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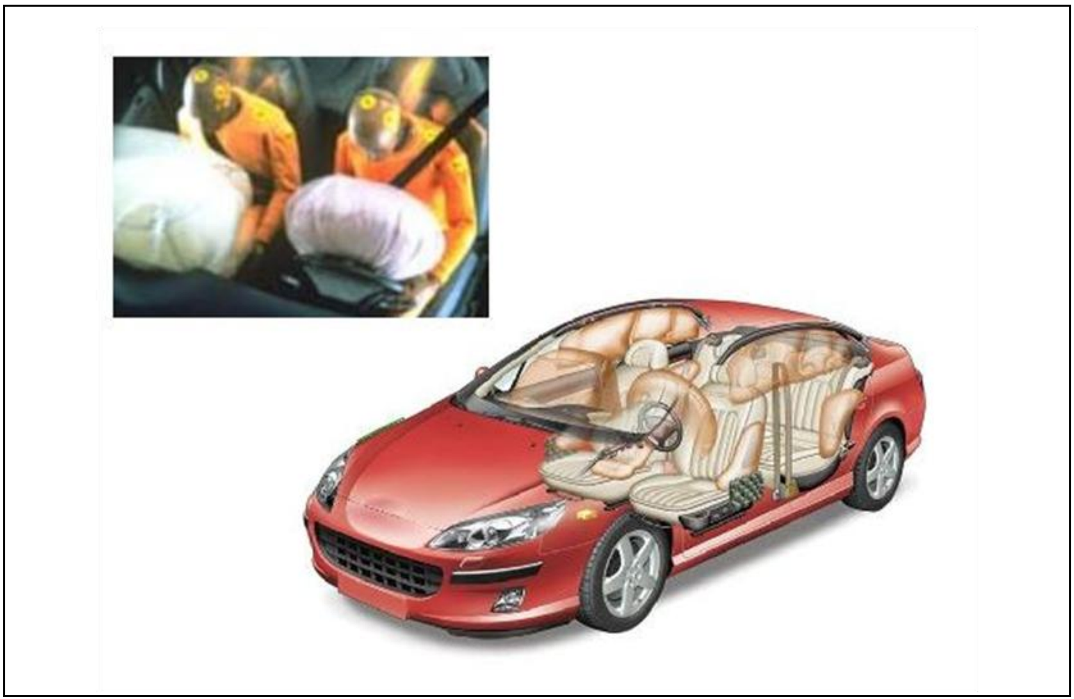

Social LCA case study of Autoliv's driver airbag system

Comparing life years saved by a driver airbag system with life years lost during its life cycle

Master of Science Thesis in the Master Degree Programme of Environmental Measurements and Assessments

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Cover:
[Autoliv's safety system and corresponding picture of frontal airbag system (available at: http://www.autoliv.com). For more information, please read this report]

Abstract

There are many indications that a system analysis tool to assess social impacts is urgently needed. Social life cycle assessment (S-LCA), which is inspired by the more well-known environmental life cycle assessment (E-LCA), has been suggested by some scholars.

The thesis presents a specific S-LCA methodology to assess a driver airbag system made by the company Autoliv. The goal is to see whether the main objective of the driver airbag system, which is to save lives and prevent severe injuries, is justified. In order to compare this in a reasonable way, the thesis applies the disability-adjusted life years (DALYs) indicator to compare life years saved by a driver airbag system with life years lost during its life cycle. Moreover, how to convert a variety of life cycle inventory data to the DALYs indicator is also discussed.

The finals results show that the main objective of an Autoliv driver airbag system seem to be justified because the number of life years saved is larger than the number of life years lost. However, the dioxin emissions during the production of the screw components and the resistor components should be paid attention to, though the dioxin emission is not unique for the two components suppliers of Autoliv.

Furthermore, after applying the UNEP/SETAC framework, it reveals that except for the prioritization suggestion and the four general steps included in both E-LCA and S-LCA, i.e. goal and scope, life cycle inventory analysis, life cycle impact assessment, and results and interpretation, the UNEP/SETAC framework could not guide much for the case study.

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List of abbreviations

2,3,7,8-TCDD: 2,3,7,8-Tetrachlorodibenzo-p-Dioxin

CIA: Central Intelligence Agency

CSR: Corporate Social Responsibility

DALYs: Disability-Adjusted Life Years

ECU: Electronic control unit

E-LCA: Environmental life cycle assessment

GBD: Global Burden of Disease

HTPs: Human Toxicity Potentials

IEA: International Energy Agency

LCC: Life Cycle Costing

LCI: Life cycle inventory

LCSA: Life Cycle Sustainability Assessment

NATSA: National Highway Traffic Safety Administration

OSHA: Occupational Safety and Health Administration

PAH: Polycyclic aromatic hydrocarbon

PCB: Printed circuit board

RCR: Risk characterization ratio

SCI: Spinal cord injury

SELCA: Social and environmental life cycle assessment

SETAC: Society of Environmental Toxicology and Chemistry

S-LCA: Social life cycle assessment

SLCIA: Social life cycle impact assessment

UNEP: United National Environmental programme

YLD: Years of Life Disabled

YLL: Years of Life Lost

WHO: World Health Organization

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1 Introduction

1.1Background

Environmental life cycle assessment (E-LCA), which has been undertaken by many researchers and consultants before, is a tool by which the environmental impacts of a product or service throughout its whole life cycle can be assessed (Baumann and Tillman, 2004). It is an important decision support tool for environmental concerns. However, an increasing number of companies are confronted with questions from society regarding a wide responsibility for the social impacts of their business activities. Due to the pressure from various stakeholders, a number of companies see themselves in need of a tool that can evaluate the social performance of their products and services. Consequently, social life cycle assessment (S-LCA) has been suggested as a method to account for social impacts of products and services.

1.2 Purpose

There are two purposes of the project. Firstly, it is to present and discuss the S-LCA methodology. Secondly, it is to apply a selected S-LCA methodology for the company Autoliv's driver airbag system, which consists of an airbag and an electronic control unit (ECU). The outcome of the thesis should find out whether the main objective of an Autoliv driver airbag system, which is to save lives and prevented severe injuries, is justified.

1.3 Method

In order to investigate the social performances of Autoliv's airbag with its ECU, a specific S-LCA methodology is developed and applied.

The specific S-LCA methodology is originally inspired by the UNEP/SETAC framework. However, its suggested indicators are not applicable for the case study because those indicators could not fulfill the comparison function, especially regarding how to present the positive aspects of an Autoliv's driver airbag system. It means that the thesis study needs to find a suitable indicator that does not exist in the UNEP/SETAC framework. First indicator come up with is the net lives saved and the net severe injuries prevented. However, there is no research so far concerning how to convert emissions during a product's life cycle to neither lives lost nor severe injuries caused. After spending a long time in reading literature, a paper written by Goedkoop *et al* (2008) has been found. It describes how to convert Human Toxicity Potentials (HTPs) indicator into the Disability-Adjusted Life Years (DALYs) indicator. The

DALYs, which will describe in detail in chapter 4, can reflect both mortality and severe health impacts. Its standardized equations are able to convert fatality records and serious lost time injuries records into life years lost. Besides, there are already methods introducing how to calculate emissions during a product's life cycle into HTPs. Then, by means of one characterization factor, HTPs can be converted into life years lost. Furthermore, the positive aspects of an Autoliv's driver airbag system can be presented by negative values of DALYs.

In summary, the thesis study follows the general steps of the UNEP/SETAC framework and not least its prioritization advice. On the same time, the thesis study applies DALYs, which is not included in the indicator list of the UNEP/SETAC framework, in order to compare the positive and negative aspects of an Autoliv's driver airbag system.

A more comprehensive description and discussion of S-LCA, particularly the UNEP/SETAC framework, is presented in chapter 3.

1.4 Data and delimitation

Most product inventory data in the thesis are based on two previous master studies, which are life cycle assessment on Autoliv's driver airbag (Arief and Susetyo, 2010) and life cycle assessment on Autoliv's electronic control unit (Gu and Liu, 2010). Other data are from governmental databases and scientific literature.

One significant delimitation is that after looking into the whole life cycle of the Autoliv's driver airbag system the study will only focus on four prioritization areas: emissions of toxic substances from production and transportation, mining of metals, electricity production and pyrotechnical material production.

