certain countries and industries, which potentially could lead to a decline in employer attractiveness.

Human capital of a book:

Human Capital		
Value chain phase	**Value created**	**% of total**
1) Paper production	€ 0.02	4%
2) Authoring and publishing	€ 0.22	39%
3) Distribution and sales	€ 0.50	52%
4) Transport to customer and recycling	€ 0.04	5%
Total book	**€ 0.78**	**100%**

1) Paper production
About 3% (€ 0.02) of human capital is allocated to employees who work in the paper production industry. The study includes paper production facilities in Brazil and in Europe, and the human capital metric indicates that on both continents wages are expected to have a small positive growth. This results in a small positive human capital gain.

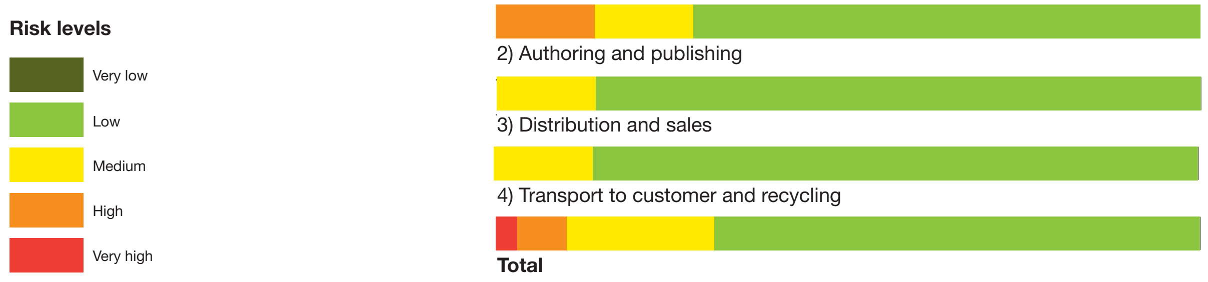
2) Authoring and publishing
About 28% (€ 0.22) of human capital is allocated to employees who are active in book authoring and publishing activities. In the Netherlands, the salary development in the book printing and binding industry is negative. However, since this loss of human capital is compensated by human capital creation by book authoring and marketing activities, the net human capital is in this part still positive.

3) Distribution and sales
With 64% (€ 0.50), the largest percentage of human capital is allocated to book store personnel, which indicates that this is an attractive profession in Europe.

4) Transport to customer and recycling
The final 5% (€ 0.04) of human capital creation is related to the transport of a customer to and from the book store, hence this value creation is mainly allocated to the employees in motor vehicle repair shops and petrol stations. However, since the estimated distance driven by car is small, this part of the total human capital is rather small.

Conclusions:
A total human capital of € 0.78 is created along the value chain. In general, the same trend is observed as for financial capital: human capital is mainly created in labor intensive steps such as book authoring, publishing, marketing and sales. Salary development varies per sector and region and defines whether human capital creation is positive or negative.

Reference: WBCSD Chemical Sector group http://www.wbcsd.org/chemicals.aspx



Social Capital, risks identified through social indicators **(B)**

Social Capital

Concept: A variety of social issues may occur in a company or industry, which can be related to either employees, consumers and/or local communities. Examples include serious topics – such as health and safety, child labor, discrimination and freedom of association, but also frequently overlooked matters, such as maintenance of a healthy work-life balance. We address these issues collectively in what we call ‘social capital’.

Determining social capital throughout the book’s value chain:
In contrast to the other three capital metrics, we have chosen not to monetize social capital. We care strongly about social matters, and therefore consider it inappropriate to associate them to a financial cost. Instead, we use a risk based screening tool developed by the Industry with the World Business Council for Sustainable Development. We used the questions from this method to review our production facilities and identified risks in the operations of our upstream and downstream value chain partners.

Since information on the risks associated with activities outside the boundaries of our own production sites is not always readily available, we additionally consulted generic public databases in which social risks are tracked per industry and country. Since this data partially has been collected from generic risk databases, it does not necessarily reflect the situation of AkzoNobel or its suppliers.

Social capital of a book, graph (B) above:

1) Paper production
The first production phase of the value chain provides the highest social risks (10% very high and 10% high risk). Forestry in Brazil for paper production and related labor issues were identified as a very high social risk category, also considering the fact that these workers have a higher risk of being underpaid. The high social risks are related to the lack of adequate health and safety awareness training for workers in forestry and chemical factories. However, many of the social indicators (43%), such as working hours, were identified to have low social risks.

2) Authoring and publishing
Some high social risks were identified (14%) during printing and publishing of a book. According to generic data, gender inequality issues occur in the publishing industry in the Netherlands. However, 71% of the social indicators in this industry identified low social risks associated with health and safety. Therefore, the overall social risks associated with this link of the value chain is lower than that associated with paper production.

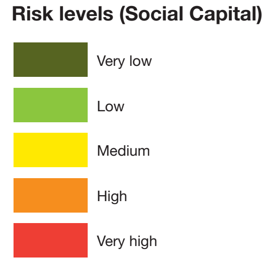
3) Distribution and sales
Activities in distribution and sales are mostly low risk associated. No high or very high risks were identified. On average, the social conditions for the employees in this industry and its surrounding communities in the Netherlands are good.

4) Transport to customer and recycling
In the assessment of possible social risks associated with transport in the Netherlands, mostly low risks (86%) were identified. The social conditions in the motor vehicle repair shops and petrol station industry in the Netherlands are good.

Conclusions:
Few social risks have been identified in the book’s value chain. The risks that were identified are generic risks related to the region (Brazil) in which certain paper production activities are performed. These generic risks should be further investigated, and actual identified risks should be addressed with relevant suppliers, both considering positive and negative human capital creation.

Results
4D profit and loss framework

A comprehensive overview of all profits and losses throughout the value chain of the book is created by combining the previously discussed results for each of the 4 capitals.

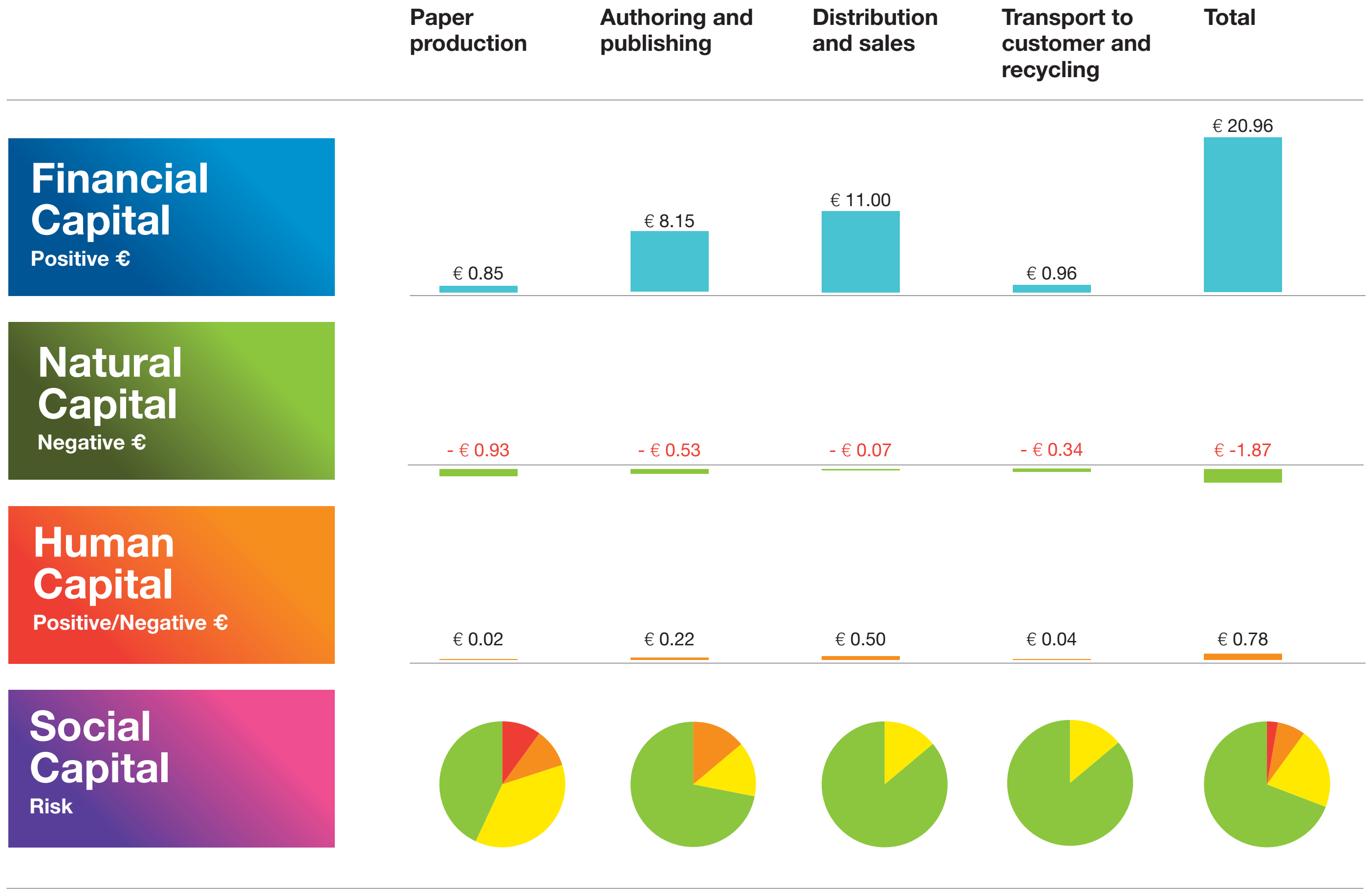


1) Paper production
In the first production phase of the value chain a small financial profit (€ 0.85) and a nearly equal loss of natural capital (-€ 0.96) are created. Consequently, if the cost for environmental remediation and resource replacement would be included in the paper costs, the latter would be doubled. In terms of human capital a small profit is made. A few high social risks are associated with paper production activities. The identified risks are generic risks related to the region in which this part of the value chain is mainly located (Brazil). These generic risks should be further investigated and where actual risks are identified, these should be addressed with the relevant suppliers.

2) Authoring and publishing
As authoring and publishing require little material input and much manual labor, the financial capital increase is larger (€ 8.15) than the loss of natural capital (-€ 0.53). Compensation for the natural capital loss would lead to a mere 6.5% cost increase for this link of the value chain. The value created in terms of human capital is positive but small as compared to the financial capital (€ 0.22). The overall social risks associated with authoring and publishing are low.

3) Distribution and sales
The profits and losses identified for distribution and sales activities resemble those in the second link of the book's value chain: a significant financial capital increase (€ 11) is accompanied by a small natural capital loss (-€ 0.07) and a modest human capital gain (€ 0.50). No major social risks have been identified.

4) Transport to customer and recycling
Transportation of the customer to and from the bookstore by car creates a small gain of financial and human capital (€ 0.96 and € 0.04, respectively) and a small loss of natural capital (-€ 0.34). No major social risks have been identified.



Conclusions:

Per book, the combined overall increase in financial and human capital (€ 21.74) is more than 10 times greater than the loss of natural capital (-€ 1.87). Few social risks have been identified. This is an encouraging result: we believe that this loss in natural capital can be (further) reduced by using our AkzoNobel technology and value chain cooperation.

www.akzonobel.com

AkzoNobel creates everyday essentials to make people's lives more liveable and inspiring. As a leading global paints and coatings company and a major producer of specialty chemicals, we supply essential ingredients, essential protection and essential color to industries and consumers worldwide. Backed by a pioneering heritage, our innovative products and sustainable technologies are designed to meet the growing demands of our fast-changing planet, while making life easier. Headquartered in Amsterdam, the Netherlands, we have approximately 45,000 people in around 80 countries, while our portfolio includes well-known brands such as Dulux, Sikkens, International, Interpon and Eka. Consistently ranked as a leader in sustainability, we are dedicated to energizing cities and communities while creating a protected, colorful world where life is improved by what we do.

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Appendix 2: SCA, *Pilot weighting method for product development and innovations*.

SCA: Report on case study for the project "Integration of Environment and Economy in Product Development Gives Opportunity for Innovations" (IMP)

Ellen Riise, SCA
October 2016

Introduction

For product life cycle studies, environmental impact assessment followed by a structured weighting process can be used for improved evaluation and interpretation of these studies. The use of a weighting method should guide towards the strategic targets of the organization and support when results are complex to interpret. In this project SCA has worked on establishing an internal weighting method and additionally worked with integration of the EPS method, primarily for weighting of SCA's People and Nature Innovations. The possibility of further use of the EPS method will be evaluated after this pilot.

Background

SCA has used life cycle assessment (LCA) since the early 1990s. The method is used both to calculate the environmental performance of new innovations as well as to measure the improvements over time for product assortments. The Carbon footprint reductions as published in SCA's Sustainability Report 2015 are examples of such improvements.

In addition to assortment analyses, the evaluation of SCA's People and Nature Innovations are important as these innovations are a part of the company's strategic targets. In 2015 SCA launched about 30 innovations and People and Nature Innovations accounted for 43% of total innovation sales.
SCA has since a number of years back had an interest in further developing the way of assessing the environmental performance of products. With a diploma work in 2010 a first approach was made to integrate the EPS system into the regular life cycle studies of the company products. At that time a major effort was needed for updating the actual LCA software with EPS data, since no prepared files for exporting these values existed at that time. Already with this diploma work the aim was to see how sustainability policies and targets could be followed up by using the EPS method.

Method

Selection of environmental impact categories

The evaluation of life cycle studies shall be credible and basic principles for deciding the most relevant impact categories should be followed as a first step. For SCA, with the aim of also creating a basis for weighting, the choice of impact categories was further based on company strategy and targets. The strategically important target for the People and Nature Innovations is:

"We will deliver better, safe and environmentally sound solutions to our customers. We strive to continuously improve resource efficiency and environmental performance considering the whole life cycle of our products."

In addition, input from Stakeholder dialogues and Materiality analyses was used. These analyses have been published in SCA's Sustainability reports since a number of years back. Different issues have been ranked in importance based on "Significance of SCA's business strategy" and "Significance to stakeholders". For importance of environmental issues, the use of resources has all the time been ranked as very important both for SCA's business strategy as well as stakeholders. The following four other issues are also mentioned: post-consumer waste, distribution, emissions of CO2 and water and waste water treatment.

When basing the choice on principles and stakeholder focus, the following impact categories are chosen for the impact assessment: total energy use, non-renewable energy use, carbon footprint, eutrophication potential, acidification potential, ground level ozone potential.

Steps towards weighting

With the selection of impact categories, a further step in supporting interpretation of life cycle studies can be taken by a strategy that clearly promotes specific results, which will support and simplify decision making. More diverse product systems, or new types of raw materials, can lead to unclear results with a more complex interpretation when some impacts are improved and some are deteriorated.

SCA has chosen that the weighting method shall be the same for personal care and tissue products. From a general point of view these demands are valid for a weighting method to be operable for different system evaluations or product evaluations for a company:

- ✓ Reflect a company's sustainability strategy and targets
- ✓ To give a clear answer from the environmental analysis of product, process or materials
- ✓ Applicable for all products/services from a company as well as alternative systems
- ✓ Be transparent, i.e. possible to predict and understand results
- ✓ Revision of the weighting method should be done regularly and in a structured way

Implementation of EPS at SCA

SCA has over the years built up a comprehensive database, with data from suppliers and own production sites. This has resulted in life cycle studies with a high level of completeness and a high degree of specific data. The choice of EPS as an additional weighting method has been evaluated by an implementation of EPS factors in SCA's LCA software tool, GaBi. By updating these data with EPS factors additional studies with EPS values can be run in parallel with regular life cycle studies.

The implementation of EPS values was, given the experiences from the diploma work in 2010, depending on a sound technical solution for import into the GaBi software. When the technical solution for an import file to GaBi was solved, this implementation was delayed because of new results from IPCC's latest assessment report. In this report nitrogen oxides were found as positive for climate impact. For a period of time the work with the case studies were delayed while discussions were being held within the project group and with other experts. Eventually the EPS values could be updated at SCA, and when they finally were in place also templates for result modelling was established. As an outcome of this work, both with consultancy support as well as SCA's LCA practitioners, evaluation of the method with case studies could start.

Comparison of weighting methods

In general, when SCA evaluates product development it is a comparison between a reference product and the product with the new feature (product design, material change, supplier change, or process change). For each of the six selected impact categories the difference between reference product and "new" product is multiplied with the internal weighting factor for that impact category. With the EPS system each product gets its result in ELU/product, and it is the difference between the two EPS values that is compared against the weighted value from the internal method. A negative value indicates an overall lower environmental impact from both systems.