2. The Autoliv company and the airbag system

2.1 Autoliv Inc.

Autoliv Inc. is a leading automotive safety company that was founded in 1997. It is a merger between Autoliv AB in Sweden and Morton Automotive Safety Products (ASP) in North America and Asia. The headquarter is located in Stockhlom. Today, Autoliv Inc. is a pioneer worldwide leader in various safety systems elements, namely seatbelt systems, airbags, steering wheels, crash electronic and pre-crash systems. Its customers include major vehicle manufacturers and most vehicle brands worldwide. It is worth mentioning that the vision of Autoliv Inc. is “to substantially reduce traffic accidents, fatalities and injuries” (Autoliv Inc., 2009).

Until 2010, Autoliv Inc. has approximately 80 manufacturing facilities in 30 countries. According to the Autoliv 2010 annual report, it has an annual net sale of $ 7.17 billion. The total market of Autoliv’s products and the intended future goals are shown in figure 1 (Autoliv annual report, 2010).

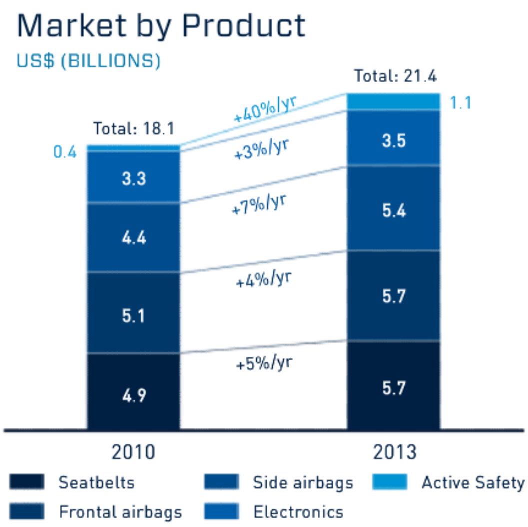

Figure 1. Major market of Autoliv’s products (Autoliv annual report, 2010).

2.2 Background of the airbag system

An airbag system consists of a crash sensor, an electronic control unit (ECU) and an airbag.

The crash sensor collects and transfers the data necessary to an ECU to make decision about the airbag deployment for certain criteria (NHTSA, 2011).

The ECU is the “brain” of the airbag system, which is typically installed in the middle of the vehicle or beneath the front seat. It determines when the frontal airbag will deploy by using the signals from a variety of sensors such as the crash sensor (NHTSA, 2011).

The airbag is a vehicle safety device, which consists of a textile cushion. It is deployed rapidly in case of automobile collision to prevent or reduce the occupant injury. It is designed as a supplementary safety device of a seat belt. There are two types of airbags, namely frontal airbag and side airbag (NHTSA, 2011). In this master thesis study a typical frontal driver airbag system is investigated.

3. S-LCA methodology

In this section, the aim and development of S-LCA, the UNEP/SETAC framework for S-LCA and the product-related S-LCA will be discussed.

The aim and development section describes the aim of S-LCA, in which context the S-LCA comes up and the two current types of S-LCA.

The UNEP/SETAC framework section introduces the S-LCA framework formed by the UNEP/SETAC life cycle initiative (UNEP, 2009). The case study follows the framework to some extent; however, some changes have been made in order to better fulfill the purpose of the thesis study.

In the third part, principles and choice of indicators of the product-related S-LCA methodology are discussed specifically, since this method has been used in the case study.

3.1 Aim and development

The framework detailed in the S-LCA Guidelines, in line with the ISO 14040 and 14044 standards for Life Cycle Assessment (2009), defines S-LCA as *"*a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle encompassing extraction and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal*"* (UNEP, 2009, pp37).

According to UNEP/SETAC (2009), S-LCA is developed in the context of incremental awareness of sustainable development, human well being and corporative social responsibility. Optimal decision making partly depends on the social perspectives which are not generally included in E-LCA. Thus, the objective of S-LCA is to assess the life cycle social impacts of products and services. Also, S-LCA meets to some extend the need to promote improvements of social conditions and sometimes even of the overall socio-economic performance of a product throughout the life cycle for all its stakeholders (UNEP, 2009, pp37). However, S-LCA does not conclude on whether a product should be produced or not. It rather provides the information on the social impacts of the product life cycle and helps inform incremental improvement (UNEP, 2009, pp37).

There are two forces driving the development of S-LCA. Firstly, the sustainability issue has attracted an increasing number of parties globally, from politicians to company managers, and is studied by a variety of researchers and authorities. One of the prominent results is the theory about the "triple bottom line" (Kloepffer, 2008). According to the theory, the sustainability is a result of the stable of the three pillars, namely environmental pillar, economic pillar and social pillar. Concerning the corporate perspective, E-LCA and Life Cycle Costing (LCC) can assess the environmental aspect and economic aspect respectively, in a holistic and systematic manner. However, a tool that can assess social aspects in a holistic way has been lacking. Some scholars find that E-LCA and LCC are consistent to each other, because of the identical physical flows and system boundaries (Kloepffer, 2008). Therefore, some researchers suggest that S-LCA can be a method based on the transformation of a life cycle inventory into social (positive and negative) impacts (Hunkeler, 2006). In other words, extending E-LCA parameters to incorporate social dimension can be a way forward. Figure 2 below illustrates the conceptual understanding of this type of S-LCA, denoted "product-related S-LCA". A more detailed discussion will be presented in the review of the UNEP/SETAC framework part and the choice of indicators part.

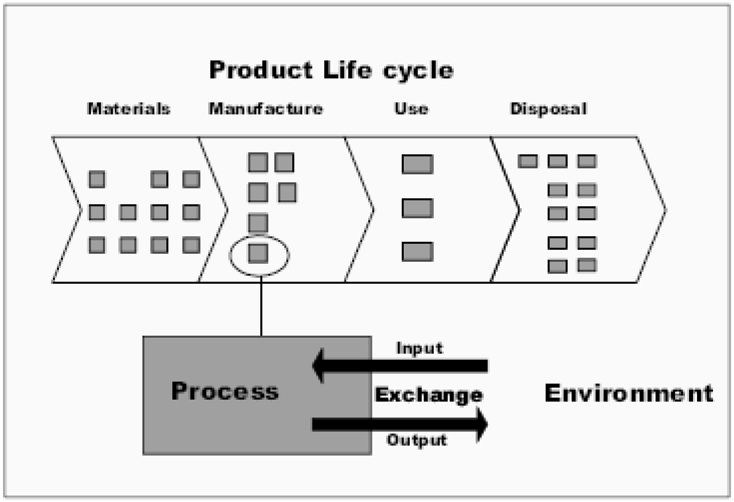

Figure 2. The conceptual understanding of the product system as perceived and modeled in the product-related S-LCA (Dreyer *et al.*, 2006).

Another driving force for the development of S-LCA is the pressure on CSR from stakeholders, such as customers, non-governmental organization (NGOs) and media. Some companies, especially large international companies, have been significantly challenged owning to the revealed fact of their poor corporate social responsibility (CSR) performance. Therefore, an assessment tool is urgently required as a tool to facilitate corporations to conduct business in a socially responsible way (Dreyer *et al.*, 2006). It means that the tool should focus on corporate activities in the life cycle that affect people.

The S-LCA methodology, as a result of these two driving forces, develops in two different ways. If the former one which was illustrated in Figure 2 can be called product-related S-LCA, then the latter one can be called "organization-related S-LCA". The organization-related S-LCA is no longer based on a process, since most impacts on people are more affected by how companies organize and manage their business (Dreyer *et al.*, 2006). In other words, impacts such as discrimination, child labor, physical working conditions, development support toward local society, are independent of the physical flows of an industrial process (Dreyer *et al.*, 2008). There is no direct link between those impacts and the actual product. In summary, the organization-related S-LCA methodology is more on a management and conduct of business level. Figure 3 illustrates the conceptual understanding of the product system as perceived in the organization-related S-LCA methodology. The figure can further show that the product life cycle, in this S-LCA methodology, is regarded as consist of many companies where industrial processes take place. The inventory data comprises the conduct of each company towards its stakeholders (Dreyer *et al.*, 2008).

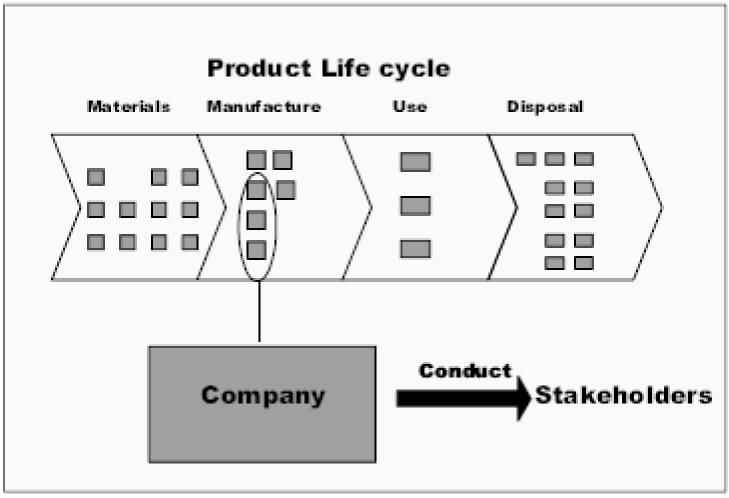

Figure 3. The conceptual understanding of the product system as perceived and modeled in the organization-related S-LCA (Dreyer *et al.*, 2006).

There is a contradictory view between these two S-LCA concepts. The organization-related S-LCA perceives occupational health impacts from direct exposure on workers, for instance mortality and morbidity, as E-LCA. Some scholars claim that in E-LCA one of the areas of protection is human health and E-LCA has thus already considered occupational health impacts from direct exposure (Dreyer *et al.*, 2008). Other occupational impacts, for instance, psychological working conditions, are more dependent on organizational aspect. They can be assessed by the organization-related S-LCA methodology (Dreyer *et al.*, 2006). However, other scholars in favor of the product-related S-LCA methodology argue that occupational health impacts from direct exposure on workers can be considered in S-LCA, since human dignity and well being are two areas of protection in S-LCA, and occupational health impacts can affect the well being impacts. In addition, life and health are the intrinsic value of humans, and thus it may be more logical to relate them to social aspect (Weidema, 2006).

In addition, S-LCA can be combined with other tools. Since the beginning of 21st century, social impact assessment has became extensive concerns of LCA, therefore, research has been carried out in this emerging field (Hunkeler *et al.*,2005). At the same time, social and environmental life cycle assessment (SELCA), life cycle sustainability assessment (LCSA) are formed as integrated tools for assessing sustainability issues, which may be used to assess various impacts of products or services (Finkbeiner *et al.*, 2010).

3.2 UNEP/SETAC framework for S-LCA

In 2003, a Task Force on the integration of social criteria into LCA was formed by the UNEP/SETAC life cycle initiative (UNEP, 2009). Before that, several approaches and frameworks were proposed. For instance, Dreyer *et al.* (2006) and Weidema (2006) each presented frameworks for impact categories. In 2009, UNEP/SETAC published a guideline for the procedures of conducting S-LCA on the basis of ISO 14000, ISO 14044 and the previous research.

According to UNEP/SETAC's S-LCA framework, the main steps in conducting S-LCA are similar to those of E-LCA (UNEP, 2009, pp38). In addition, general considerations are put forward as a basis on which the framework is build, and these are discussed below.

3.2.1 General considerations

There are concepts, perspective and considerations that should be defined before carrying out S-LCA (UNEP, 2009, pp43). Concepts, as a foundation of the framework, encompass social impacts, stakeholder categories, impact categories, subcategories and subcategory indicators.

Social impact refers to consequences caused by activities corresponding to various stakeholders. As far as social impacts are concerned, the consequences may be derived from three dimensions: behaviors (specific behavior/ decision) social-economic processes (the socio- economic decision e.g. investment decision) and capitals (human, social, cultural context).

As UNEP/SETAC defines (2009, pp46), a *stakeholder category* is "a cluster of stakeholders that are expected to have shared interests due to their similar relationship to the investigated product systems". The framework provides a list of stakeholder categories, which can be seen in Appendix 1 and Appendix 2 (UNEP, 2009). There are five main stakeholder categories: worker/employees, local community, society (national and global), consumers (covering end-consumers as well as consumers who are part of each step of the supply chain) and value chain actors. Meanwhile, there are two additional stakeholder categories: NGOs, and public authorities/ state.

Impact categories are logical grouping of S-LCA results, related to social issues of interest to stakeholders and decision makers.

In each defined impact category, there are *subcategories*, which are identified as various social issues of concern and used to subdivide the impacts (UNEP, 2009, pp84). A subcategory is also described as "one composite index" and "socially significant theme or attribute”. Subcategories are often classified according to the stakeholder categories and impact categories when conducting inventory analysis. Notably, these two classification schemes, i.e. “stakeholder category” scheme and “impact category” scheme, are complementary and not contradictory (UNEP, 2009, pp45).

Subcategories are assessed by the use of *subcategory indicators* (or inventory indicator) which provide the most direct evidence of the condition or result they are measuring. Several inventory indicators may be used to assess each of the subcategories.

An illustration of impact category, subcategories and subcategories indicators is shown in figure 4.

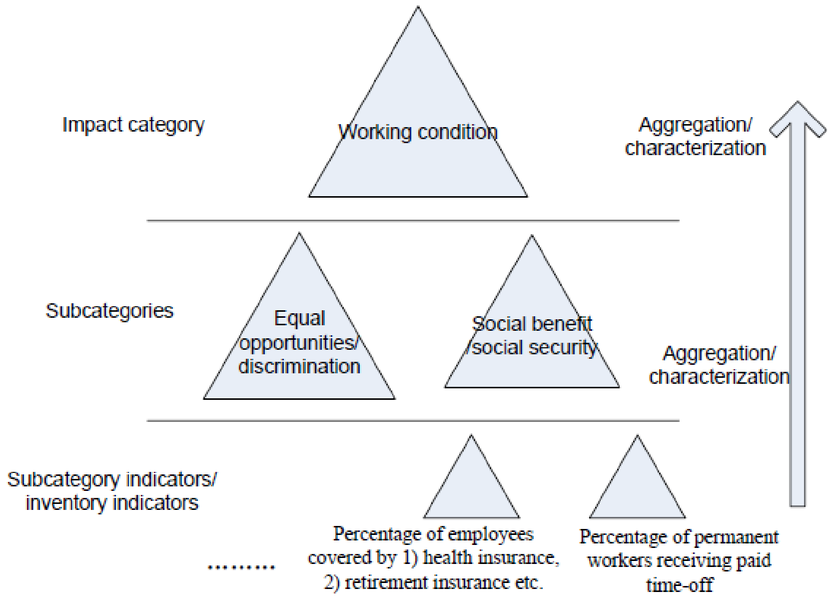

Figure 4. Example of concepts (Adapted from UNEP, 2009, pp45 &70).

3.2.2 Definition of goal and scope

The goal of the study states the intended application and potential audience (UNEP, 2009, pp50). Based on the goal of the study, critical review and peer review are necessary to conduct to ensure the fulfillment of the intended application. The scope of the study defines the depth and the width of the study. It also defines the details including limits of the product’s life cycle, the data source and the method of dealing with data and results. A flowchart is to be drawn to illustrate the product process (UNEP, 2009, pp37).

3.2.3 Life cycle inventory analysis

In this phase, data collection and system modelling are carried out iteratively. The data are classified several ways. Generic data which is not site or enterprise specific and site specific data which is data collected “for a specific process, occurring in a specific enterprise, in a specific location with those stakeholders involved or affected” (UNEP, 2009, pp57). Quantitative data describes issues using numbers, while qualitative data describes issues using words. Semi-quantitative data are categorizations of qualitative indicators into a scoring system (UNEP, 2009, pp72).

The framework suggests that the following operational steps should be done (UNEP, 2009, pp58):

- Data collection (for prioritizing and screening, using generic data)
- Preparing for main data collection
- Main data collection
- Data needed for impact assessment (characterization)
- Validation of data quality
- Normalization
- Refining the system boundary
- Data aggregation (depend on the application)

According to the guideline, data collection, encompass three steps. The first step of data collection basically gathers generic data and for a desktop screening to assist in prioritization. In other words, data collected in the first step should indicate the relative importance of different unit processes in a product life cycle. The second step is the preparation for the main data collection, including development of strategy of inventory indicator and collection methods etc. The third step is the main data collection which provides a depth screening of specific process or enterprise.