Results

Table 1 shows a set of results from different product development projects, with the difference between the internal weighting process and the difference between products evaluated with EPS.

Table 1 Examples of internal weighting and compared EPS values

	Difference in % between products	
Comparison between reference product and new product	**Result from internal weighting**	**Result from compared EPS values**
A. Difference in product solution	-12	-10
B. Different material option	-2	-2
C. Different product design	-5	-6
D. Different material option	0	-1
E. Different material option	-1	-1

Discussion and conclusion

Evaluation of environmental impacts

The difference between the two evaluations is the higher focus by EPS on resource use, where the internal weighting to a higher degree also takes emissions, especially to water into account. The EPS method and the internal weighting both seem to be a viable way for securing a solid evaluation of innovations and developments of the company's products, processes and system. The focus on resource use in the EPS system, where use of renewable energy is zero and low values are found for emissions to water, would maybe call for some additional thoughts. As a long term strategy for product development use of resources is of an overarching interest, and maybe the use of renewable energy wares would need some more consideration. The more locally impacting emissions like emissions to water can be steered by more local interventions such as production permits. However, it can still be important to follow such impacts in some more details since, in a global perspective, there is variations on how local authorities work with these issues.

Thus results for both ordinary LCA weighting (internal method) and EPS data are available and interpretation of results from both types of evaluation can contribute to strategic indications for future development.

Evaluation of possible use of monetary values

We assess environmental and financial impact of our products in separate ways today. The integration of monetary values for environmental impacts gives an opportunity to evaluate the potential financial cost of environmental impacts. This will broaden the environmental assessment beyond direct environmental impact such as GWP, acidification or eutrophication. Monetarization has been researched for many years but is still a “new” assessment method for many person working with other financial tools. The internal implementation from the current pilot to integration will take time.

In general, for a company to integrate monetary values for environmental impact, the company would as a start need to anchor the purpose and value of adding the monetarization of environmental and social aspects. Secondly, it is a very good foundation to have a good way of working with Life Cycle Management. Good procedures, tools and data are needed for handling environmental and social aspects for the company’s products in an efficient and credible way. Communication of learnings and results will be an important part of the future monetarization work and the upcoming international standard will support this work.

Annex 1: Examples of internal weighting and difference between EPS values for three different product comparisons, A, B, and E.

Figure 1 Internal weighting result (A) – different product design -12%

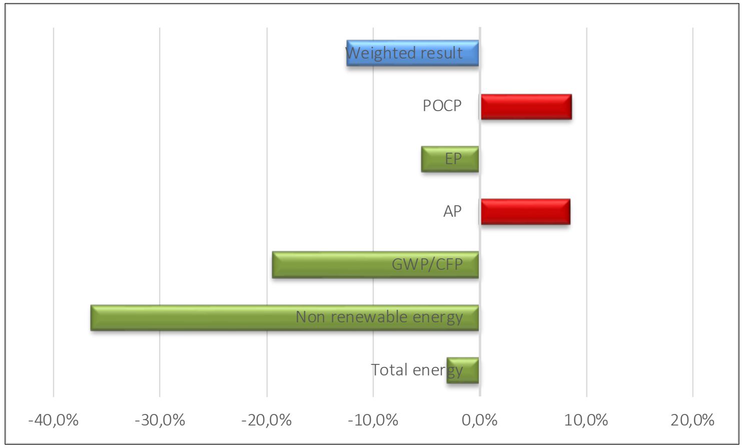


Figure 2 EPS values (A) for different product design, -10

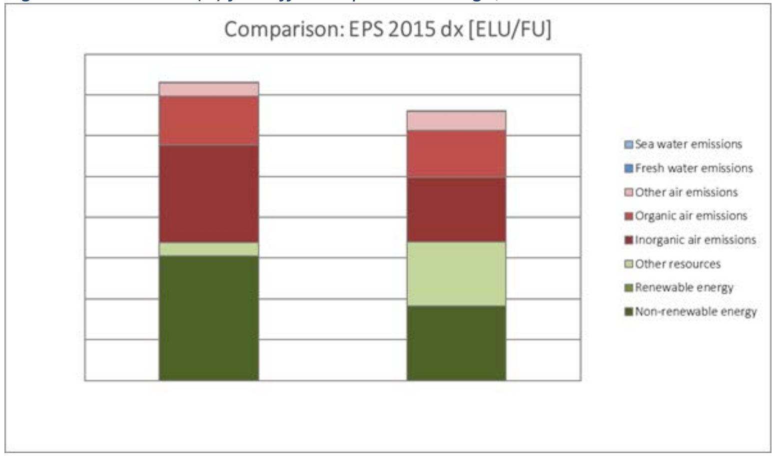


Figure 3 Internal weighting result (B) - product with material changes, giving higher resource efficiency, -2%

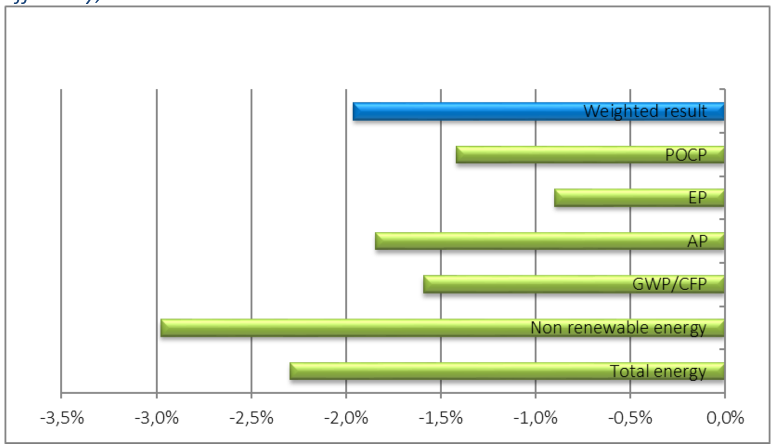


Figure 4 EPS values (B) for product with material changes, -2%

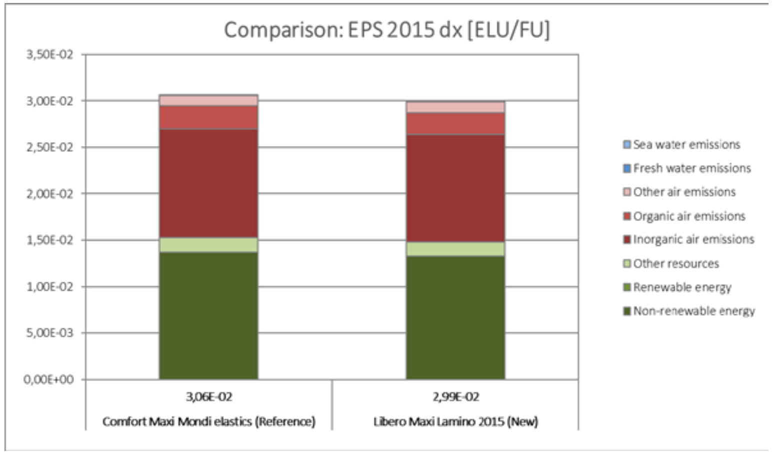


Figure 5 Internal weighting (E) - product with material changes causing improved emissions profile, -1

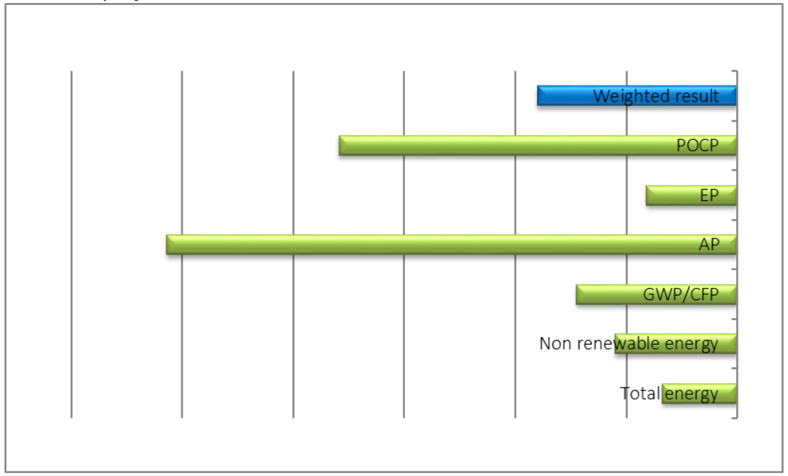
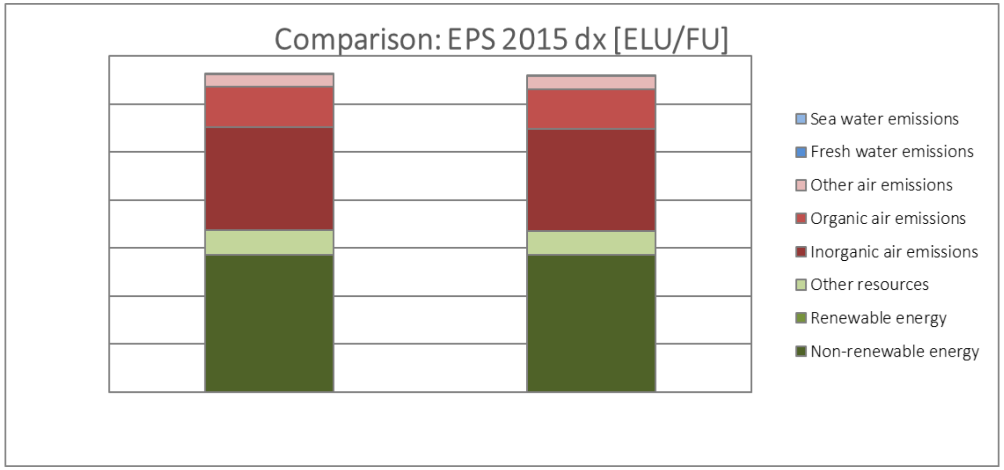


Figure 6 EPS values (E) for product with material changes, -1



Appendix 3: Volvo Group, The Effect on Environmental Damage Costs and Eco-Efficiency of introducing Recycling of Sand in Volvo Group's Engine Plant in Skövde

The Effect on Environmental Damage Costs and Eco-Efficiency of introducing Recycling of Sand in Volvo Group's Engine Plant in Skövde

This study investigates how the information of environmental damage costs can be calculated and presented for investment in a production facility.

Volvo Group Trucks Operations, Powertrain Production in Skövde needs large amounts of sand for their two foundries. The old one has no recycling of the excess sand and it becomes more and more difficult to get new sand, because of the specification and the unwillingness to start new sandpits due to environmental reasons. Also Volvo has high costs for deposition of the used sand although it is used for filling of ground for industrial areas, and thus avoiding the landfill fee.

Recycling of the sand would reduce the need for virgin sand. There is technique for this that is mechanical which was hypothetically calculated with in this report. There are also other possibilities to reduce the need of virgin sand, such as using bauxite (a common ore) or natural clay. Both solutions are, however, expensive.

The environmental damage costs for the current situation and a hypothetical future with recycling were calculated and compared. It serves as an example of how environmental damage costs would be changed in comparison with hypothetical investment costs. The damage cost/kg of the natural sand had been calculated earlier. A theoretical calculation was also made for the case if the foundry is using bauxite sand and considers recycling.

Most of the environmental costs of the hypothetical recycling case of natural san would be due to the sand itself and not the transports involved (96%).

The hypothetical introduction of recycling of the natural sand is eco-efficient, thus both environmental damage costs and direct costs decrease, given a payoff time that is shorter than the probable usage time for the investment and that current sand price stays the same. It is however probable that the sand price increases, which makes the recycling option even more eco-efficient.

Bauxite sand does not give an environmental benefit compared to natural sand even if it would be used afterwards in the aluminium industry. To use bauxite sand or other minerals with a content of a useful resource but to not use them after the use in the foundry would however cause very high environmental costs illustrated in this study in a case where the bauxite sand is not used afterwards in the aluminium industry.

For bauxite sand, the cost for CO_2 emissions are mainly from sand making. For calculations of risk in investments it is recommended to subtract the CO_2 emissions where the society has internalized the costs (tax or fees) and in this case the truck transports in Sweden and Norway pay CO_2 tax. However, still the natural sand would have the highest risk, because its dominance in the environmental damage costs result. It can thus be the fossil energy use causing CO_2 emissions in synthetic sand production that has the highest internalization risk.

If the energy use in the world would come from sustainable sources, then the CO_2 emission problem in this study would be solved and if the sand can be made from rock without scarce minerals, nearly all the environmental risk would have disappeared. In the meantime it is recommended to invest in energy and sand efficiency.

To summarize, with the recycling rate assumption in this study, it is a risk not to invest in recycling of natural sand, since it is a limited resource and the synthetic alternatives are expensive and environmentally impacting with current production technology.

1 Contents

List of abbreviations

EoL	End of Life, thus the scrapping and recycling phase
EU ETS	EU Emission Trading System
SCC	Social Cost of Carbon
LCA	Life Cycle Assessment
LCI	Life cycle inventory
LCIA	Life Cycle Impact Analysis
MAC	Marginal Abatement Cost

1 Introduction

1.1 About this report

This report presents the results from the life cycle assessment performed as a part of the research project *Integration of Environment and Economy in Product Development Gives Opportunity for Innovation*. The project is financed by VINNOVA (Sweden's innovation agency) and project partners include IVL Swedish Environmental Research Institute, Chalmers University of Technology, AkzoNobel, SCA Hygiene and Volvo Group. The project is hosted by the Swedish Life Cycle Center.

The reason for conducting the assessment is to better understand the complete life cycle environmental implications of changing to recycling of sand in order to make a more conscious decision.

The target audience is both the project members, who mainly will focus on the assessment of the newly updated EPS method. Additionally, the assessment is targeted to the staff in the Volvo GTO foundry that are calculating on the business case of recycling of sand in order to evaluate how the calculation of environmental cost can be useful for them in building a more solid foundation for the decision whether to invest in sand recycling or in other improvements. Here a hypothetical case is however presented, because of the public character of this report.

The environmental cost can be considered as a valuable parameter both in itself, but also as an indicator of risks for internalized costs. Many environmental damage costs will be internalized according to the "polluter pays principle" and some are already internalized, such as CO_2 emissions from transports in Sweden, through CO_2 tax. Other examples of internalized costs are landfill fees in Sweden.

The LCA and environmental cost assessment is performed by Lisbeth Dahllöf, Volvo Group – Advanced Technology and Research, with support from Mia Romare in the same group

The LCA and environmental cost assessment is presented so that its results are accessible to non-LCA practitioners, but contains an appendix that will deepen the knowledge of the modeling choices and boundaries of the LCA. The information in the appendix is mainly for LCA practitioners and persons with experience of LCA methodology

1.2 The current situation and the possibilities for the future

The group Trucks Operations, Powertrain Production in Skövde needs large amounts of sand for their foundry. The old foundry has no recycling of the core sand and it becomes more and more difficult to get new sand, because of the specification and the unwillingness to start new sandpits due to environmental reasons. There is however a possibility to buy sand from the XX area instead of the current Lidköping area, but that would increase the transport need, and it is not a sustainable solution. The sand price is currently increasing. Also Volvo has high costs for deposition of the used sand although it is used for filling of ground for industrial areas, and thus avoiding the landfill fee (Ålander, 2016).

Recycling of the core sand would reduce the need of virgin. There is technique for this that is mechanical, and which is calculated on in this report. In this study a hypothetical sand recycling system was set to have a recovery rate of 40% in Foundry 1 as an example (Ålader, 2016).

There are also other possibilities to reduce the need for virgin sand, such as using bauxite sand (bauxite is a common ore) or natural clay. Both solutions are, however, expensive. (Bergman 2016). If bauxite sand would be used, it would probably have a second use in the aluminium industry as an ore resource for aluminium. In theory also e.g. chromite, zircon or olivine sand should be possible to use as raw material for synthetic sand in the future.

2 What is LCA?

Life cycle assessments (LCA) investigate the environmental impacts related to a product system during its whole life cycle. This includes evaluating energy and resource consumption as well as emissions, from all life cycle stages including; material production, manufacturing, use and maintenance, and end-of-life (EoL, thus the scrapping phase). LCA methodology is a widely used and accepted method for studies of environmental performance of various product systems. For more details on how an LCA is performed and what parts it contains, see Appendix A.

The LCA in this report is performed in accordance with ISO 14040:2006 (European Committee for Standardization, 2006) and ISO 14044:2006 standards (European Committee for Standardization, 2006).