Data quality is important to addressed in the context of S-LCA as well as in E-LCA. However, there is no guidance document currently available addressing the data quality requirements for social data in S-LCA. A set of preliminary criteria are proposed and specific challenges are presented in the guideline (UNEP, 2009, pp65-68)

Data collection is an iterative and time-consuming process and it is hardly possible to conduct a complete range of social impacts for every process. Therefore, prioritization plays a guiding role in the data collection process. Furthermore, generic data or site-specific data may be employed depending on the application as well as on methodologies employed in the study. Obtaining data is another significant concern during this step.

3.2.4 Life cycle impact assessment

S-LCIA can deal with assessment of social and socio-economic impacts that can range from specific to very general, from final to preliminary, depending on which level of precision is reached and the data availability. The S-LCIA phase consists of the three mandatory steps (UNEP, 2009, pp70):

- Selection of impact categories and characterization methods and models;
- Classification: linkage of inventory data to particular S-LCIA subcategories and impact categories;
- Characterization: determination and/or Calculation of subcategory indicator results.

Impact categories are related to the social issues of interest to stakeholders and decision makers. As described above, subcategories reflect the specific impacts within an impact category, which means that several subcategories may be used to aggregate into one impact category.

Another important decision is characterization model selection. The terminology “social and socio-economic mechanism” is used to represent the casual pathway or social processes which link the inventory flows through natural or social process to potential impacts. It is more general than cause-effect modeling as social factors are more complicated to model. Moreover, weighting and aggregation step are optional steps to convert an impact categories result to a one-dimensional result.

3.2.5 Life Cycle Interpretation

Three main steps to engage in the life cycle interpretation are (UNEP, 2009, pp74):

- Identification of the significant issues: Significant issues are the important social finding both positive and negative, and the critical methodological choice.
- Evaluation: This steps aims to performance the critical review, ensure transparency and verify the result.
- Conclusions, recommendations and reporting.

To which is added:

- Level of engagement with stakeholders

3.3 Product-related S-LCA

3.3.1 Principles

The product-related S-LCA methodology, as indicated by the name and as stated previously, relates the social impacts to the product's life cycle. In this methodology, the social impacts are, to a large extent, caused by physical flows, for instance, hazardous materials. Therefore, the analysis can be based on life cycle inventory data. However, sometimes, it needs characterization factors to transfer the LCI data. The example could be transferring LCI data, such as resources and emissions, into working hours data. However, the product-related S-LCA has identical functional unit, physical processes and system boundaries as the corresponding E-LCA. Moreover, the main steps of S-LCA resemble those of E-LCA (Hunkeler, 2006).

However, because social aspects are much complex and can be highly diverse, sometimes, they cannot be related to product processes. Instead, some impacts, such as corruption and education of employees, are much more relevant to how companies conduct business. Thus, the product-related S-LCA can only assess some of the social impacts. Others have to be analyzed on the conduct of the company level.

3.3.2 Social indicators

Concerning feasibilities of S-LCA, there are mainly two prominent areas that need to be taken into consideration. The first is the indicator formulation, which is relevant to the fundamental issue on which impact categories to include in the assessment and how to measure them. The second challenging issue is the data acquisition for the chosen indicator/indicators.

With regard to indicator formulation, this is discussed in several papers. Two fundamental methods are presented, namely a bottom-up approach and a top-down approach (Dreyer *et al.*, 2006). The bottom-up approach refers to the indicators obtained from an identification of social issues in the business context, while top-down approach refers to the indicators gained from an identification of what is valuable to society. For instance, the new area of protection in S-LCA, human dignity and well being, is suggested by means of top-down approach; while, the impact from the product system activities on the defined impact categories is traced by means of the bottom-up approach. In the development of the social indicators in S-LCA, Dreyer *et al* (2006) emphasize the importance of combining the two approaches, i.e. define areas of protection by means of the top-down approach and at the same time find out the impact pathways from product system activities toward the defined areas of protection by means of the bottom-up approach.

Parent *et a.l* (2010) discuss two types of indicator categories, namely Type 1 and Type 2. They are distinct from each other owning to the different characterization models. Type 1 impact category is to use scoring and weighing systems, based on Performance Reference Points, to aggregate indicators results. The Performance Reference Points can be thresholds or objectives that are accepted internationally, according to regulations or conventions. It does not make use of the cause-effect chains. One example of Type 1 indicators is wage per hours of work, for which there may be a minimum level. It is aggregated following a scoring and weighting system that can present international consensus (Parent *et al.,* 2010). On the contrary, Type 2 impact categories utilize impact pathways, based on the cause-effect chains, to measure impacts derived from the inventory data. An example of Type 2 indicators is child labor which can be translated into damage categories such as autonomy infringement (Parent *et al.,* 2010). The comparison between Type 1 and Type 2 can be seen from the Figure 5 below. The UNEP/SETAC recommends the use of Type 2 impact category (UNEP, 2009, pp71).

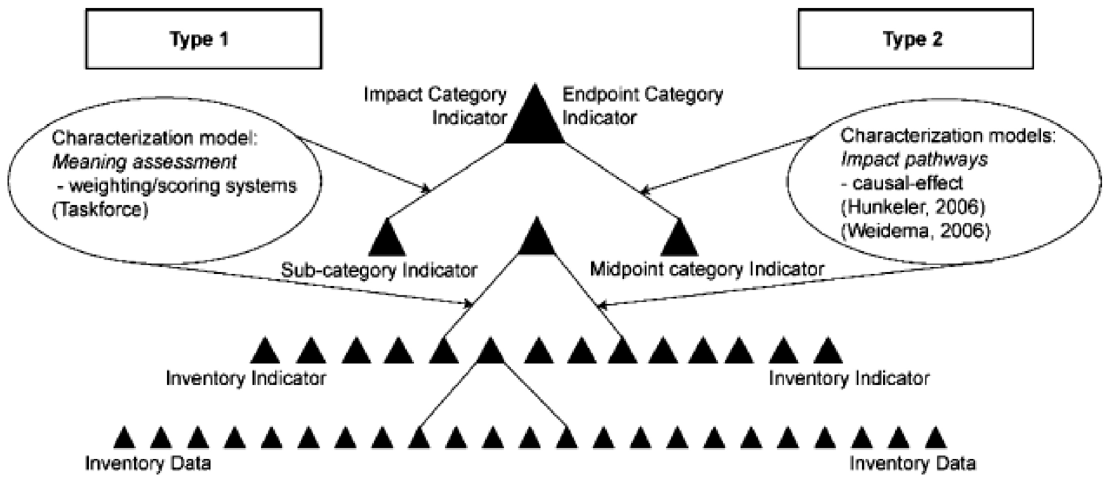

Figure 5. Comparisons between Type 1 and Type 2 (Parent *et al.,* 2010).

Hunkeler (2006) presents a case study by using working hours as indicator to present how life cycle inventory data can be transferred into social impact data. This transferring method is instructive since it illustrates a way to carry out relative product comparisons instead of absolute analysis.

In summary, the social impacts indicators are diverse. The lists of the S-LCA indicators are presented in Appendix 1 and Appendix 2. Notably, some of the S-LCA indicators are hard to track by the cause-effect chains. The relationship between sources and stressors, sometimes, is not obvious. However, there are several methods that can overcome the difficulties, for instance, the combined approach of top-down and bottom-up and a relative product comparison approach (Parent *et al.,* 2010).

4. Goal and scope definition

4.1 Goal of the study

The goal of the S-LCA is to compare life years saved by an Autoliv's driver airbag system minus life years lost during its life cycle. The assessment will therefore investigate whether the main objective of an Autoliv's driver airbag system, which is to save lives and prevent severe injuries, is justified. The intended audiences for the study are mainly academics and managers at the company Autoliv.

4.2 Scope of the study

An essential aspect of the thesis is that it is a continuation of two previous master studies, which together present an environmental life cycle assessment of an Autoliv's driver airbag system. Therefore, the scope of the study is mostly derived from them.

4.2.1 Functional unit

The functional unit of the S-LCA assessment is **one Autoliv's driver airbag system**, which includes a crash sensor, an ECU and an airbag. According to Arief and Susetyo (2010), the driver airbag consists of six essential components, which are label, nut, cushion, can, cover, and inflator. According to Gu and Liu (2010), the ECU consists of five essential components, which are label, cover, housing, screw and PCB. The crash sensor sits in the printed circuit board (PCB) of ECU.

4.2.2 System boundaries

The same system boundaries as described in the two previous E-LCA master studies will be used, see Arief and Susetyo (2010) and Gu and Liu (2010). The cradle of the S-LCA assessment is the raw material extraction and the grave of the study is the waste to the nature as a result of two possible waste management methods – landfill and incineration of waste. Recycled materials are not considered in the study since they were excluded in the previous studies. The geographical boundaries are illustrated in detail in the flowchart chapter.

4.2.3 Allocation

The allocation issue in the study is mainly based on the weight approach, which means the allocation is in terms of the material masses in an Autoliv's driver airbag system.

4.2.4 Choice of social indicators

The major indicator applied to compare life years saved and life years lost is DALYs. It can reflect both mortality and severe health impacts.

The DALYs of a disease is derived from human health statistics on life years lost as well as disabled. When equal weightings to the significance of one year of life lost for all ages and no discount for future damages are applied, DALY is the sum of years of life lost (YLL) and years of life disabled (YLD) (WHO, 2011). Therefore, it can summarize morbidity and mortality to one single number, which can be expressed as the equation below:

$$\mathrm{DALYs} = \mathrm{YLL} + \mathrm{YLD} \tag{1}$$

The YLD is equal to

$$\mathrm{YLD} = \mathrm{w} \times \mathrm{D} \tag{2}$$

Where: *w* is a severity factor between 0 (complete health) and 1 (dead);

D is the duration of the disease.

DALYs belongs to the type 2 indicator category because it is based on the cause-effect chains (Parent *et al.*, 2010). For instance, the toxic elements can be traced towards workers' health conditions. In addition, it can be characterized as the "bottom-up indicator", since the starting point of the indicator is to find out the link between industrials' actions and their possible impacts (Dreyer *et al*, 2006). However, it can also be regarded as the "top-down indicator", because it relates to the intrinsic values of life as stated in the universal declaration of human right (2011), i.e. "Everyone has the right to life, liberty and security of person".

4.2.5 Assumptions and prioritization

There are three essential assumptions made in the study will be listed as follows:

The two previous master reports state that the studied driver airbag and the studied ECU are responsible for 80% of the corresponding Autoliv products. In addition, the driver airbag will be installed in Volvo cars while the ECU will be installed in BMW MINI cars. Since both cars belong to the light car group, we make our first assumption here that the driver airbag and the ECU investigated before can match each other and become one Autoliv's airbag system.

The second significant assumption is that since the studied driver airbag represents 80% types of airbags produced by Autoliv we assume that the driver airbag account for 80% of all sold Autoliv airbags.

The third assumption is that there is no huge change regarding material production and technology innovation for the airbag system during last few years..

It should be mentioned that after looking into the whole life cycle of the Autoliv's driver airbag system, four prioritization areas will be focused in the project:

- Emissions of toxic substances from production and transportation;
- Mining of metals;
- Electricity production;
- Production of pyrotechnical materials.

5 Flowcharts

The flowcharts are based on the previous two master studies, see Arief and Susetyo (2010) and Gu and Liu (2010). Maps presenting relevant production locations (figure 8 and figure 10) are used to help calculations and analyses.

5.1 The flowchart of the driver airbag

The driver airbag consists of six components, which can be seen in the figure 6. The components are produced in more than ten countries and regions. After the productions, all the components are transported to Vårgårda in Sweden and assembled there. The overall flowchart is shown in the figure 8, and the figure 7 pinpoints the relevant production places. The assembled airbags are installed in Volvo cars and then transported to all over the world. After some years of car operation, the airbags are dismantled together with Volvo cars.

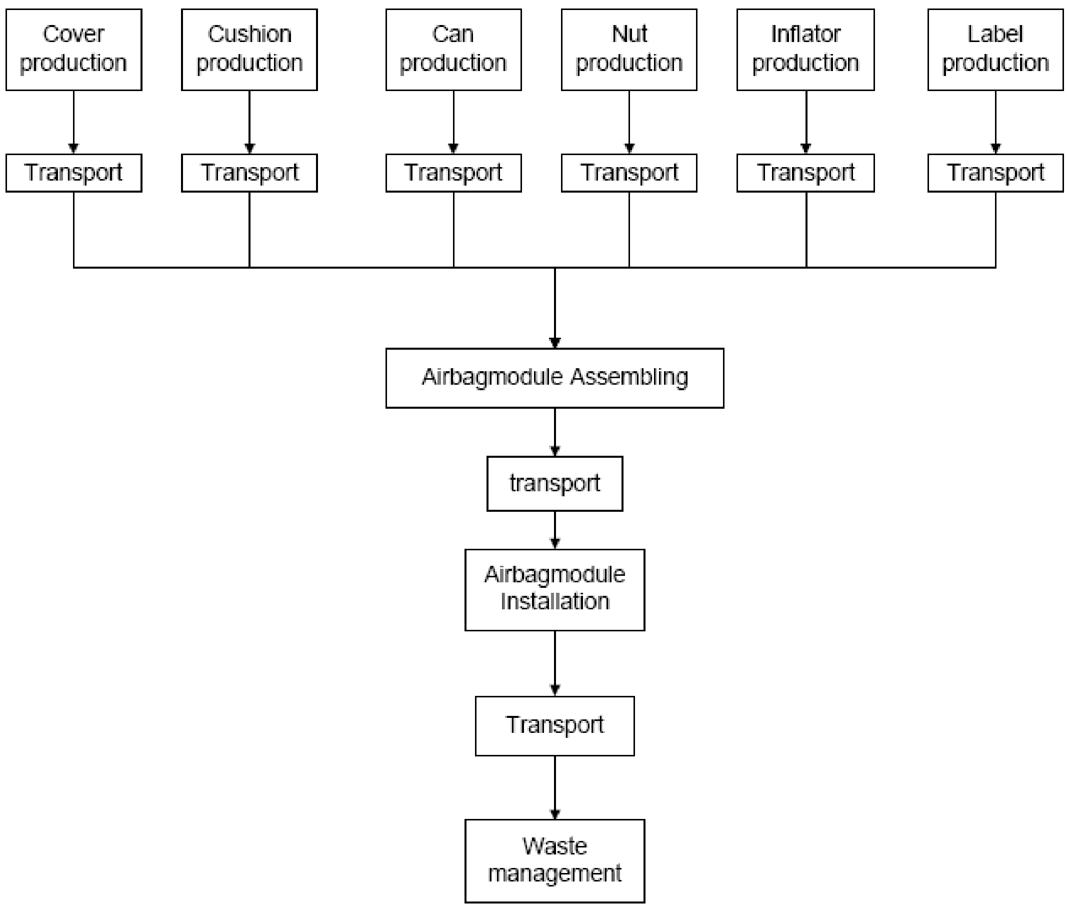

Figure 6. General flowchart of airbag life cycle.

Figure 7. Production places of airbag components.

5.2 The Flowchart of the ECU

The ECU module consists of five components, which can be seen in the figure 8. The components are produced in 10 countries and regions. After the productions, all the components are transported to Motala in Sweden and assembled there. The overall flowchart is shown in figure 8, and figure 9 pinpoints the relevant production places. The assembled ECUs are installed in BMW MINI, Oxford, England. After some years of car operation, the ECUs are dismantled together with BMW MINI cars.