2.1 Monetization

Monetization of the LCA results simply means that an economic value is assigned to the different impacts that are covered within a life cycle assessment. This for example implies that a price is placed on the effects of different environmental damages. The EPS method is one way of performing this monetization, and more details of the method can be found below.

Monetization can help in decision making by creating a common language that is used both for the environmental assessment as well as the economic aspects of an investment or technology update. Monetary valuation can also help us better understand the magnitude of the impact.

One last potential benefit of discussing the environmental impact in terms of money is that we better understand if the price we pay includes the external cost, cost that are paid by society. These costs are a potential business risk as they may become internal due to regulation and taxes.

2.2 The EPS method

One common way to present LCA results is by looking at the life cycle impact in different impact categories. This implies looking at how much each resource use or emission contributes to for example acidification, global warming or ozone depletion. These impacts are measured in a standard unit, and all emissions are translated into this unit. One such unit is CO_2 equivalents, used for measuring global warming potential. CO_2 is of course then worth 1 CO_2 equivalent, while other greenhouse gases are worth more or less, depending on if they impact global warming more or less than carbon dioxide.

To show environmental impacts not on the level of impact categories, but aggregated in a single value (“single score”), a methodological weighting of environmental impacts against each other is necessary. How important is for example acidification compared to global warming? This is often helpful for non-LCA practitioners, as it gives one result to consider and not several.

In comparison to the results of impact categories, which are based on scientific models, it is important to understand that “single-score”-methods always rely on subjective value choices. Results are therefore dependent on subjective preferences integrated in the respective method, and should be understood as representative only under the valued conditions.

The EPS method strives to minimize the subjectivity by introducing it only in the last stage. Only the monetary valuation is subjective. The harm (for example lives lost) caused by different environmental impacts is taken from scientific studies, implying that the harm is not evaluated subjectively, only the value of the harm. Compare this to evaluating the value/cost of human lives lost due to CO_2 (EPS case) and evaluating the cost of CO_2 emissions directly.

EPS 2000d is value based, meaning it aims to assess actual real life impacts and their financial implications. In this method the environmental impacts evaluated, and expressed in terms of "willingness to pay" to hinder the damage on five safeguard subjects: human health, biological diversity, eco-system production, natural resources and aesthetic values. The calculation is based on an average OECD citizen.

The damage from different impacts is expressed in category indicators such as "years of lost life" (YOLL), "crop production capacity" or "oil reserves". These are then related to an economical value, and the entire effect over the life cycle is summed up to get the final result. As a guide for non-LCA practitioners it can be commented that the calculation of environmental impact in terms of cost is a way to both highlight the effect of emissions on current and future generations, but also a way to highlight what cost can be expected due to environmental legislation in the future(EPS 2015A and B).

For resources (except fossil) the overall principle is that the environmental cost depleting a resource equals to the cost of replacing the resource from earth's average crust or another non scarce rock. For fossil resources the cost to produce a bio-based equivalent gives the damage cost for resource depletion. For emissions it is the added costs of impacts on safeguard subjects: Ecosystem services, access to water, biodiversity, human health. In appendix C a list of important damage costs used in this study is reported.

EPS is the only monetary weighting method in LCA that takes both resource use and emissions into consideration with a sustainable development perspective.

2.3 Eco-efficiency

Measuring eco-efficiency can be a way to find out which environmental improvement that is achieved to the lowest cost. The idea is to include the concept of value when there are several alternatives to choose between, in order to not sub-optimize. When there is a limited budget for improvement, it is important that the choice does most good.

Eco-efficiency can be measured in many ways, and the method chosen here is the ratio between the change in the environmental indicator and the change in the value or price indicator was studied. In this way we get a measure of the environmental load per investment cost and how this changes between different options.

3 Goal and scope of the LCA

A clearly defined goal and scope are crucial in order to fully understand the LCA and the results. Together with the functional unit - a reference unit by which the inputs and outputs of the LCA should be scaled - the scope is what defines the circumstances under which the LCA results are valid.

A detailed description of these boundaries can be found in Appendix B, but a short summary aimed at increasing the understanding of the presented results can be found below.

3.1 Goal

The goal of this LCA is to assess the environmental impact calculated as environmental damage costs of the sand use in the foundry and a comparison between the current process and hypothetical future alternatives, including mechanical recycling of sand will be made. See chapter 1.2 for the background and the reason for the study. It is also to assess the costs of CO_2 emissions separately. Eco-efficiency is also to be calculated.

The different scenarios are found in Table *1*. Also the different transports and hypothetical electricity use for the different cases are reported.

Table 1. The different cases and the transports and hypothetical electricity use.

Cases in the study	Weight of sand per year (tons)	Truck distance to Skövde for natural sand (km)	Sea transport bauxite producer to Gothenburg (km)	Truck distance Skövde - Årdal (km)	Truck distance Gothenburg - Skövde (km)	Sea distance bauxite producer to Årdal (km)	Electricity use/year (hypothetical) (kWh)
1. Base case	50000	60	0	0	0	0	0
2. Natural sand from theoretic new supplier	50000	352	0	0	0	0	0
3. Recycling of natural sand	30000	60	0	0	0	0	600000
4. Bauxite sand without recycling. Includes system expansion in EoL meaning that the Norwegian aluminium industry uses the sand as resource for aluminium.	50000	0	6406	659	155	6649 (for calculation of eco-efficiency)	0
5. Bauxite sand with recycling. Includes system expansion in EoL meaning that the Norwegian aluminium industry uses the sand as resource for aluminium.	30000	0	6406	659	155	6649 (for calculation of eco-efficiency)	600000
6. Bauxite sand without system expansion in EoL phase and without recycling	50000	0	6406	659	155	0	0

Scenario 2 and 3 are the possible near future scenarios to meet the scarcity of natural sand from nearby Skövde.

Scenario 4 and 5 are theoretical scenarios for bauxite sand which is possible to use in practice, but expensive (X SEK/kg instead of Y SEK/kg for natural sand).

Scenario 6 is a theoretical scenario of bauxite sand if no offset of the used sand can be done. This can also illustrate a general case if a new type of sand is used, which is made of a scarce or slightly scarce rock and where the sand will be downcycled or deposited after use.

The intended audience is both LCA practitioners with interest in the EPS method, but mainly the decision makers for investments in the old foundry. The results can help identify potential risk areas where we either pay more than the environmental cost, or where we pay less and thus risk higher future prices.

The study is for internal use at Volvo Group and for the public research project *Integration of Environment and Economy in Product Development Gives Opportunity for Innovation*, partly funded by Vinnova.

3.2 Scope

A well-defined scope will clarify the boundaries under which the conclusions from the LCA are valid. The presentation in this section will give the reader a basic grasp of the scope, and more details can be found in Appendix B.

This report only presents the results from the environmental assessment using the EPS method and global warming with focus on CO_2 emissions. More common is to also include other impact categories (eutrophication, acidification etc.), but the focus of this assessment is the EPS method based on the project goals. Global warming was extra for the investment considerations.

Additionally, the results from analyzing the life cycle impact with the EPS method will be put in relation to the actual tangible value of the part. This type of comparison is called an eco-efficiency measure, and will be performed according to ISO 14045 (ISO 14045:2012)

3.2.1 Functional unit

A functional unit is used to relate the result to a fixed reference, and to enable comparison of different cases based on the prerequisites of a certain function. This is important both when comparing results, but also important to understand in what cases the LCA results are valid as the results showing the environmental impacts are given in light of this function.

The desired function is to serve the Skövde plant with core sand for the molds in the old foundry.

Functional unit: Sand to serve the old foundry in Skövde with core sand for a typical year's use

3.2.2 Limitations and cut-off

It is crucial to always study the results of an LCA with a very clear understanding of the conditions under which the results are relevant and applicable. Below are listed limitations and cut-offs of the study, to give more details to the scope and clearly show what stages, inputs or actions that are not included in the assessment.

In general, all processes not directly linked to the sand recycling were excluded since they do not change.

Excluded:

- Production of the recycling equipment, possible extra area need in the plant and trucks and infrastructure for the transports. The investment costs were however included for the eco-efficiency calculations. The environmental impact was assumed to be insignificant.
- Transport to deposition after use, since deposition occurs in the area of Skövde which is a short distance. Also the landfill does not add extra environmental impact, since it is placed under new buildings.

(Excavation (transport with wheel loader, cleaning classing, drying) of natural sand are included in the environmental damage cost for sand)

3.2.3 LCIA choice

The assessment was done with the EPS method, a method for determining the environmental cost during the life cycle. This monetized result was compared to the actual tangible price in an eco-efficiency assessment. The goal was to highlight the environmental improvement per invested €.

The indirect effects on global warming by NOx and SOx emissions are complicated due to numerous chemical reactions in the atmosphere which depend on many parameters. Thus there is a large uncertainty for these indices and therefore the indirect effects were set to 0.

3.2.4 Choice of eco-efficiency indicator

The eco-efficiency was calculated based on one value indicator and one environmental indicator. The environmental indicator was chosen as the EPS value and as indicator of value the cost for the sand usage.

In a business situation a reasonable way to estimate value is to choose the current technology as base line and set the change in price to correspond to the change in value; higher price, less value for the company. With this measure of value the economic aspect of decision making can be included more in the environmental assessment. Thus the indicator will be calculated with the following equation:

$$eco - efficiency\ B = \frac{\Delta EPS}{\Delta Cost}$$

4 Results - Life cycle inventory (LCI)

In this part of the LCA study, the relevant inventory data (input and output of material and energy) for sand use were collected and the quantities of these related to the functional unit were calculated. The result presents both how much and what type of inputs/outputs that are part of the life cycle.

The inventory analysis is the base for the impact assessment, where the actual environmental impact from the use of material and energy is calculated.

The material data of the system have been gathered by Department BF 40820, Volvo Group, Advanced Technology and Research. Calculations were made in the LCA program GaBi supplied by thinkstep.

4.1 Life cycle inventory results

Important to note is that all the data presented in this section relates to the functional unit of the LCA, implying the total amount of core sand needed for the old foundry in Skövde during one year.

In the current situation 50000 tons of virgin core sand is used and then deposited. In a hypothetical future recycling scenario, 20000 tons of these 50000 tons are recycled, see **Error! Reference source not found.** and **Error! Reference source not found.** (Ålander, 2016).

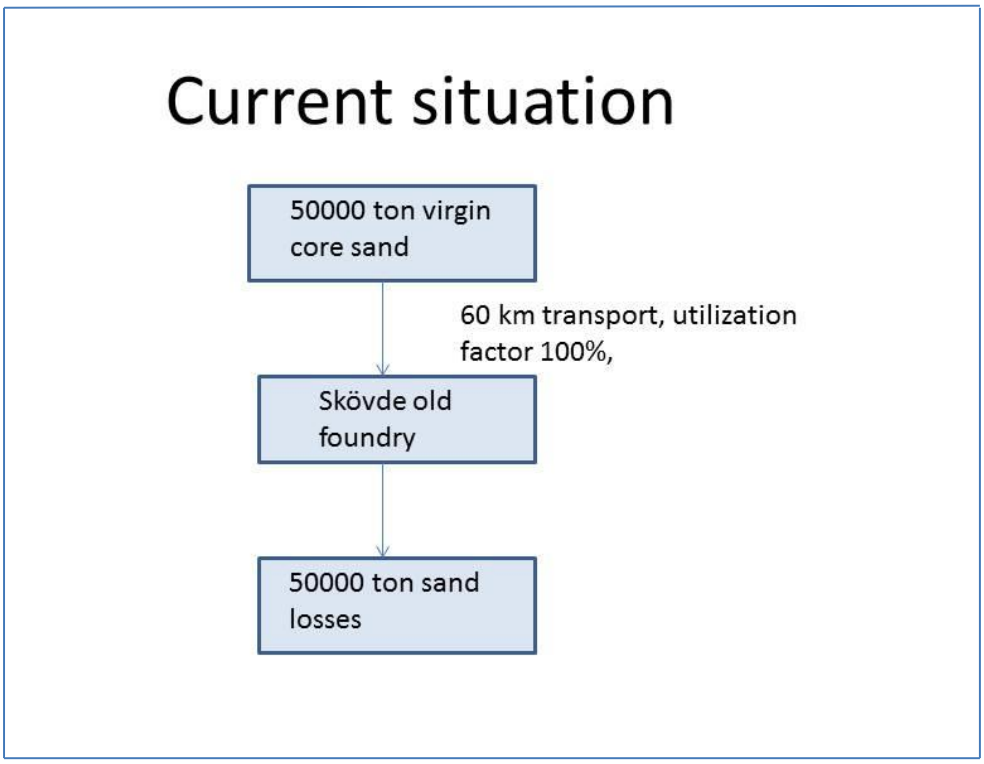


Figure 1. Current use of core sand for the old foundry (Ålander, 2016)

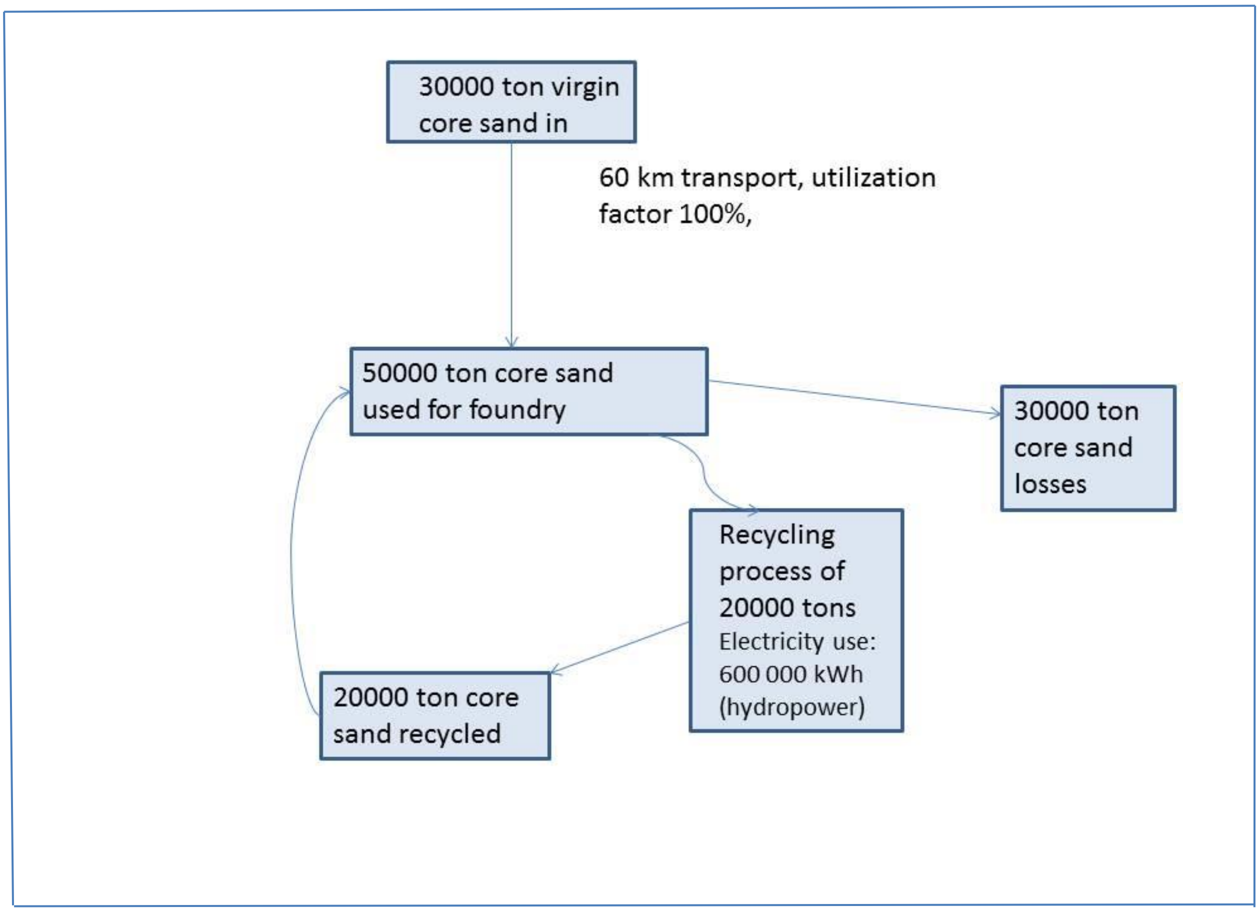


Figure 2. Hypothetical use of core sand and its recycling for the old foundry (Ålander, 2016).

Figure 3 shows the principle for the cases 4 and 5 with bauxite sand with credit in the scrapping of the sand phase when the aluminium industry uses the bauxite resource in the sand.