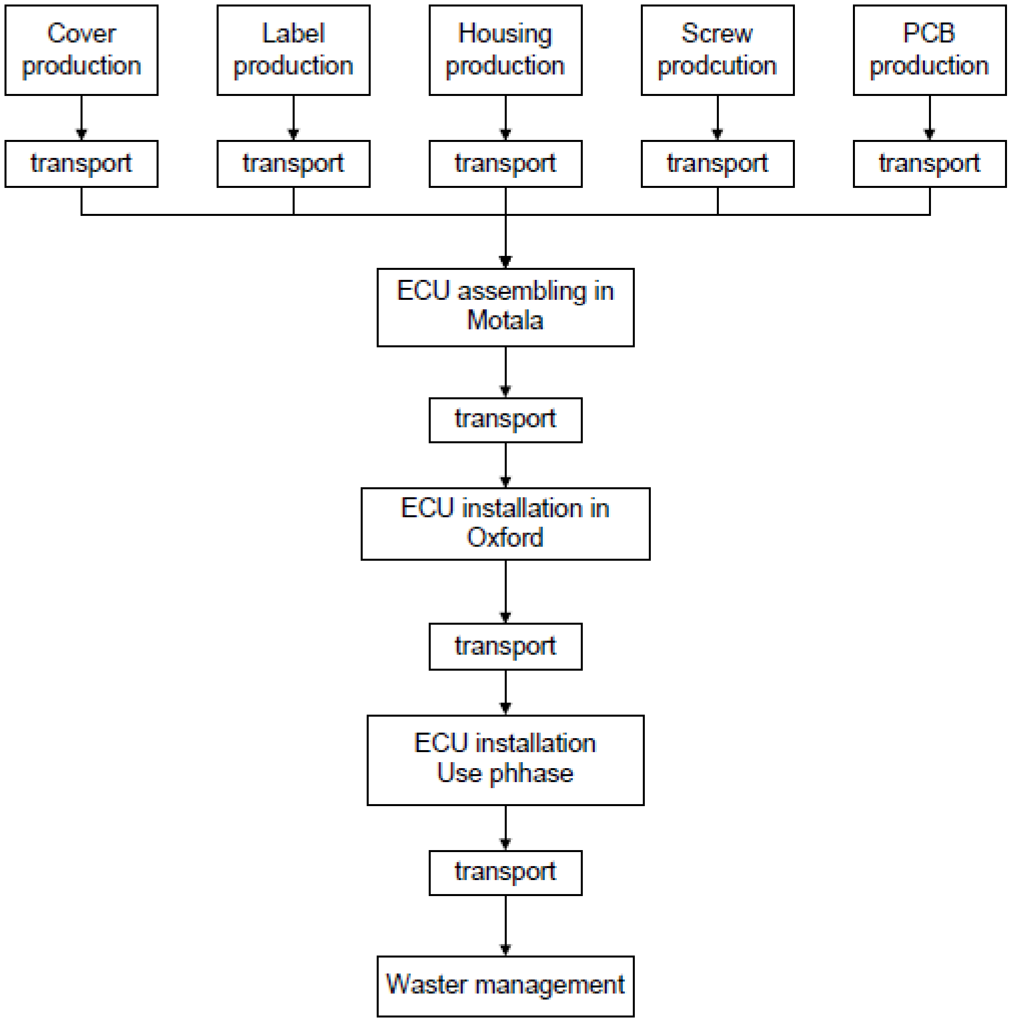

Figure 8. General flowchart of ECU life cycle.

Figure 9. Production places of ECU components.

6 Life cycle inventory analysis

For inventory analysis, the data on the number of lives saved and severe injuries prevented by an Autoliv's driver airbag system is needed. At the same time, the data on the number of lives lost and severe injuries caused during an Autoliv's driver airbag system is also needed.

6.1 Lives saved by an Autoliv's driver airbag system

In reality, airbag systems often work together with seatbelt systems. Therefore, how to attribute the life years saved by airbags and seatbelts is an issue needed to be handled here. Glassbrenner (2003), who is a researcher in NHTSA, presents a method to attribute the lives saved by airbags and seatbelts together. He claims that there are three attribution methods, which are the belt-maximizing method, the bag-maximizing method and the restraint-neutral method. The belt-maximizing method attributes the maximal benefits possible to the seatbelts, and attributes only the residual benefits to airbags. On the contrary, for the bag-maximizing method, the maximal benefits possible are attributed to airbags and only residual benefits possible to seatbelts. The third method - the restraint-neutral attribution - does not give any preference to either restraint. Appendix 3 shows the original equations and the notations for the three attribution methods.

Glassbrenner (2003) also mentions that each method is scientifically valid. Which one to choose is a policy decision. For the case study, the restraint-neutral method is preferred since any preferences to either restraint are avoided. Besides, there are simplified calculations suggested by Glassbrenner (2003) for the restraint-neutral method as showed below. The simplified calculations are very convenient and do not require the fatality count data (Fi), which is required for the other two methods.

$$\mathrm{S(bag)} = \mathrm{S} \times \mathrm{e(bag)}/[\mathrm{e(bag)} + \mathrm{e(belt)}] \quad (3)$$

$$\mathrm{S(belt)} = \mathrm{S} \times \mathrm{e(belt)}/[\mathrm{e(bag)} + \mathrm{e(belt)}] \quad (4)$$

Where: S(bag) is the number of lives saved by airbags alone;

S(belt) is the number of lives saved by seatbelts alone;

e(bag) is the effectiveness of airbags alone;

e(belt) is the effectiveness of seatbelts alone.

Autoliv Inc. homepage (2009) states that Autoliv products annually save more than 25000 live in traffic (the variable S in the equation 3). In terms of the equation 3, two additional data are needed, namely, the effectiveness of airbags alone (the variable e(bag) in the equation 3) and the effectiveness of seatbelts alone (the variable e(belt) in the equation 3). NHTSA (1996) lists two figures: fatality reduction of seatbelt alone is 45% while fatality reduction of airbag alone is 13%. Glassbrenner (2003) also lists two figures: fatality reduction of seatbelt alone is 48% while fatality reduction of airbag alone is 14%. It is fortunate to find that the variation between the two sets of data is small. Since the latter set of figures is more recent, it is decided to use the latter set.

Therefore, the restraint-neutral method attributes 5645 of the 25000 saved lives to Autoliv's airbags annually, which is $25000 \times 0.14/(0.48+0.14)= 5645$, and the remaining 19355 to Autoliv's seatbelts annually.

Moreover, from personal contact with the life cycle manager in autoliv, we get to know that they approximately sold 30 million frontal airbags, 30 million side airbags and 27 million curtain airbags in 2010. According to the assumption made in goal and scope section about the percentage of the studied driver airbags, roughly, 5646 / $[(30+30+27) \times 0.8 \times 1.0E+06]= 8.112E-05$, lives can be saved by one Autoliv driver airbag system in 2010.

6.2 Severe injuries prevented by an Autoliv's driver airbag system

The same attribution method as used for lives saved is applied for severe injuries prevention. The reasons are because: firstly, there are no principle differences between how seatbelts and airbags work when preventing life lost and when preventing severe injuries; secondly, there are no specific attributing methods have been found concerning severe injuries prevention.

Autoliv Inc. homepage (2009) states that Autoliv products annually help prevent more than 250000 severe injuries in traffic (the variable S in the equation 3). NHTSA (1996) lists two figures: the likelihood of serious and greater injury reduction of seatbelt alone is 60 % (the variable e(belt) in the equation 3) while the likelihood of serious and greater injury reduction of airbag alone is 7% (the variable e(bag) in the equation 3). No more recent data that have been found.

Therefore, in terms of the equation 3, the restraint-neutral method attributes 26119 of the 250000 prevented severe injuries to Autoliv's airbags, which is $250000 \times 0.07/(0.6+0.07)= 26119$, and the remaining 223881 to Autoliv's seatbelts.

Furthermore, the assumption made in the goal and scope section about the percentage of the studied driver airbags will be applied again, therefore, roughly, 26119 / $[(30+30+27) \times 0.8 \times 1.0E+06]=3.753E-04$, serious injuries can be prevented by this kind of Autoliv driver airbag system.

6.3 Lives lost and severe injuries caused due to the life cycle of an Autoliv's driver airbag system

The reason why there is no division between lives lost and severe injuries caused during the life cycle is that the method of HTPs could only indicate the overall human health effects. This means that the HTPs results could not present lost lives and caused severe injuries respectively but integrated results. Moreover, it is difficult to find the serious lost time injuries data regarding the electricity generation. For this practical reason, only lost lives during the electricity production will be considered.