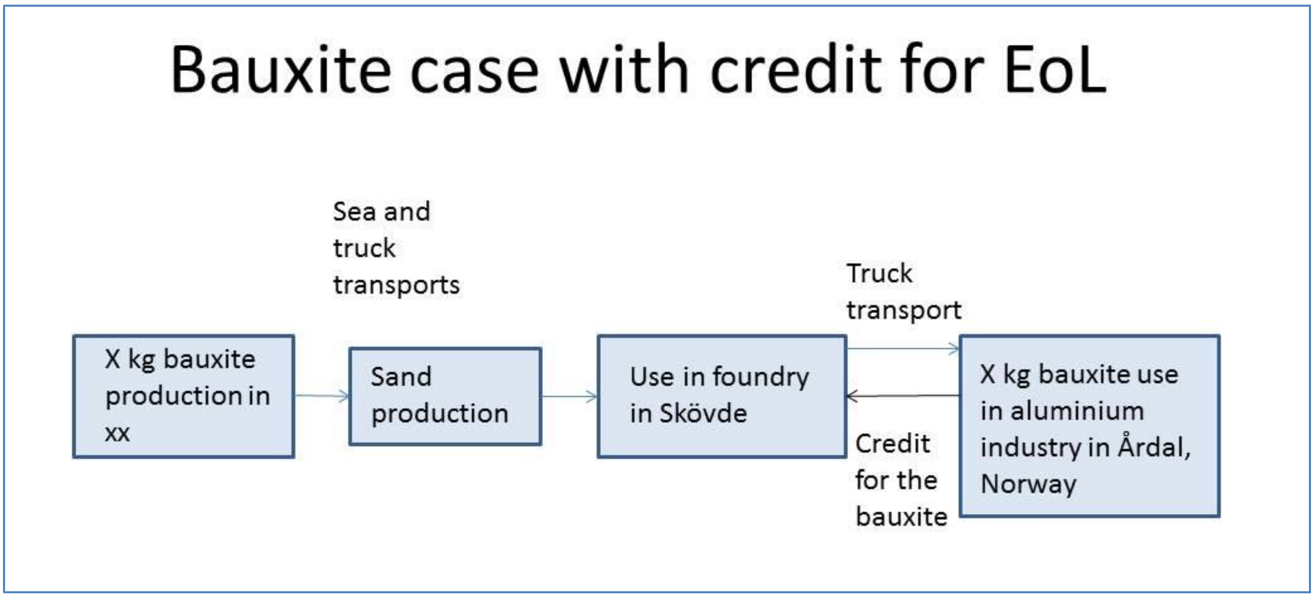


Figure 3. The principle for the cases 4 and 5 with bauxite sand with credit in the scrapping of the sand. The black arrow shows the credit.

For the truck transport to Norway, only the extra distance due to the use in Skövde before the use in the aluminium plant was accounted for as an environmental burden for the Skövde foundry.

In **Error! Reference source not found.** important (according to EPS) resource uses are reported.

Table 2 *Important resource uses(kg) (sand use is 50000 tons).*

Confidential

For the production of 660 000 kWh hydropower with 9% grid losses, the most impacting resource use is (according to EPS): copper: X kg and molybdenum Y kg. Crude oil use is Z kg and XX kg water is used. For Swedish hydropower we did not expect the water to be scarce.

5 Results - Life cycle impact assessment

Life cycle impact assessment implies taking the inventory results and evaluating each material and emission's impact on different impact categories. This LCA uses EPS to evaluate the impact, and this means that all different types of environmental impacts (global warming, acidification, resource depletion etc.) are evaluated on a common scale and given a score based on what they will cost future generation. This final score is measured in ELU corresponding to € to further highlight that it is an evaluation of the value of the harm done due to the environmental impact.

The cost is in most cases not one that we pay today, but is borne by society and can guide us to sound environmental choices in several ways. Firstly it can help to make choices that are beneficial not only for us today, but for all future generations; the only truly sustainable way to choose. Additionally, the environmental cost of different materials and emissions shown in the results can give a hint of what can become internal cost in the near- or long term future. One example of this fact is the cost of CO_2 which is already partly internalized (paid by the company) with the help of taxes.

5.1 EPS results

5.1.1 EPS index for natural sand

Currently, it is not possible to use any kind of sand quality and the best suited is clay or sand from bauxite (Bergman 2016), but for a future where we have better processes for synthetic sand we assume in this study that crushed rock should be possible to use. According to Göransson (2015) it is important that the thermal expansion is not high, so the molded part does not get stuck in the mold, and that could be achieved in the future with a rock that is not scarce with a certain concentration of feldspar. Therefore synthetic sand making is assumed. According to Ravelo (2016) CO_2 emissions from production of synthetic sand from rock are 100-200 kg CO_2/ton. If we assume that the reason for the emissions are 1/3 hard coal, 1/3 crude oil and 1/3 natural gas calculated on energy value, the environmental damage costs would be 0.037 ELU/kg. Steen (2016) suggests 0.02 ELU/kg according to a calculation for EPS 2000d where the costs for crushing of rock and polishing was calculated with. The value calculated here and the value calculated earlier by Steen (2016) are in the same range. We use the value calculated by Steen, 0.02 ELU/kg, since this value was already suggested for the EPS system.

In appendix D the most important EPS indices (environmental damage cost indices) are found.

5.1.2 EPS index for bauxite sand

Data for bauxite mining was used in GaBi and the EPS index became 0.166 ELU/kg. Another 0.02 ELU/kg (se chapter 5.2.1) was added for sand making giving a total of 0.186 ELU/kg.

5.1.3 EPS results for the scenarios

In Table *3* and Figure *4* the EPS results for the different scenarios are found.

Table 3 The EPS results for the different scenarios

Scenarios / ELU (Euro)	Sand	Transports	Electricity	EoL including transports	Total
1. Base case	1,00E+06	4,06E+04	0,00E+00	0,00E+00	1,04E+06
2. Natural sand from theoretic new supplier	1,00E+06	2,38E+05	0,00E+00	0,00E+00	1,24E+06
3. Recycling of natural sand	6,00E+05	2,44E+04	8,88E+03	0,00E+00	6,33E+05
4. Bauxite sand without recycling	9,30E+06	7,02E+05	0,00E+00	-7,85E+06	2,15E+06
5. Bauxite sand with recycling	5,58E+06	4,21E+05	5,33E+03	-4,71E+06	1,30E+06
6. Bauxite sand without credit in EoL and without recycling	9,30E+06	7,02E+05	0,00E+00	0,00E+00	1,00E+07

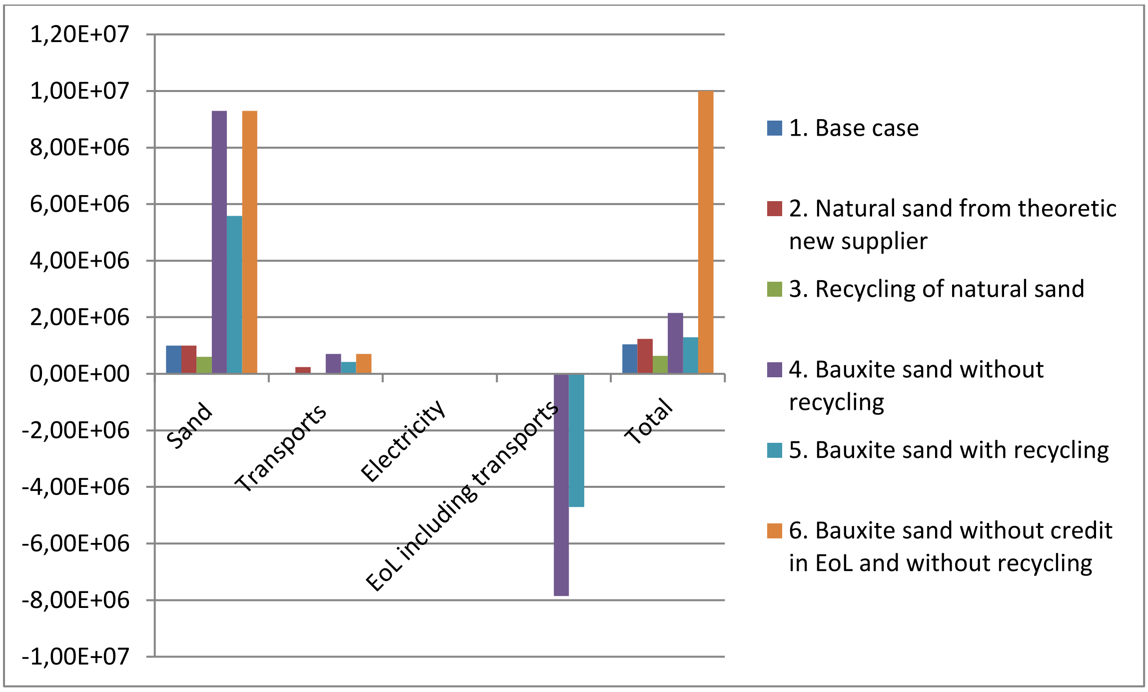


Figure 4. The EPS results for the different scenarios (ELU=Euro).

For natural sand, the resource including excavation as such contributes clearly the most to the ELU values, 80% – 96%, see Figure 5. For bauxite, scenario 4 and 5, the bauxite is credited for and therefore CO_2 emissions or other activities than mining become more important although sand is still important, 46-47%, see Figure 6. For bauxite without credit in EoL the sand contributes to 95% of the environmental damage costs.

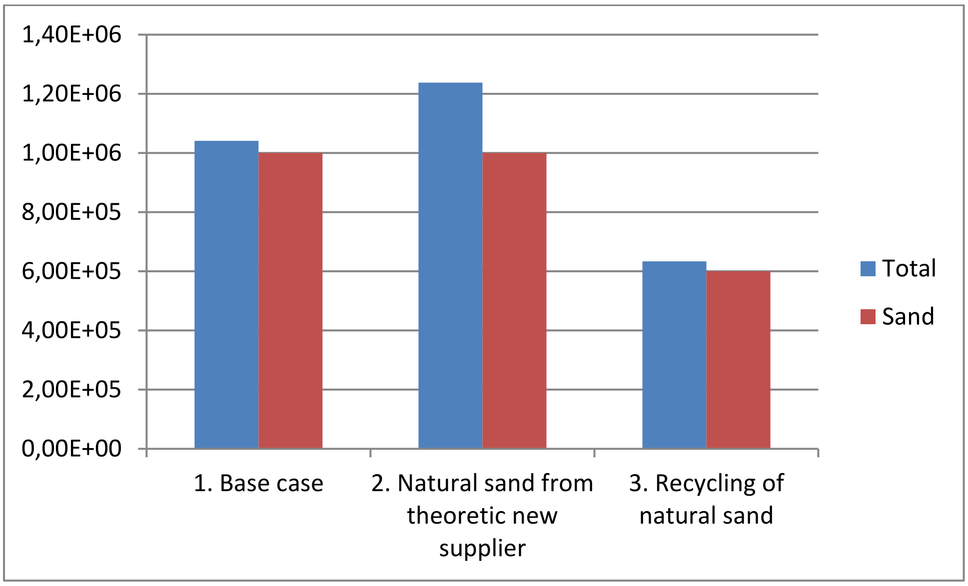


Figure 5 Total ELU (=Euro) compared to the sand contribution for scenarios 1-3.

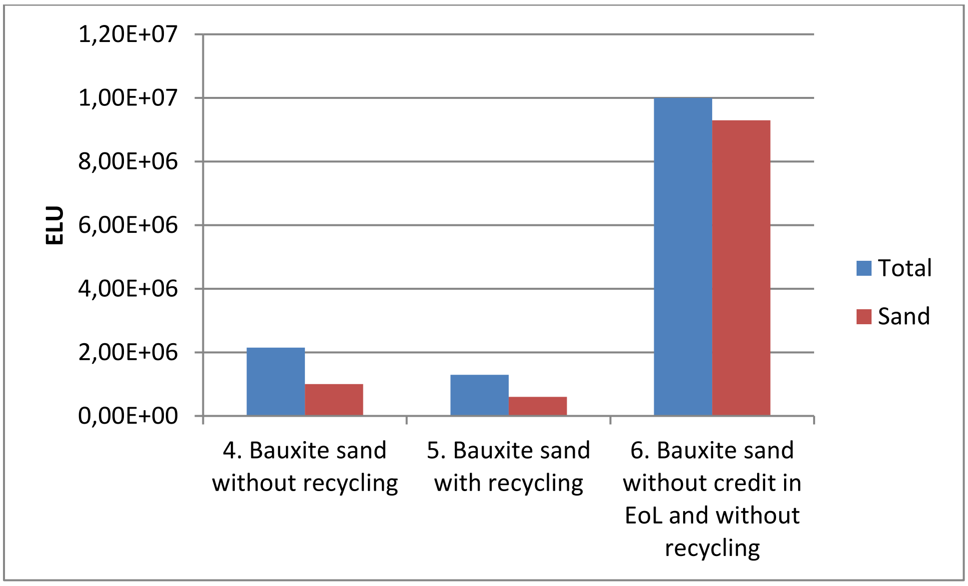


Figure 6 Total ELU (=Euro) compared to the sand contribution for scenarios 4-6.

5.2 Eco-efficiency of the planned recycling investment and two theoretical decision scenarios

See chapter 2.3 for the description of the eco-efficiency concept. The calculation in this report is according to the equation $Eco - efficiency\ B = \frac{\Delta EPS}{\Delta Cost}$

The hypothetical different direct costs are reported in appendix D. The hypothetical investment in machinery and building was included and the payback time was XX years. The amount of sand for this time was calculated with in order to get a figure for the cost/kg sand. The shipping costs were estimated. In Table 4 the eco-efficiency result is shown together with an analysis of the numbers.

Table 4. Eco-efficiency results for the different scenarios with a complementing analysis of change in environmental and directs costs and a conclusions. + = the cost increases less than 50%. ++ = 50% to 100% increase and +++ =more than 100% increase. Similar for – (decrease). Direct costs and therefore the eco-efficiency numbers are confidential.

Scenarios	ELU (€)	Direct costs (€)	Eco-efficiency	ΔELU (Δ€)	Δ Direct costs (€)	Conclusion
1. Base case	1,04E+06					
2. Natural sand from theoretic new supplier	1,24E+06			+	++	Negative for environment and not good for investment
3. Recycling of natural sand	6,33E+05			-	-	**Positive for environment and investment**
4. Bauxite sand without recycling	1,26E+06			+	+++	Negative for environment and very bad for investment
5. Bauxite sand with recycling	7,61E+05			-	+++	Positive for environment, very bad for investment
6. Bauxite sand without credit in EoL and without recycling	1,00E+07			+++	+ ++	Very bad for environment and investment

The number for eco-efficiency should be as large as possible, but it was not possible to set a limit for when a change is considered eco-efficient. The value may also be below zero, but then the solution is not eco-efficient. Therefore the actual changes in costs were also reported to make the analysis more clear.

5.3 CO_2 emissions and their environmental damage costs

This chapter is because there is a focus in the environmental goals in Skövde on CO_2 emissions. The data here regards only CO_2 from non-renewable resources and not from biogenic, since the biogenic takes part in the CO_2 circulation in nature. More organic molecules than just CO_2 are actually creating increased global warming. In this case, CO_2 is however dominating and for truck transports it stands for 96%, sea transport and hydropower: 100%, and bauxite mining 94%.

The CO_2 emissions are reported in Table *5*. Note that EoL including transports is only transports from Skövde to Årdal. There are no CO_2 emissions for the credit of bauxite resource.

Table 5 CO_2 emissions for different scenarios.

Scenarios/CO2 emissions (kg CO2)	Sand production	Transports	Electricity	EoL including transports	Total
1. Base case	0,00E+00	1,31E+05	0,00E+00	0,00E+00	1,31E+05
2. Natural sand from theoretic new supplier	0,00E+00	7,68E+05	0,00E+00	0,00E+00	7,68E+05
3. Recycling of natural sand	0,00E+00	7,86E+04	9,35E+03	0,00E+00	8,79E+04
4. Bauxite sand without recycling	7,71E+06	4,67E+06	0,00E+00	1,44E+06	1,38E+07
5. Bauxite sand with recycling	4,63E+06	2,80E+06	0,00E+00	8,63E+05	8,29E+06
6. Bauxite sand without credit in EoL and without recycling	7,71E+06	4,67E+06	0,00E+00	0,00E+00	1,24E+07

Here, for CO_2 emissions, it would have been better to actually calculate with the emissions from the excavation, cleaning, classing and drying of the natural sand, but the cost in % of the ELU total would anyhow become very low, see table 6.

In figure Figure 7 the CO_2 emissions for the different scenarios are shown.