6.3.1 Emissions of toxic substances from production and transportation

The health affects due to emissions from production and transportation are reflected by the HTPs indicator. HTPs is calculated by global nested multi-media fate, exposure and effect model USES-LCA, which is based upon the Uniform System for the Evaluation of Substances 2.0 (USES 2.0). USES 2.0 provides several modules to compute different risk levels, locally, regionally, continentally and globally (Huijbregts *et al.*, 2000).

There are two important calculations regarding HTPs (Huijbregts *et al.*, 2000). The first calculation is the human risk characterization ratio (RCR) equation, which is the principle calculation. It comes from the fate, exposure and effect model in the risk assessment.

$$RCR_{human,x,s,e} = \sum_{r=1}^{r=n} \frac{PDI_{r,x,s,e}}{HLV_{r,x}} \tag{5}$$

Where: $RCR_{human,x,s,e}$ is the human risk characterization ratio (RCR) of substance x at geographical scale s due to an emission to compartment e;

$PDI_{r,x,s,e}$ (kg kg^{-1}_{bwt}, day^{-1}) is the predicted daily intake (PDI) via exposure route r (oral and inhalatory) of substance x for humans at geographical scale s after emission to compartment e;

$HLV_{r,x}$ (kg kg^{-1}_{bwt}, day^{-1}) is the human limit value (HLV) for exposure route r (oral and inhalatory) of substance x.

The second calculation is the human toxicity potential equation (Huijbregts *et al.*, 2000), which is the basis calculation for this study.

$$HTP_{x,e} = \frac{\text{Weighted } RCR_{human,x,e}}{\text{Weighted } RCR_{ref}} \qquad (6)$$

Where: $HTP_{x,e}$ (1,4-DCB equivalent) is the human toxicity potential for substance x after emission to compartment e;

Weighted $RCR_{human,x,e}$ (-, kg_{wwt}) is the weighted RCR of human impact category for substance x after emission to compartment e;

Weighted RCR_{ref} (-, kg_{wwt}) is the weighted RCR for 1,4-DCB after emission to the defined reference compartment, which is air compartment for human toxicity.

The HTPs of airbag and ECU are calculated via Excel in terms of the equation 6. The calculation processes consist of three main steps. Step one is to select all toxic substances in the outflows tables of the inventory data according to toxicity potentials of 182 substances shown in Appendix 4. Step two is to use the specific factor (weighted RCR_{ref}) in Appendix 4 for each selected toxic substance x to calculate their $HTP_{x,e}$. Step three is to sum up all the $HTP_{x,e.}$ Appendix 5, Appendix 6 and Appendix 7 show parts of the calculation processes. The calculation results based on the equation 6 can be seen in table 1 and table 2.

Table 1. Human toxicity potentials of an Autoliv's driver airbag.

Airbag	**Value**	**Unit**
Label	1.25E+02	g 1,4-DCB_{eqv}
Nut	6.07E+00	g 1,4-DCB_{eqv}
Cushion	3.32E+02	g 1,4-DCB_{eqv}
Can	2.48E+02	g 1,4-DCB_{eqv}
Cover	4.41E+01	g 1,4-DCB_{eqv}
Inflator	7.35E+02	g 1,4-DCB_{eqv}
Transportation	3.07E-01	g 1,4-DCB_{eqv}
Total	**1.49E+03**	g 1,4-DCB_{eqv}

Table 2. Human toxicity potentials of an Autoliv's ECU.

ECU	Value	Unit
Label	4.01E-03	g 1,4-DCB_{eqv}
Housing	2.57E+03	g 1,4-DCB_{eqv}
Cover	1.18E+01	g 1,4-DCB_{eqv}
Screw	3.82E+08	g 1,4-DCB_{eqv}
PCB	2.68E+09	g 1,4-DCB_{eqv}
Transportation	2.39E+04	g 1,4-DCB_{eqv}
Total	**3.06E+09**	g 1,4-DCB_{eqv}

6.3.2 Mining of metals

From the two figures below, it is obvious that metals account for a large part in the airbag system by weight. Mining safety is always a hot topic because mining is rather a dangerous industry compared with most other industrials (Coleman and Kerkering, 2007). Therefore, it could be interesting to investigate the deaths and serious lost time injuries due to the mining for an Autoliv’s driver airbag system.

The deaths/kg data is calculated based on the the Western Australian mining fatalities database and Western Australian Mineral and Petroleum Statistics Digest 2008 report (Government of Western Australia Department of Mines and Petroleum, 2008). The serious lost time/kg is calculated based on the Western Australian Mineral and Petroleum Statistics Digest 2007-2008 report (Government of Western Australia Department of Mines and Petroleum, 2008) and the direct information emailed from the Government of Western Australia Department of Mines and Petroleum. A more detailed calculation can be found it in Appendix 8. The metal contents data is calculated based on the two previous master studies inventory data. The calculation results are shown in table 3 and table 4.

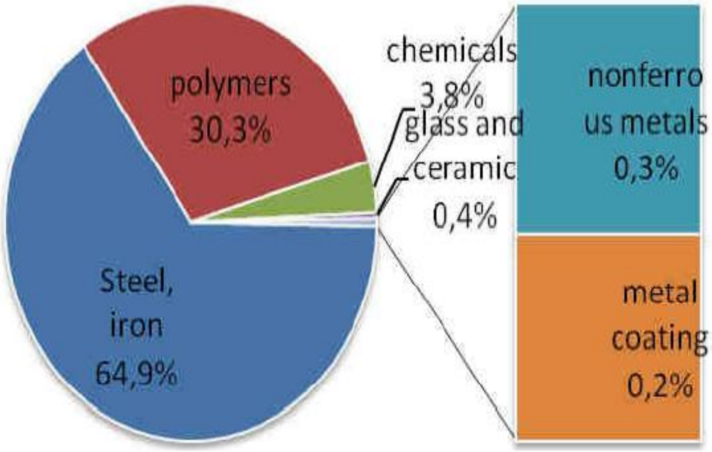

Figure 10. Basic substance composition for one airbag (Arief and Susetyo, 2010).

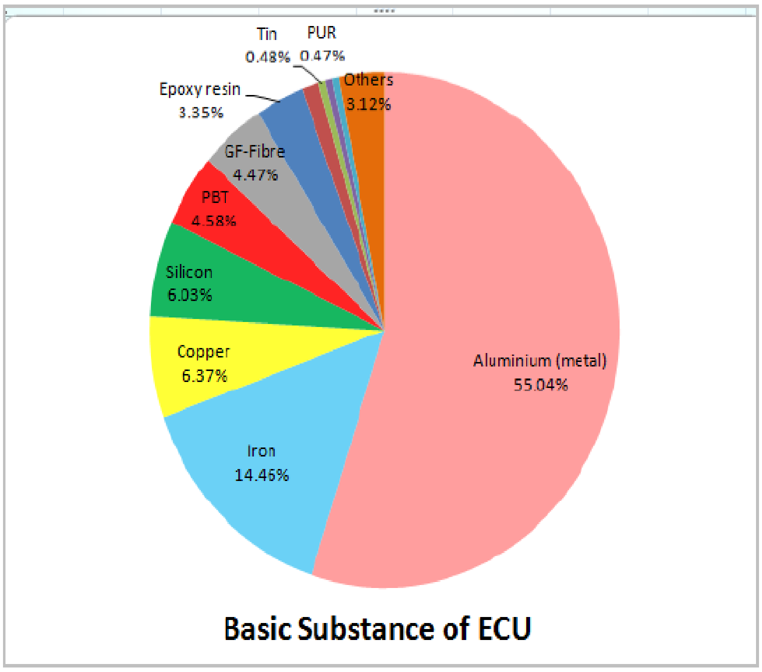

Figure 11. Basic substance composition for one ECU (Gu and Liu, 2010).

Table 3. Deaths caused by metals mining – airbag part.