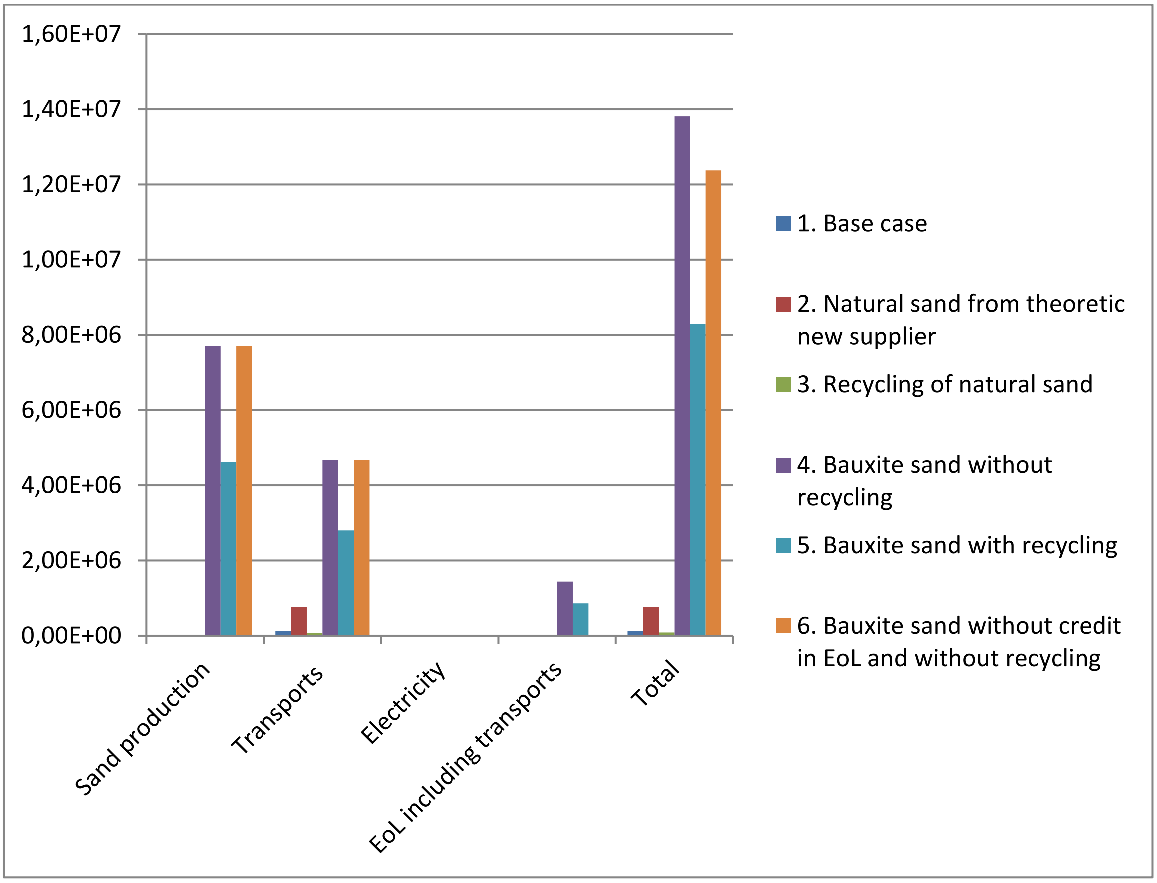


Figure 7 CO_2 emissions for the different scenarios.

The environmental cost of CO_2 emissions for the different scenarios is found in**Error! Reference source not found.**.

Table 6. Environmental costs for the CO_2 emissions for the different scenarios.

Scenarios/CO2 emissions (Euro)	Sand	Transports	Electricity	EoL including transports	Total	% of ELU total
1. Base case	0,00E+00	1,77E+04	0,00E+00	0,00E+00	1,77E+04	1,70E+00
2. Natural sand from theoretic new supplier	0,00E+00	1,04E+05	0,00E+00	0,00E+00	1,04E+05	8,37E+00
3. Recycling of natural sand	0,00E+00	1,06E+04	1,26E+03	0,00E+00	1,19E+04	1,87E+00
4. Bauxite sand without recycling	0,00E+00	6,31E+05	0,00E+00	1,94E+05	8,25E+05	8,67E+01
5. Bauxite sand with recycling	0,00E+00	3,78E+05	0,00E+00	1,16E+05	4,95E+05	8,64E+01
6. Bauxite sand without credit in EoL and without recycling	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,67E+01

For case 1,2,3 and 6 the CO_2 costs are low compared to the total damage costs. This is because the sand resource has the highest, see EPS results 5.1. The high ratio for scenario 4 and 5 is because the modelling includes credit for the subsequent use of the bauxite in the aluminium industry, so this industry takes the environmental costs for the resource bauxite and its mining as such. And since there is this credit,, but the extra transport to the aluminium industry because of the use in Skövde has to be included, the % cost for CO_2 emissions compared to ELU is so high.

6 Which CO_2 emission cost to choose for decision making?

The CO_2 emission value estimates vary a lot. In Isacs et al (2016) a literature review was made and recommendations for choice of CO_2 costs were given.

The environmental damage costs which are calculated for CO_2 emissions in chapter 5 are also called Social Cost of Carbon (SCC). There is also Marginal Abatement Cost (MAC). Thus MAC is the cost to reach a certain emission reduction target, while SCC is the actual damage cost.

The values vary depending on SCC or MAC and how the calculations are made. The trends for the future costs are also differently calculated. For 2015, the literature review showed a range in MAC value of 6.5 and 120 €/ton where the lower value is the current low EU Emission Trading System (ETS) price and the higher is the maximum Swedish CO_2 tax rate. The range in SCC value was 6.1 and 724 €/ton.

Since EPS was used for all resource use and emissions, it was logical to use EPS and thus the value of 135 €/ton in this study.

Isacs et al (2016) distinguish between 3 decision situations:

1. LCA calculations when environmental impact is measured. Comparison between different options.
    - Recommendation: use SCC in order to compare with other emissions and resource use.
2. Where the social costs of CO_2 are to be compared to other costs, e.g. for procurement, product development, permit applications.
    - Recommendation: use MAC where there are binding targets and SCC where there are no binding targets.
3. Where possible financial risk is considered, e.g. when investing. Maybe the cost is to be internalized in near future or is it already internalized.
    - Recommendation: use SCC minus the already internalized cost. Use a value that is on the higher side since here the risk is considered.

This report focused on environmental impact, so situation 1 is applicable. But if this study will indeed be used for decision making, on whether to invest in recycling of natural sand additional calculations need to be done because situation 3 would be applicable. So in practice the cost for CO_2 emissions from truck transports in Sweden and Norway should be subtracted from the CO_2 cost values, if the financial risk is to be calculated. It is not probable that there are CO_2 taxes or fees in Guyana or for countries making synthetic sand. So in this case, the financial risk is much higher regarding sand than regarding the CO_2 emissions.

7 Discussion and Conclusions

Most of the environmental costs for hypothetical recycling case of natural sand are due to the sand itself and not the transports involved (96%).

The hypothetical introduction of recycling of the natural sand is eco-efficient, thus both environmental damage costs and direct costs decrease, given a payoff time that is shorter than the probable usage time for the investment and that current sand price stays the same. It is however probable that the sand price increases, which makes the recycling option even more eco-efficient.

Bauxite sand does not give an environmental benefit compared to natural sand even if it would be used afterwards in the aluminium industry. To use bauxite sand or other minerals with a content of a useful resource but to not use them after the use in the foundry would however cause very high environmental costs illustrated in this study in a case where the bauxite sand is not used afterwards in the aluminium industry.

For bauxite sand, the cost for CO_2 emissions are mainly from sand making. For calculations of risk in investments it is recommended to subtract the CO_2 emissions where the society has internalized the costs (tax or fees) and in this case the truck transports in Sweden and Norway pay CO_2 tax. However, still the natural sand has the highest risk, because its dominance in the environmental damage costs result. It can thus be the fossil energy use causing CO_2 emissions in synthetic sand production that has the highest internalization risk.

If the energy use in the world would come from sustainable sources, then the CO_2 emission problem in this study would be solved and if the sand can be made from rock without scarce minerals, nearly all the environmental risk would have disappeared. In the meantime it is recommended to invest in energy and sand efficiency.

The study would have benefitted from better data especially for sand making.

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Appendix A. LCA description and presentation

LCA methodology assesses the environmental impacts related to a product or a system during its whole life cycle. This includes energy and resource consumption as well as emissions from material production, use, and end-of-life. LCA methodology is a widely used and accepted method for studies of environmental performance of various products and systems.

The LCA in this report is performed in accordance with ISO 14040:2006 (European Committee for Standardization, 2006)and ISO 14044:2006 standards (European Committee for Standardization, 2006). The following description of the LCA method is based on ISO 14040:2006 (European Committee for Standardization, 2006). The structure of the methodological framework is shown in Figure A1.

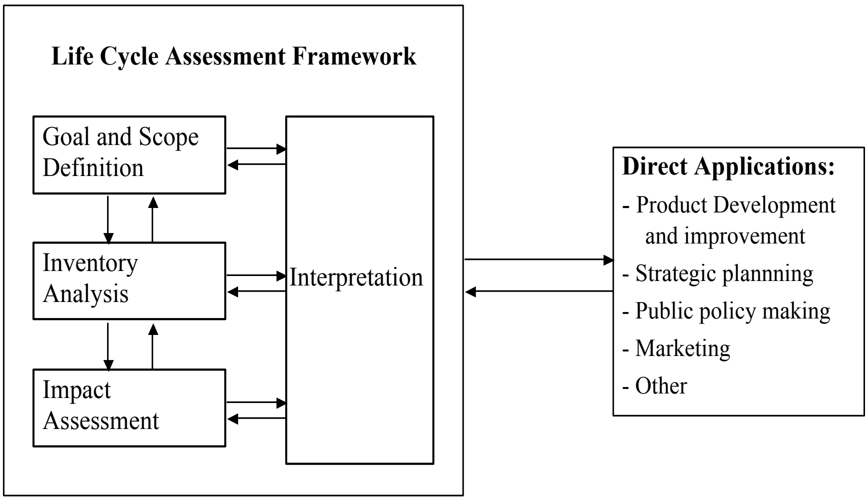

Figure A1: The framework of an LCA study is shown.

In the first phase, goal and scope, the aim of the study is formulated, as well as the scope and the limitations of the study. The function of the system to be studied as well as the functional unit, which is a quantified performance of the system, is defined.

In the life cycle inventory analysis (LCI), all in- and outflows of materials and energy that are related to functional unit are collected and calculated.

The third phase is the life cycle impact assessment (LCIA). Here the elementary flows, which are the result of the inventory analysis, are first assigned to pre-selected impact categories (classification). Indicator results are then calculated for each category (characterization). Classification and characterization are mandatory parts of each LCA study (European Committee for Standardization, 2006). The impact assessment may be complemented by optional elements, such as normalization, grouping, weighting, or by a combination of these.

Weighting is the process whereby the indicator results for the various impact categories are converted, according to predefined value-choices, to an overall environmental impact. The weighting values might be based on various preferences and therefore it needs be transparent and available for the interpretation of results and for their presentation.

In the interpretation phase of the LCA study, the results are analyzed with respect to the goal and the scope, which should lead to relevant conclusions and recommendations.

Appendix B. Detailed definition of goal and scope

B.1. System boundaries

B.1.1 Spatial system boundaries

When no specific data was available global averages where used where possible. For electricity use in Skövde, Swedish hydropower was chosen. In generally, the most relevant average data for materials were used.

B.1.2 Natural system boundaries

Mineral resources and water are traced back to their reserves in nature and emissions are followed to air, water and soil.

B.1.3 Temporal system boundaries

Datasets of the most impacting materials are obtained within recent 5 years. Despite the end-of-life occurring in the range of 4-15 years in the future no alterations where done to the data to fit future conditions.

B.1.4 Process system boundaries

The production phase consists of raw material production, transports and recycling. For the raw material production, the inventory data (in- and outflows of various resources, emissions and energy flows) as well as the transportation of the raw materials are included. For the manufacturing phase only processing is included.

The use phase of the sand included electricity use.

B.1.5 Excluded processes

In addition to the limitations discussed in section 3.2.2, the follow cut-offs where also made.

The following activities will be excluded in the analysis, as they are assumed to contribute to less than 1% of the environmental impacts assessed:

- Maintenance of capital goods and infrastructure (buildings, machines, vehicles, power distribution grid etc.) used within the different activities in the life cycle.
- Personnel-related environmental impact (travel to work, business travels, food etc.)

B.2. Allocation methods

For the recycling stage of the LCA, the retrieved material must be credited with a value, for natural sand it is 0 but for bauxite it has the value as the resource bauxite in the sand.

B.3. Data quality requirements

Data from the international organizations or thinkstep, the LCA-program provider, were preferred.

B.4. Critical review considerations

The report has been reviewed internally at Volvo Advanced Technology and Research and by Prof. Bengt Steen. Some of the data used in this study has already been internally or externally reviewed depending on the data source.

Appendix C. Meta data for LCI data used in GaBi

- Truck transport: Euro 5 truck, 32 ton gross, 24.7 tons payload, 100% utilization factor, one way (thinkstep data)

- Sea transport: Container ship global average, 2.7% S content, DWT 2.75E4, Cap utilisation 0.48, one way (thinkstep data)

- Hydropower: Swedish production of hydropower without grid losses. (thinkstep data)

- Bauxite mining: EU-27 Bauxite. Production and import mix for consumption in EU-27. (thinkstep data)

Appendix D. Summary of EPS indices

Below in **Error! Reference source not found.** is a summary of the most important EPS indices.

Table D1: Important environmental damage cost indices for this study, according to EPS 2015A and B.

Resource or emission	Index (ELU/kg=€/kg)	Principle for cost calculation
Diesel (about the same as for crude oil)	0.47	Cost for making HVO (hydrated vegetable oil) from wood
Hard coal	0.16	Cost for making charcoal from wood
Natural gas	0.28	Cost for making methane from wood
CO_2 emissions used for the LCA*	0.135	Impact on safeguard subjects
Natural sand	0.02	100 SEK for crushing plus 100 SEK for polishing, calculation by Steen (2016)
Bauxite sand	0.186	LCI data (thinksteps') for bauxite plus natural sand production (0.02 ELU/kg).

* For cost calculation of CO_2 for short time investments MAC (Marginal Cost) value is recommended if there is a binding target. CO_2 tax is such a binding target for e.g. transports and 2015 it was 1.12 SEK/kg (2015) (Isacs et al. 2016).

D.1. Comment on NOx and SOx

Indirect effects from NOx and SOx were not included, since the uncertainties of the environmental damage are huge.

Appendix E. Direct Costs (confidential)

The costs for sea transport are estimated.

Appendix 4: Volvo Group, Environmental Cost and Eco-Efficiency Assessment of Copper and Aluminium High Power Cables

Engineering Report VOLVO **ER-664242**

Date				Secrecy level
2016-09-30				4-Open

Receiver (dept, name, location / email address)	Order No / EWR No.	Project	Classification	No. of pages, incl appendices
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	Issued by (dept., name, location): AA12440, Mia Romare			
	Approved by (dept., name, location): AA12440, Henrik Kloo			

Environmental Cost and Eco-Efficiency Assessment of Copper and Aluminium High Power Cables

Summary

This report presents the results of a life cycle assessment of two different high power cable alternatives: copper based cables and aluminium based cables. The report is part of the VINNOVA project Integration of Environment and Economy in Product Development Gives Opportunity for Innovation, and to align with the goals of this project, the assessment differs from most LCA studies as it focuses on presenting the results weighted into one single monetized score using the EPS method.

The results indicate that the environmental cost of the copper cable is significantly higher than that of the aluminium cable. This is due to the fact that copper is much more scarce than aluminium in the earth's crust, and thus the environmental cost (and in the long run economic cost) of using it in a sustainable way is much higher.

The lower weight of the aluminium cable is beneficial in the use phase, but this has a much smaller impact on the environmental cost than change of material. If the efficiency of the copper recycling can be improved, the losses will decrease, and the total impact over the life cycle due to the material can be decreased.

It is important to note that the results indicate the long term issues and environmental cost of the different cable alternatives. When choosing, also short term considerations must be made, where the use phase might be more important. As the choice of aluminum is beneficial both in the long term, as well as for the energy consumption in the use phase it can be recommended as the alternative with least environmental cost.

As the results are presented in monetized terms, the environmental gains of the change of cable material can be weighed against the investment cost. This can help decision-makers evaluate how sizable the gain is in terms that are already familiar within decision-making.

Table of Contents

List of abbreviations

EAA	European Aluminum Association
EC	European commission
EOL	End of Life
IISI	World Steel Association
ISSF	International Stainless Steel Forum
LCA	Life Cycle Assessment
LCI	Life cycle inventory
LCIA	Life Cycle Impact Assessment

1 Introduction

1.1 About this report

This report presents the results from the life cycle assessment performed as a part of the research project *Integration of Environment and Economy in Product Development Gives Opportunity for Innovation*. The project is financed by VINNOVA (Sweden’s innovation agency) and project partners include IVL Swedish Environmental Research Institute, Chalmers University of Technology, AkzoNobel, SCA Hygiene and Volvo Group. The project is hosted by the Swedish Life Cycle Center.
The assessment aims to investigate the environmental impacts of two different cable types, using different metals (aluminium and copper). The assessment is done using the EPS method, which indicated the cost of our resource consumption and emissions for future generations, giving a way to monetize the environmental impact. The data for the calculation of environmental cost is based on a life cycle assessment (LCA).
The target audience is both the project members, who mainly will focus on the assessment of the newly updated EPS method. Additionally, the assessment is targeted to purchasers in order to evaluate how the calculation of environmental cost can be useful for them in building a more solid foundation for decision making. The environmental cost can be considered as a valuable parameter both in itself, but also as an indicator of future internalized costs.
The LCA and environmental cost assessment is performed by Mia Romare, Volvo Group – Advanced Technology and Research, with support from the rest Environmental analysis team within the Environment and Chemistry group.
The LCA and environmental cost assessment is presented so that its results are accessible to non-LCA practitioners, but contains an appendix that will deepen the knowledge of the modeling choices and boundaries of the LCA. The information in the appendix is mainly for LCA practitioners and persons with experience of LCA methodology.
The reason for conducting the assessment is to better understand the complete life cycle environmental implications of changing cable material. It is important to understand both how the new material choices impact the production phase, but also how the performance and weight is altered and how this affects the use phase part of the life cycle, where the cable is used within a vehicle.

1.2 What is LCA?

Life cycle assessments (LCA) investigate the environmental impacts related to a product or a system during its whole life cycle. This includes evaluating energy and resource consumption as well as emissions, from all life cycle stages including; material production, manufacturing, use and maintenance, and end-of-life. LCA methodology is a widely used and accepted method for studies of environmental performance of various products and systems, for more details on how an LCA is performed and what parts it contains, see Appendix A.
The LCA in this report is performed in accordance with ISO 14040:2006 (European Committee for Standardization, 2006)and ISO 14044:2006 standards (European Committee for Standardization, 2006).

1.2.1 Monetization

Monetization of the LCA results simply means that an economic value is assigned to the different impacts that are covered within a life cycle assessment. This for example implies that a price is placed on the effects of different environmental damages. The EPS method is one way of performing this monetization, and more details of the method can be found below.

Monetization can help in decision making by creating a common language that is used both for the environmental assessment as well as the economic aspects of an investment or technology update. The familiar nomenclature can also help us better understand the magnitude of the impact.
One last potential benefit of discussing the environmental impact in terms of money is that we better understand if the price we pay includes the external cost, cost that are paid by society. These costs are a potential business risk as they may become internal due to regulation and taxes.

1.2.2 The EPS method

One common way to present LCA results is by looking at the life cycle impact in different impact categories. This implies looking at how much each resource use or emission contributes to for example acidification, global warming or ozone depletion. These impacts are measured in a standard unit, and all emissions are translated into this unit. One such unit is CO_2 equivalents, used for measuring global warming potential. CO_2 is of course then worth 1 CO_2 equivalent, while other greenhouse gases are worth more or less, depending on if they impact global warming more or less than carbon dioxide.
To show environmental impacts not on the level of impact categories, but aggregated in a single value ("single score"), a methodological weighting of environmental impacts against each other is necessary. How important is for example acidification compared to global warming? This is often helpful for non-LCA practitioners, as it gives one result to consider and not several.
In comparison to the results of impact categories, which are based on scientific models, it is important to understand that "single-score"-methods always rely on subjective value choices. Results are therefore depended on subjective preferences integrated in the respective method, and should be understood as representative only under the valued conditions.
The EPS method strives to minimize the subjectivity by introducing it only in the last stage (Steen, 2015). Only the monetary valuation is subjective. The harm (for example lives lost) caused by different environmental impacts is taken from scientific studies, implying that the harm is not evaluated subjectively, only the value of the harm. Compare this to evaluating the value/cost of human lives lost due to CO2 (EPS case) and evaluating the cost of CO2 emissions directly.
EPS 2000d is value based, meaning it aims to assess actual real life impacts and their financial implications. In this method the environmental impacts evaluated, and expressed in terms of "willingness to pay" to hinder the damage of five safeguard subjects: human health, biological diversity, eco-system production, natural resources and aesthetic values. The calculation is based on an average OECD citizen (Steen, 2015).
The damage from different impacts is expressed in category indicators such as "years of lost life" (YOLL), "crop production capacity" or "oil reserves". These are then related to an economical value, and the entire effect over the life cycle is summed up to get the final result.
As a guide for non-LCA practitioners it can be commented that the calculation of environmental impact in terms of cost is a way to both highlight the effect of emissions on future generations, but also a way to highlight what cost can be expected due to environmental legislation in the future.

1.2.3 Eco-efficiency

Measuring eco-efficiency is a way to ensure that the most environmental improvement is achieved to the lowest investment cost. The idea is to include the concept of value when there are several alternatives to choose between, in order to not sub-optimize. When there is a limited budget for improvement, it is important that the choice does most good.
Eco-efficiency can be measured in many ways, and the method chosen here is to look at the ratio between the change in the environmental indicator and the change in the value or price indicator. In this way we get a measure of the environmental load per investment cost and how this changes between different options.

2 Goal and scope of the LCA

A clearly defined goal and scope are crucial in order to fully understand the LCA and the results. Together with the functional unit - a reference unit by which the inputs and outputs of the LCA should be scaled - the scope is what defines the circumstances under which the LCA results are valid.
A detailed description of these boundaries can be found in Appendix B, but a short summary aimed at increasing the understanding of the presented results can be found below.

2.1 Goal

The goal of this LCA is to assess the environmental impact of two different cable alternatives, using either aluminium or copper. The assessment is to be done with the EPS method, a method for determining the environmental cost during the life cycle. This monetized result will be compared to the actual price in an eco-efficiency assessment.
The assessment is interesting both due to the difference in materials and their inherent availability, but also due to the change in weight that will be the result of changing material. Additionally, the environmental cost will be compared with the actual paid price of the cables to determine if the current price mirrors the environmental impact or if there is a risk of increased internalized cost.
The goal of the LCA on which the assessment is based is thus to make a comparative LCA between the cable types. In order to fully understand the impact of changing material it must be assessed how the change impacts all life cycle stages. The goal is to include the impacts from extraction and production of the raw material, the processing, use in an automotive application as well as a potential end of life scenario.
In addition to the LCA, an eco-efficiency calculation will be performed using the results. The goal is to highlight which case gives the least environmental impact per SEK.
The intended audience is both LCA practitioners with interest in the EPS method, but mainly procurers and designers working with the material choice for the high power cables. The results can help identify potential risk areas where we either pay more than the environmental cost, or where we pay less and thus risk higher future prices.

2.2 Scope

A well-defined scope will clarify the boundaries under which the conclusions from the LCA are valid. The presentation in this section will give the reader a basic grasp of the scope, and more details can be found in Appendix B.
This report only presents the results from the environmental assessment using the EPS method. More common is to also include impact categories (global warming, acidification etc.), but the focus of this assessment is the EPS method based on the project goals.
Additionally, the results from analyzing the life cycle impact with the EPS method will be put in relation to the actual value of the part. This type of comparison is called an eco-efficiency measure, and will be performed according to ISO14045.

2.2.1 Functional unit

A functional unit is used to relate the result to a fixed factor, to enable comparison of different cases based on the prerequisites of a certain function. This is important both when comparing results, but also important to understand in what cases the LCA results are valid as the results showing the environmental impacts are given in light of this function.
The desired function is to allow transfer of high power electricity through the vehicle, for the life time of the vehicle. Therefore the functional unit for the LCA is:

Cables to transfer required high power electricity to the truck's functions, during the truck's entire life.

The amount of material needed, thickness, weight and durability all relate to being able to perform this function.

2.2.2 Limitations and cut-off

It is crucial to always study the results of an LCA with a very clear understanding of the conditions under which the results are relevant and applicable. Below are listed limitations and cut-offs of the study, to give more details to the scope and clearly show what stages, inputs or actions that are not included in the assessment.

- Only the cables, including metal and plastic cover is included, no connectors or other electronics are included as they are common between cable choices.
- The drawing of wire is excluded as it is unknown what thickness the cable metal is present in. The impact of wire drawing is small compared to the material production.

In general, all processes not directly linked to the cables are excluded, including transportation, maintenance, losses in assembly and quality testing etc.
It is assumed that all material is from primary sources, but it is also assumed that the cables are fully collected and recycled. In this way the worst case material impact is highlighted in the production phase, but compensated for in the recycling phase.
Using recycled input would lower the impact at production, but also lower the credit in the recycling stage. The total impact from the materials over the life cycle would be the same regardless of modelling choice, as it is only the loss of material from the value chain that adds to the total burden.
In the case of the high power cables, primary copper is a reasonable assumption.

2.2.3 Choice of eco-efficiency indicator(s)

The eco-efficiency will be calculated based on one value indicator and one environmental indicator. The environmental indicator is chosen as the EPS value and as indicator of value the price of the cable in relation to the base case was chosen.
In a business situation a reasonable way to estimate value is to choose the current technology as base line and set the change in price to correspond to the change in value; higher price, less value for the company. With this measure of value the economic aspect of decision making can be included more in the environmental assessment.
The value for the company should be negative compared to the baseline copper if aluminium is more expensive. Thus the formula for the change in value for the company can be described as:

$$Change\ in\ value = Cost_{Cu} - Cost_{Al}$$

The eco efficiency will be represented by the factor of the change in environmental indicator divided by change in price. With this indicator we can see the effects of four cases:

1. The environmental cost and price go down (-ELU/-cost)
   - Best case scenario where action can always be recommended. Adds value and decreases impact.
2. The environmental cost goes up and the price as well as the cost (ELU/cost)
   - Worst case scenario where we get neither economic nor environmental benefits.
3. The environmental cost goes down and price goes up (-ELU/cost)
   - Common trade off that should be seen as an investment in environmental performance, and weighed against other investment options

4. The environmental cost goes up but the price goes down. (ELU/-cost)
    - This adds value at the cost of the environmental performance. This can be viewed as a reverse investment where staying with the more costly alternative is seen as the environmental investment and this should be weighed against other options

3 Results - Life cycle inventory (LCI)

In this part of the LCA study, all the inventory data (input and output of material and energy) for the studied cables are collected and the quantities of these related to the functional unit were calculated. The result presents both how much and what type of inputs/outputs that are part of the life cycle. For more detailed information on how the collection process was performed for each stage, see Appendix C
The inventory analysis is the base for the impact assessment, where the actual environmental impact from the use of material and energy is calculated (see section 4 for this assessment), but it is also interesting in itself. To understand what life cycle stages cause what material and energy use, the results from the inventory are divided into sub-parts relating to the different stages of the life cycle; Raw material extraction/production, manufacturing, use phase and end of life.
The material data of the system have been gathered by Department BF 40820, Volvo Group, Advanced Technology and Research. The full list of references for each material and energy inventory input can be found in Appendix C.

3.1 Life cycle inventory results

Important to note is that all the data presented in this section relates to the functional unit of the LCA, implying the total weight of each material is based on what is necessary in order for a truck to function during its whole life cycle.

Table 1: The table shows the input of material from different parts of life cycle. The amount corresponds to the materials needed to perform the desired function. The function is to transfer required high power electricity during the truck's life time.

	Material choice	*Copper cable (reference case)*	*Aluminium cable*	*Unit*
Conductive metal	Aluminium		4,2	kg
	Copper	8,4		kg
Sheath	PVC	0,8	1,0	kg
Insulation	PEX	0,4	0,5	kg
Terminal	Copper	0,4	0,6	
Use[1]*	Diesel	80	62	l
	Urea (AdBlue)	6,4	4,9	l

In Table 1, the type of materials used for the cables are listed. Additionally, the amount of material used in the cables is given. More materials will be needed during production, and this is included by using datasets that cover (for example) the production of one kg of copper, in this way the whole production stage up to the point where we place the material in our product is accounted for.
The energy and emission flows from entire life cycle are presented in Table 2. Here the flows from the entire production chain are included, and it is important to note that the use phase and end of life (where credit is given for recovered material is included) are also a part of this total.
It can also be interesting to remember that the data in the table can be seen as the base for the environmental cost presented in section 4. The full list of dataset references and modeling choices can be found in Appendix D.

[1] The amount presented is the part of the life use phase that is allocated to the cable. Read more about the use phase calculation in Appendix C.

Table 2: The table below shows the resulting inventory when it comes to energy consumption and emissions to air. The data is the basis for the impact assessment presented in the next section.

	Aluminium cable	Copper cable (reference case)
Energy resources (MJ)		
Renewable energy	159	225
Non renewable energy	2718	3674
Emissions to air (g)		
CO2	180773	249214
CO	44	88
VOC	336	487
NOX	4	6
SO2	105	292
PM	12	70

4 Results - Life cycle impact assessment

Life cycle impact assessment implies taking the inventory results and evaluating each material and emission's impact on different impact categories. This LCA uses EPS to evaluate the impact, and this means that all different types of environmental impacts (global warming, acidification, resource depletion etc.) are evaluated on a common scale and given a score based on what they will cost future generation. This final score is measured in ELU corresponding to € to further highlight that it is an evaluation of the value harm done due to the environmental impact.
This environmental cost is in most cases not one that we pay today, but it can guide us to sound environmental choices in several ways. Firstly it can help to make choices that are beneficial not only for us today, but for all future generations; the only truly sustainable way to choose. Additionally, the environmental cost of different materials and emissions shown in the results can give a hint of what can become internal cost in the near- or long term future. One example of this fact is the cost of CO_2 which is already partly internalized (paid by the company) with the help of taxes.
It has historically been shown that environmental costs go from being external costs (the effects are paid for by society and not by those who emit) to being internalized (implying that those who emit also pay). This is done by implementing environmental legislation, like carbon taxes.

4.1 EPS results

LCAs of heavy duty vehicles often show a large impact from the use phase. This is due to the long duration of this life cycle stage, as well at the fact that large amounts of diesel are consumed in total. When assessing a component, the total use phase impact is allocated to the part based on its weight in relation to the total weight of the vehicle. For a whole vehicle, the use phase is very important, but when it comes to a single part the relative importance of materials and use phase depends on the weight and what materials are used. For a small, and relatively light component like the high power copper cables the metal is the dominating impact. For the aluminium alternative the chosen material is much more common, and the (smaller) burden is shared more evenly between material and use phase.
With recycling included the use phase is still present and stand for a larger part of the impact.

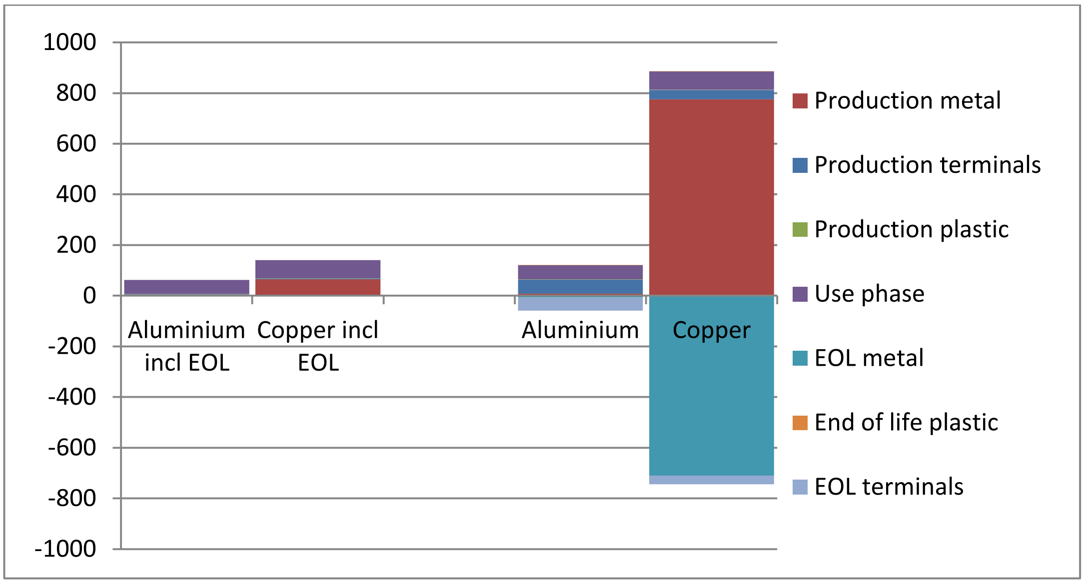

Figure 1: The figure shows the results of the environmental cost assessment. It is clear that copper is the dominating environmental cost for the cables. If the end of life handling is effective a large part of the effect is mitigated and the use phase becomes a more important consideration.

Additionally, the EPS method places focus on long term sustainability, where the availability of materials is a crucial factor in order to ensure that future generation get what they need. This focus on resources can further shift the focus from the use phase to the production and recycling phases, especially for some more rare materials.
In the case of the high power cables assessed in this report, it is clear that the copper plays a huge role in the environmental cost. In order to understand why we must understand that copper is relatively uncommon in earth's crust. This implies that our depletion of reserves will cause the need for future generations to extract copper from a source with very low concentration. Aluminium on the other hand has a much lower environmental cost than copper as it is more abundant in the crust.

Table 3: The table shows the result of the environmental cost assessment in numerical terms. The results are also presented in the figure above.

ELU (€)	Metals	Terminals	Plastic	Use phase	EOL metal	EOL plastic	EOL terminals	Total
Aluminium	8	55	1,5	56,1	-7,5	0,06	-51	63
Copper	775	37	1,1	72,1	-710	0,04	-34	141

One other thing that becomes very clear when looking at the results from the two cable options is how crucial good recycling is for the life cycle result. The value of what is recovered in end of life depends both on how much of the material that is recovered, and also on the state in which it is recovered. If the material is in a worse state than the pure material, the value for future generations has decreased, and the difference is visible in the life cycle of the product.
Since the cables are relatively easy to sort, this assessment assumed that they are recycled with a high degree of quality maintained. The reason why the end of life bar does not fully compensate for the input in the production stage is due to losses and environmental costs in the recycling process.
For those who are interested in the EPS method it should be noted that the results shown in this section is from the version of EPS that does not include indirect climate effects from secondary particles. The effect of changing method showed a minor change in the life cycle results, more details on this can be found in Appendix E. This appendix also presents the results when applying EPS to elementary flow instead of valuable input.

4.2 Eco efficiency

4.2.1 Product system value

As described in section 2.2.3, the product system value is based on the price of the cables, with copper as the base. The interesting question is the change in price in correlation to the change in environmental impact. The change in value is calculated as

$$\Delta Value = Price_{Cu} - Price_{Al}$$

	Copper	Aluminium
Estimated Price	74€	151 €

The change in value is thus -77€. This can also be seen as a 77€ additional cost and thus an investment, and should be related to the effects of other investment options using eco efficiency calculations.
The price in relation to the EPS result shown in the previous chapter indicates that there is a large mismatch between current price and environmental cost for the copper, although this is mitigated when

including good recycling. There is thus a larger risk that the external cost will internalize and lead to a higher price – a risk factor to be assessed together with other economic risks.
For aluminium there is no such mismatch, indicating a lower risk of internalized costs.

4.2.2 Eco efficiency results

The eco efficiency calculated as the factor between the change in environmental load and the change in value. In this way we get a representation of how much decrease of environmental load we get per invested cost (loss of value).

$$Ecoefficiency = \frac{\Delta EPS}{\Delta Cost} = \frac{63 - 141\ ELU}{151 - 74€} = \frac{-78ELU}{77€_{Cost}} \approx \frac{-1\ ELU}{€_{Cost}}$$

This result implies that for every € in additional cost (=lost € in value and thus revenue) we reduce the cost of our long term environmental impact with roughly 1€ when switching from copper to aluminium cables. This of course includes a good and qualitative recycling of the materials. Without the end of life, the environmental cost would be reduced with almost 10€ per invested € (going from 885 ELU to 121 ELU) when changing from copper to aluminium cables.
In the cable case assessed in this report we thus have a trade-off between value and environmental impact, where the copper alternative has a higher value for the company (higher margin for revenue) due to its lower price, while the aluminium alternative has much better environmental cost.
The eco efficiency of this change between cables does not give much additional information when assessed by itself. When choosing between two different investment options, however, the value representing the eco efficiency of this change can be set against the eco efficiency of another investment and used to determine which option will result in the best environmental improvement per spent €.
It is also important to note that this eco efficiency is calculated per vehicle, and that this must be summed into a total savings if the effect is to be compared with a static one-time investment.

5 Discussion and conclusions

Main conclusions and recommendations:

- The copper alternative holds the highest environmental cost.
- A good choice of sustainable material is more important in the long run than the potential weight reduction for the environmental performance.
- Recycling is critical in order to minimize the total life cycle environmental cost. Proper collection, separation and processing to secure quality is essential
- It is clear that the difference between internal and extern cost is very large in the case of the copper cable input material. This indicates a risk that the price of this cable alternative might increase. End of life value might also increase accordingly.
- The eco efficiency assessment shows that the change from copper to aluminium is an investment that will decrease the environmental cost with 1-10ELU per invested € depending on if the end of life if included.

5.1 Discussion

The assessment of the environmental cost for each of the alternatives shows that the use phase is as important as the materials, or more important in the case of aluminium. This is of course only valid with proper and efficient recycling.
If there is no recycling, the impact from resource depletion becomes dominating, especially for the copper cable case. It also implies a greater risk of internalized costs, as an increase in material cost most likely would be mitigated somewhat by a corresponding increase in the value of recycled material. Without the opportunity to sell the end of life material, Volvo would be left with only the production cost and no way to motivate the higher price.
In this report the focus is, however, not the individual life cycles, but rather the improvement when changing between alternatives. With this focus the use phase is more static, as it is more similar between options than the material production. The use phase environmental cost decreases with 22% when going from copper to aluminium cables.
The change in environmental cost due to the change of material itself is much larger. The environmental cost from the main metal decreases with almost 99% from 775 ELU to 8 ELU when changing from copper to aluminium, and it is thus clear that it is the choice of sustainable material that is the main source of the decrease. This is true also with recycling included although the absolute decrease is smaller.
The importance of the material themselves leads to another important focus area namely end of life. Correct collection and handling of the crucially important material resource is a key factor in order to decrease the impact of the cable on the environmental life cycle cost. If the recycling in reality is worse than assumed in this report, the change from copper to aluminium is even more beneficial.
Another interesting aspect of the environmental cost is how it relates to the price in each alternative. For the aluminium cable the price is higher than the environmental cost. This implies that the risk for price increases due to regulations and taxes is relatively small. For the copper cable however, the environmental cost is substantially higher, even when including a proper end of life handling. This indicated a risk of increase price, both for primary and secondary material as these two are related.
The eco efficiency calculation included in this report can be used to compare the environmental value gained per loss of economic value. It should be weight against other investment alternatives if necessary. On its own it simply relates the size of the environmental improvement to the cost.
The environmental value (reduced cost) of each invested € is 1-10 ELU (€). The range depends on how effective the end of life stage of the life cycle is. 10€ is the environmental gain per € if no recycling or any other end of life costs is included. This is of course not a realistic case, but can be used to see the importance of the recycling.

5.2 Recommendations

The results of this assessment clearly indicate that the aluminium cables give less environmental impact than their copper counterparts. Thus the recommendation would be to change to this alternative if this is a reasonable technical option.
The eco efficiency assessment additionally indicated that the improvement in environmental cost is larger than the loss of value. If different investment options must be set against each other the gain per invested € must be used to choose the most appropriate one.

Suggestions for future life cycle assessments:
This report focuses on the long term environmental cost of the different cable alternatives. The results can guide in choosing the most sustainable long term route, but it could also be interesting to look at more short term indicators. One example could be to focus on the common global warming indicator, or to look at energy efficiency.
This assessment shows that the recycling is a crucial factor in both the assessment of environmental cost as well as the assessment of the environmental gains per invested € in the eco efficiency calculation. The assumptions for this life cycle stage are quite crude and a more detailed modeling is needed for more exact results.
However, as long as the losses in the recycling process remain small, the results of this assessment hold true. It is likely that the main loss of material is from poor collection, where the cables are lost before they are even sent to recycling. It will improve the results if it is investigated the exact amount of cables that is send to metal recycling.

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Appendices

Appendix A. LCA description and presentation

LCA methodology assesses the environmental impacts related to a product or a system during its whole life cycle. This includes energy and resource consumption as well as emissions from material production, use, and end-of-life. LCA methodology is a widely used and accepted method for studies of environmental performance of various products and systems.
The LCA in this report is performed in accordance with ISO 14040:2006 (European Committee for Standardization, 2006)and ISO 14044:2006 standards (European Committee for Standardization, 2006).
The following description of the LCA method is based on ISO 14040:2006 (European Committee for Standardization, 2006). The structure of the methodological framework is shown in Figure 0.1.

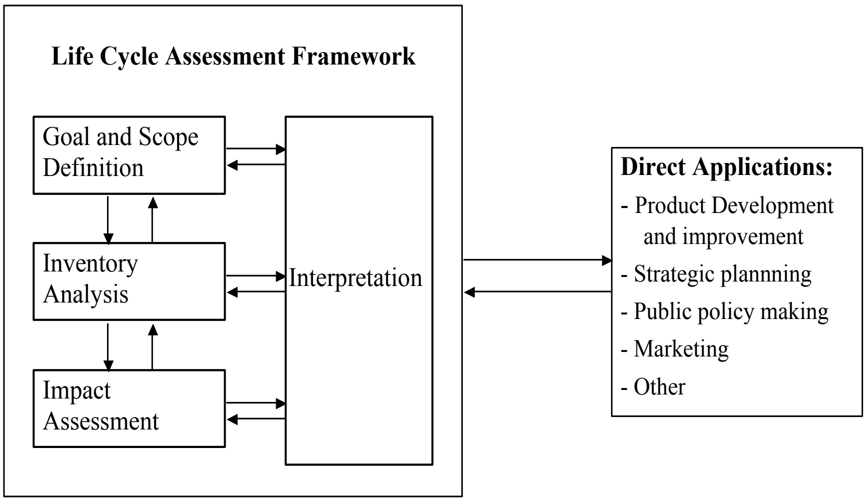


Figure 0.1: The framework of an LCA study is shown.
In the first phase, goal and scope, the aim of the study is formulated, as well as the scope and the limitations of the study. The function of the system to be studied as well as the functional unit, which is a quantified performance of the system, is defined.
In the life cycle inventory analysis (LCI), all in- and outflows of materials and energy that are related to functional unit are collected and calculated.
The third phase is the life cycle impact assessment (LCIA). Here the elementary flows, which are the result of the inventory analysis, are first assigned to pre-selected impact categories (classification). Indicator results are then calculated for each category (characterization). Classification and characterization are mandatory parts of each LCA study (European Committee for Standardization, 2006). The impact assessment may be complemented by optional elements, such as normalization, grouping, weighting, or by a combination of these.
Weighting is the process whereby the indicator results for the various impact categories are converted, according to predefined value-choices, to an overall environmental impact. The weighting values might be based on various preferences and therefore it needs be transparent and available for the interpretation of results and for their presentation.
In the interpretation phase of the LCA study, the results are analyzed with respect to the goal and the scope, which should lead to relevant conclusions and recommendations.

Appendix B. Detailed definition of goal and scope

B.1. System boundaries

B.1.1 Spatial system boundaries

When no specific data was available European averages where used where possible. In generally, the most relevant average data for materials were used.

B.1.2 Natural system boundaries

Mineral resources and water are traced back to their reserves in nature and emissions are followed to air, water and soil.

B.1.3 Temporal system boundaries

Datasets of the most impacting materials are obtained within recent 5 years. Despite the end-of-life occurring in the range of 4-15 years in the future no alterations where done to the data to fit future conditions. This choice mainly impacts the energy use in the end-of-life stages as well as the credited value of the materials.

B.1.4 Process system boundaries

The production phase consists of raw material production and parts manufacturing. For the raw material production, the inventory data (in- and outflows of various resources, emissions and energy flows) as well as the transportation of the raw materials are included. For the manufacturing phase only processing is included.
The use phase of the cables includes production and use of diesel.
End-of-life phase has high uncertainty, since it covers possible future scenarios. In this LCA the scenario chosen is that the cable metal is fully recovered and recycled while the plastic is not.

B.1.5 Excluded processes

In addition to the limitations discussed in section 2.2.2, the follow cut-offs where also made.
The following activities will be excluded in the analysis, as they are assumed to contribute to less than 1% of the environmental impacts assessed:

- Production and maintenance of capital goods and infrastructure (buildings, machines, vehicles, power distribution grid etc.) used within the different activities in the life cycle.
- Personnel-related environmental impact (travel to work, business travels, food etc.)
- Impacts from packaging material used to transport cable parts or materials.
- Road and filling infrastructure required for the use phase of the vehicle.

B.2. Allocation methods

For the recycling stage of the LCA, the retrieved material must be credited with a value. All recycled material is credited with a minus input of the primary material used. This way of modelling implies that only the losses caused by the product in its life cycle are a burden to the complete cycle.
When it comes to the use phase, the impact of the entire vehicle is allocated to the cables system based on weight.

B.3. Data quality requirements

Data from the international organizations European Aluminum Association (EAA), World Steel Association (IISI), International Stainless Steel Forum (ISSF) and Plastics Europe are preferred, since they have been reviewed by third party, and report average data for two or more plants. Data from thinkstep based on data from these organizations are regarded as equal to these. Additionally, data from thinkstep alone and Ecoinvent (Ecoinvent, 2013) are also considered as acceptable.
To avoid data gaps, some approximations were made for materials not available in these databases, see Appendix D for data choices in GaBi.

B.4. Critical review considerations

The report has been reviewed internally at Volvo Advanced Technology and Research. Some of the data used in this study has already been internally or externally reviewed depending on the data source.

Appendix C. Life cycle inventory, detailed description

In section 3 the final amount of each material and energy input is listed for the different life cycle stages. In this appendix more background can be found on how the data was collected and calculated.

C.1. Production

All input in this LCA was modeled back to a form so that the raw materials extraction and production phase could be found in our software database.
The cables are assumed to be made of a conductive metal center, lined with a plastic coating of PVC and PEX. It is assumed that primary material is required due to quality demands.

C.2. Use phase

The use phase includes the materials and emissions related to the driving of the truck during its life. The fuel consumption is on average 31.8614 l/100km, and the life of the truck is 1 000 000km.
In order to relate the use phase to the cable, only a percentage of the total fuel consumption is allocated to the cable. The allocation is done based on the weight of the cable compared to the total weight of the vehicle, assumed to be 40 tons.
As the weight is changed when the material changes from copper to aluminium, the decrease in weight is assumes to add 4,802 l/kg consumption over the life cycle. This is based on information that each added km contributed to a fuel consumption of 0.0004802 l/100km/kg.

Expressed numerically, this implies that the total consumption of the reference cable (copper) is:

$$Diesel_{CuCable} = \frac{weight_{CuCable}}{total\ weight_{vehicle}} * Diesel_{Total}$$

While the consumption of the aluminium cable is:

$$Diesel_{AlCable} = Diesel_{CuCable} + 4{,}802(weight_{AlCable} - weight_{CuCable})$$

It is always assumed that 8% addition of AdBlue Urea mix is needed.

C.3. End-of-Life

The end of life of the metals in the cables is modeled in the LCA to consist of the following stages, see also Figure 2:

1. A recycling process turning the scrap metal into secondary resource
2. A credit process where some of the input primary material is offset by crediting with an amount equal to the amount of secondary exiting the system

This way of modeling gives a total result (if the entire life cycle is summed up) where only the losses caused in the life cycle is accounted as a burden. The losses include losses in collection and the loss of material in the recycling process. The collection is assumed to be 100%, as large scale cables are most often visible at disassembly and thus removed.
No specific end of life information was available in the project. For the plastic part of the cables it is assumed that the material ends up in landfill.

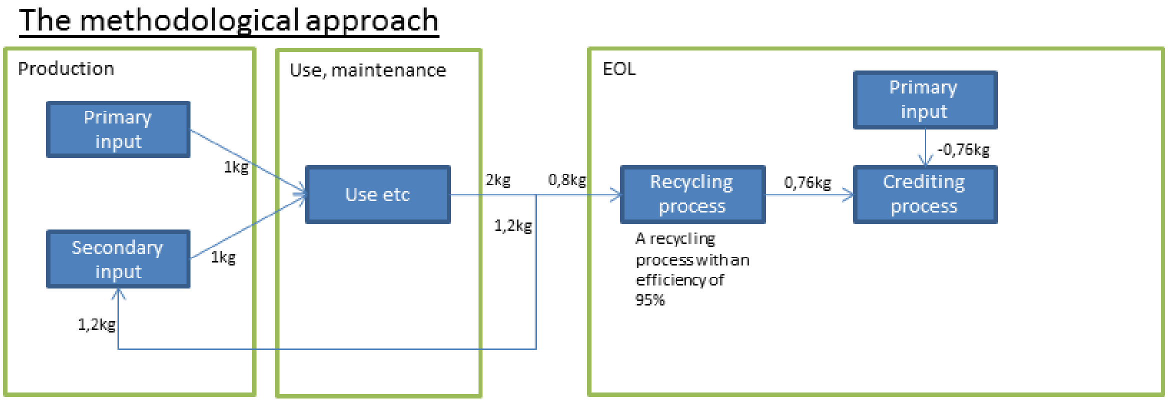


Figure 2: The figure shows the modeling choice for end of life. In this assessment the flows connected to the secondary input is zero.

Appendix D. GaBi data

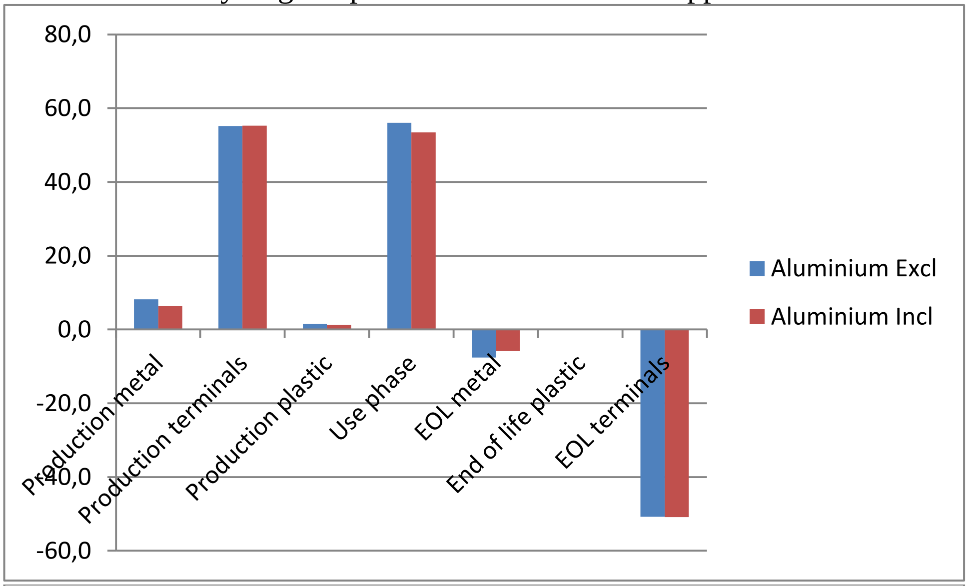
This section presents the datasets used in the LCA software GaBi

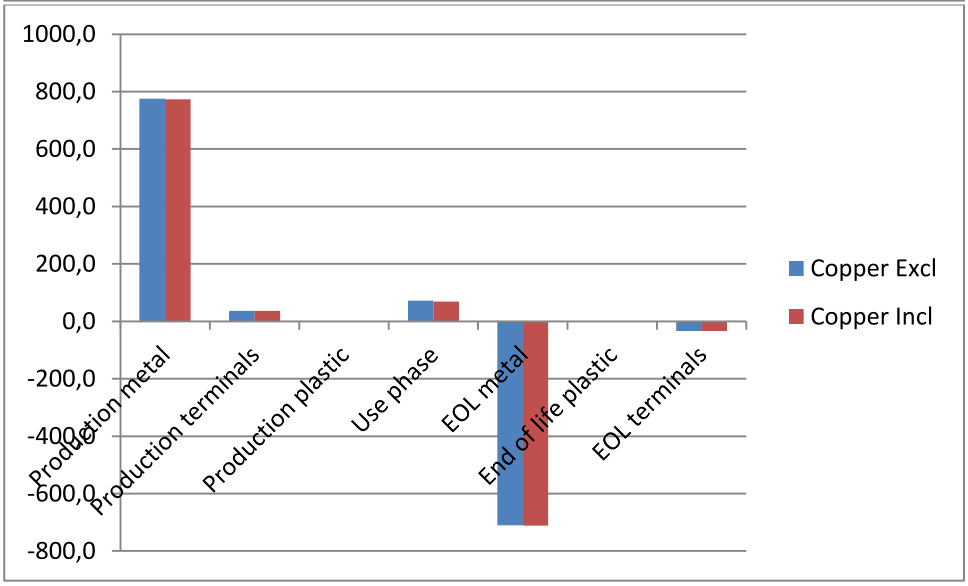
Materials	Modeled as in GaBi 6	Nat	Source	Year
Aluminium	Aluminium ingot mix ts	EU-27	ts	2018
Aluminium EOL credit	Aluminium ingot mix ts	EU-27	ts	2018
Aluminium recycling	Aluminium recycling (2010)	EU-27	EAA	2014
Copper	Copper mix (99.999% from electrolysis)	DE	ts	2018
Copper EOL credit	Copper mix (99.999% from electrolysis)	DE	ts	2018
Copper recycling	treatment of copper scrap by electrolytic refining	RoW	Ecoinvent	
Diesel	Diesel mix at refinery	EU-27	ts	2018
PVC	Polyvinylchloride granulate (Suspension, S-PVC)	DE	ts	2018
PEX	Polyethylene Cross-Linked (PEXa)	DE	ts	2018
Plastics EOL	Plastic waste on landfill	EU-27	ts	2018
Urea	Urea (46% N)	EU-27	Fertilizers Europe	2018
Water	Water (desalinated; deionised)	EU-27	ts	2018

Appendix E. Additional results and visual material

E.1. Results when including or excluding indirect effects

The assessment presented in this report focuses on the results when the indirect effects were not included. The reason for choosing the version without these effects is due to the ongoing discussion regarding the uncertainties in these calculations along with the controversial results some of these effects have on the environmental cost (emissions commonly seen as damaging causing positive contribution to the environmental impact).
In this appendix the effects of using the two different versions of the EPS method are commented on further. The results varied very little, especially the main conclusion held true; that the copper cable version has a very large impact due to the fact that copper causes extraction of several important metals.





Even in the case of the aluminium cable the effect was quite small; excluding indirect effects gave a 5% increase in cost. The change is due to the releases of SO_2 and NO_X emissions and their valuation, and these emissions mainly come from the diesel and the aluminium processing.

E.2. Modeling in GaBi – EPS score on elementary flows of valuable input

When using the updated EPS score in this assessment issues arose when implementing the method in the LCA software GaBi from thinkstep. The issue concerned the validity of having the EPS score on the elementary inputs, and stems from the economic allocation used in GaBi.
In GaBi datasets the elementary flows from a mine are divided between the different products depending on value. For materials that are mined together with others, for example copper, this leads to a dataset where there is an inflow of not only elementary copper, but also lead, silver, gold, zinc etc.
Using economic allocation for impacts that happen here and now is reasonable, for example when looking at emissions, but when considering the effects of our material use on future generations it is less clear if the method is useful.
When considering this long term perspective the key factor is the losses of material from the technosphere that we cause. Often this can be seen as the difference between what is used in the product and what is recycled. Including other materials than those actually used is thus less appropriate as we do not change their status in the technosphere.
In this report we have for this reason chosen to exclude these allocated elementary flows and only present the economic costs of the emissions as allocated in the GaBi software. In addition to this we add the EPS score of the actual inflow of material in the product.
This appendix presents the results using both methods, in order to be used for method development and understanding of the concepts. The chosen method in this report is not yet clearly defined as the go-to option when performing environmental cost assessment based on life cycle data.

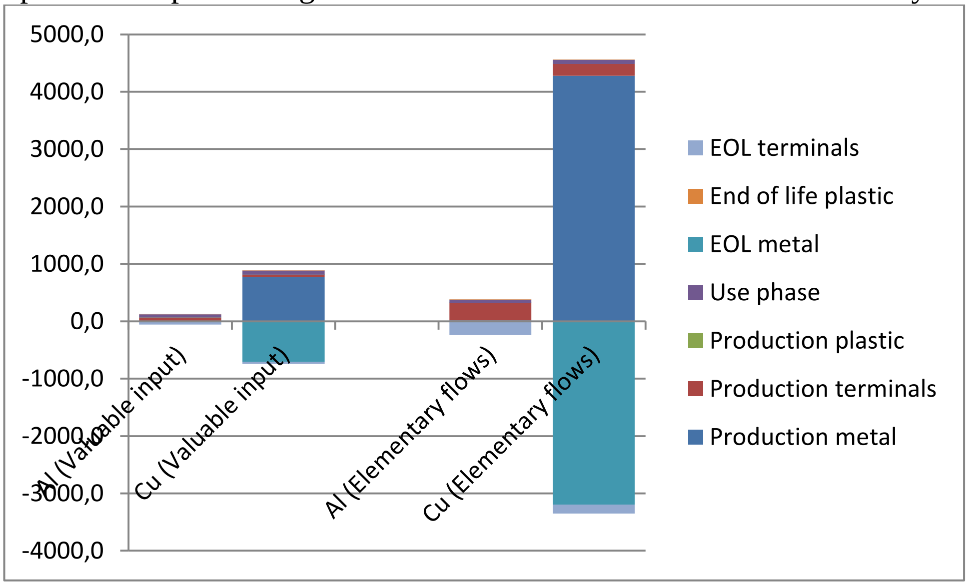


Figure 3: The two columns to the left present the results as they are using the method of scoring valuable input. The columns to the right are when the score is on elementary flows.

As the graph shows, the end recommendation to change from copper cable to aluminium cable holds true regardless of which method is used. The copper is a large impact regardless although it does not out shadow all other impacts when using the EPS score on the valuable input compared to elementary flows.

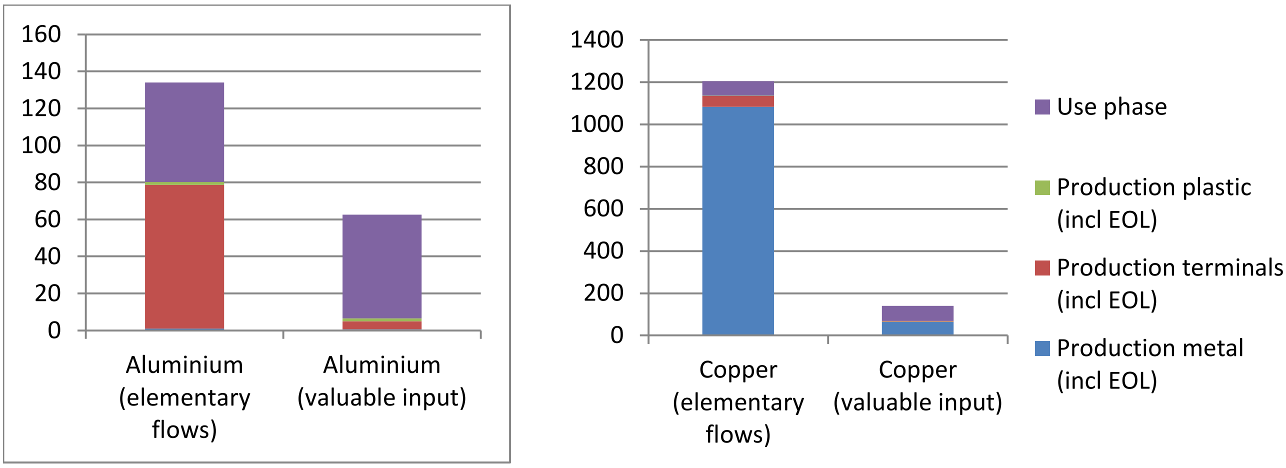


Figure 5: The figure illustrates how the relative importance of different life cycle stages changes when applying the EPS score on valuable input or elementary flows. The use phase grows in importance when no allocated elementary flows are included in the life cycle.

What is interesting is that the relative importance of different life cycle stages changes between the methods. Figure 5 shows the total score when combining the production and the end of life stages. When the valuable input method is used, the use phase becomes an increasingly important part of the life cycle. The important part of this assessment is not the size of each life cycle stage compared to others, but rather the change when going from one option to another. In light of this, and the fact that the general conclusion to recommend a change to aluminium holds true, the choice of method is not a critical factor for this report.

If the aim was to assess hotspots in the life cycle a more thorough analysis of the different methods would be necessary.

There are issues related to using the valuable input approach as well. Using two different allocations within the same assessment is often regarded as problematic. Additionally, the datasets in GaBi cover all steps up to the finished processed material. The EPS score instead only covers material production up to a stage representing a metals grade similar to processed ore.

Currently, the valuable input method requires manual corrections to the results from GaBi, and thus is of course a difficulty if applied to more complex products. It should, however, be possible to update the way EPS is calculated in the software, if this method is deemed most suitable.

Currently hard in GaBi, but possible to change

Appendix 5: IMP Workshop

Appendix 5: IMP Workshop

On October 10, 2016, a joint workshop was conducted with 22 participants from the project group and other interested. Apart from presentations about EPS, ISO and the case studies, including a panel debate, two sessions were devoted to discussions. The workshop took place at IVL, Swedish Environmental Research Institute, in Gothenburg.

First discussion session

The first discussion session made a swot analysis on monetization of environmental damage costs.

On *strengths*, the groups identified:

- Monetization creates a common language – "everybody understand money"
- Monetization clarifies where in the supply chain environmental damage costs occur
- Facilitates risk management
- Facilitates communication about environmental aspects and environmental risks
- Facilitates portfolio steering on a strategic level
- Creates a long-term view in strategic decisions
- Knowledge about future costs
- EPS is widely and systematically used in the environmental impact categories
- Enables concrete measurement of environmental costs
- Enables comparison of different types of environmental impact in the economy

On *opportunities*, the groups identified:

- Easier to compare products
- Creates benefits for the society
- The use of risk management tools are already practiced regarding environmental cost estimates
- Risk management - long-term strategy - finance
- Risk management and risk management communication
- Communication
- Enables proactivity by activity early in the decision process
- Enables CO2 estimates
- Creates goodwill
- Make companies' "hot spots" visible
- Long-term competitive advantage
- Opportunity to visualize the company's improvements - targeted initiatives

On *weaknesses*, the groups identified:

- Difficulty in weighting long-term risks against short-term risks
- The time perspective, and it can create misconceptions
- Trade-offs can be (almost too) clear - which can also be good.
- The issues where there are no factors will not be accounted for, how do we cover those?
- (Preventive) legal requirements vs. environmental costs can be tricky - both to weigh between and to explain
- Hypothetical cost
- Not "real" money (yet)
- Requires a lot of knowledge and competence, also for its communication
- Founded on subjective valuations
- Do not follow the usual calculations
- Provide the right information to the costumers

On *threats*, the groups identified almost the same issues as for weaknesses, why these are not repeated in this text.

To summarize, many strengths and opportunities, and especially weaknesses and threats are similar to each other. While monetization of environmental damage costs provides many strengths and opportunities in the strategic area regarding the ability to calculate for future risks and costs, as well as facilitation in communication, these are at the same time both weaknesses and threats as it requires a high knowledge to manage the methodology and also to communicate its results. Similarly, the time perspective provides both a strength and a weakness.

Second discussion session

In the second discussion session, the groups discussed different questions.

Question: To what extent are environmental costs (materials and resources) involved in your decisions today? Why are/ why are environmental costs not involved?

- Example 1: In investment decisions and in product development for comparison between two products. As a complement to LCA.
- Example 2: LCC at the project level. EPS again. Involve EPS for help with decisions to complement the CO_2 calculations, for set environmental targets. Set the direction in the long term.
- Example 3: Carbon dioxide and risk; in product development. Customer needs. Customer savings for major development projects.

Question: Who in your organization has an interest in including environmental costs in decision making?

- Whoever has the interest - must also have a mandate (interest is not enough for action)
- The person may be limited in what they believe are economic demands on them.

Question: What is missing to be able to involve environmental costs in decisions today?

- Pressure from customers, management, the rest of society
- Major general interest
- Knowledge

Question: Are there any barriers to include environmental costs in decisions today? Which are they?

- Too many steps in the organization
- Disconnection - strategy & expertise - procurement competence
- Environment must be involved earlier, now we analyze in retrospect. Environment must become closer to strategies. Lifecycle management - key issues
- The organization - can we even receive the results now? Who and Where? That must be the first step.
- Many demands already – those come at the first place
- Wrong competence in management groups