Metal	Deaths/kg metal mining	Serious lost time injuries/ kg metal mining	kg metal content per airbag	Deaths caused by metal contents	Serious lost time injuries caused by metal contents
Aluminium	5.15E-10	-	1.20E-03	6.19E-13	-
Gold	8.01E-06	5.38E-04	2.00E-07	1.60E-12	1.08E-10
Lead	1.72E-07	1.99E-05	3.63E-04	6.24E-11	7.22E-09
Zinc	5.43E-07	2.59E-06	1.54E-03	8.35E-10	3.99E-09
Copper	2.85E-07	1.25E-05	2.02E-05	5.76E-12	2.53E-10
Nickel	3.27E-09	3.04E-07	1.53E-04	5.00E-13	4.65E-11
Iron	4.64E-12	1.72E-10	1.01E+00	4.69E-12	1.74E-10
Total				**9.80E-10**	**1.18E-08**

Table 4. Deaths caused by metals mining – ECU part.

Metal	Deaths/kg metal mining	Serious lost time injuries/ kg metal mining	kg metal content per ECU	Deaths caused by metal contents	Serious lost time injuries caused by metal contents
Aluminium	5.14E-10	-	2.35E-01	1.21E-10	-
Gold	8.01E-06	5.38E-04	6.53E-06	5.22E-11	3.51E-09
Lead	1.72E-07	1.99E-05	1.37E-05	2.35E-12	2.73E-11
Zinc	5.43E-07	2.59E-06	2.90E-04	1.58E-10	7.51E-09
Copper	2.85E-07	1.25E-05	2.72E-02	7.76E-09	3.40E-07
Nickel	3.27E-09	3.04E-07	8.96E-05	2.93E-13	2.72E-11
Iron	4.64E-12	1.72E-10	6.18E-02	2.87E-13	1.06E-11
Total				**8.09E-09**	**3.45E-07**

6.3.3 Electricity production

In the Science's Soup website, an article on Deaths per TWh for all energy sources is published as can be seen in table 5. The article is based on two scientific reports. One is comparative risk assessment of energy options - the meaning of results (Dreicer *et al.*,1999). The other one is economic analysis of various options of electricity generation - taking into account health and environmental effects (Starfelt, 2011). Based on table 5, deaths caused by electricity generation in different countries can be calculated, which can be checked in Appendix 9. Then, deaths due to electricity generation for Autoliv's driver airbag and ECU can be calculated as shown in table 6 and table 7.

Table 5. Comparing deaths/TWh for all energy sources.

Energy source	Death rate (deaths per TWh)	Remarks
Coal-world average	161	26% of world energy, 50% of electricity
Coal-China	278	
Coal-USA	15	
Oil	36	36% of world energy
Natural gas	4	
Biofuel/biomass	12	
Peat	12	
Solar (rooftop)	0.44	Less than 0.1% of world energy
Wind	0.15	Less then 1% of world energy
Hydro	1.1	Europe death rate, 2.2% of world energy
Hydro-world including Banqiao	1.4	About 2500TWh/yr and 17100 banqiao dead
Nuclear	0.04	5.9% of world energy

Table 6. Deaths due to electricity generation for Autoliv's driver airbag.

Airbag	**Value**	**Unit**
Label	5.34E-11	Deaths per label due to electricity generation
Nut	5.51E-10	Deaths per nut due to electricity generation
Cushion	3.26E-08	Deaths per cushion due to electricity generation
Can	1.02E-09	Deaths per can due to electricity generation
Cover	2.24E-08	Deaths per cover due to electricity generation
Inflator	8.48E-08	Deaths per inflator due to electricity generation
Total	**1.41E-07**	Deaths per driver airbag due to electricity generation

Table 7. Deaths due to electricity generation for Autoliv's ECU.

ECU	**Value**	**Unit**
Label	1.24E-10	Deaths per label due to electricity generation
Housing	3.33E-08	Deaths per housing due to electricity generation
Cover	5.42E-08	Deaths per cover due to electricity generation
Screw	9.76E-09	Deaths per screw due to electricity generation
PCB	1.48E-06	Deaths per PCB due to electricity generation
Total	**1.58E-06**	Deaths per ECU due to electricity generation

6.3.4 Pyrotechnical materials production

According to the information from Autoliv, in the US production, where pyrotechnic materials and inflators are produced, there are 227 claims in 2010, but no fatal/ serious lost time injuries records according to Occupational Safety and Health Administration (OSHA) standards.

7 Life cycle impact assessment

In the life cycle impact assessment chapter, the DALYs method is used to transfer all data that have been gathered in the inventory analysis chapter to life years saved or potential life years lost due to an Autoliv's driver airbag system.

7.1 Life years saved by an Autoliv's driver airbag system

In order to calculate life years saved by an Autoliv's driver airbag system, the data of lives saved and the data of severe injuries should be transferred to years in terms of the DALYs equation, i.e. the equation 1. Moreover, there are two more figures needed for the calculation. One is the world life expectancy. The other one is the average age of drivers in accidents.

According to central intelligence agency (CAI, 2011), the world life expectancy is 67. 07. However, most motorized countries such as China, European Union and USA, the life expectancies there are all over 70. Thereby, the life expectancy of 70 year is decided to be used as a representative figure.

YLL calculation

Based on licensed drivers and number in accidents by age: 2007 (National Safety Council, 2008), we calculate the average age of drivers in fatal accidents is 42.8. The calculation can be seen in appendix 11. Therefore, potential YLL saved by an airbag system is 2.21 E-03 yr, i.e. $\sum_{i}^{n} \text{fatality}_i \times \text{lost years} = (8.112\text{E}-05) \times (70-42.8) = 2.21\text{ E}-03\text{ yr}$.

YLD calculation

It is difficult to find duration data and severity factor for general severe traffic injuries. Fortunately, in a PPT presentation on Disability adjusted life years (DALYs) and the traffic-related burden of disease in California (Carol Kolb, 2010), the author lists duration data and severity factor for a specific severe traffic injury, which is spinal cord injury (SCI). The set of data of SCI, which is 36 year for duration and 0.725 for severity factor, is planning to be used to represent severe traffic injuries in the study. Therefore, in terms of equation 2, the potential YLD saved by an airbag system is 9.76 E-03 yr, i.e. $\sum_{i}^{n} \text{severe injuries}_i \times \text{the severity factor} \times \text{duration} = (3.753\text{E}-04) \times 0.725 \times 36 = 9.76\text{ E}-03\text{ yr}$.

DALYs calculation

In summary, in terms of the equation 1, the potential DALYs saved by an airbag system is 1.20 E-02 yr, i.e. $\text{YLL} + \text{YLD} = (2.21\text{ E}-03) + (9.76\text{ E}-03) = 1.20\text{ E}-02\text{ yr}$.

7.2 Life years lost due to an Autoliv's driver airbag system

In order to calculate life years lost due to an Autoliv's driver airbag system, the HTPs results, deaths due to mining industrials and deaths due to electricity generation should be all transferred to years in terms of DALYs equation, i.e. the equation 1.

7.2.1 HTPs to DALYs

Regarding HTPs results, Goedkoop *et al.* (2008) present a method to connect HTPs to DALYs. Appedix 10 sketches the relations between LCI parameters, midpoint indicators (including HTPs) and endpoint indicators (including DALYs).

The underlying principle for connecting midpoint indicators and endpoint indicators can be expressed as the equation below (Goedkoop *et al.*,2008):

$$I_e = \sum_m Q_{em} I_m \tag{7}$$

Where: I_m is the midpoint indicator m. For human health, it is HTPs (kg 1-4-DCB_{eq});

Q_{em} is the characterization factor that connects midpoint impact category m with endpoint impact category e. For human health, the factor is 7.0E-07;

I_e is the endpoint indicator e. For human health, it is DALYs (yr).

DALYs calculation

Therefore, the DALYs results can be calculated in terms of the equation 7.

$$DALYs_{(airbag,HTPs)} = HTP_{(airbag)} \times Q_{em}$$

$$= (1.49E+03) \times (1.00E-03) \times (7.0E-07) = 1.04E-06 \text{ yr}$$

$$DALYs_{(ECU,HTPs)} = HTP_{(ECU)} \times Q_{em}$$

$$= (3.06E+09) \times (1.00E-03) \times (7.0E-07) = 2.14 \text{ yr}$$

7.2.2 Deaths and serious lost time injuries in the mining industry to DALYs

YLL calculation

The modified world life expectancy, 70 years, is applied again. Furthermore, based on the Government of Western Australia Department of Mines and Petroleum database as well as the United States Department of Labor data the average death age for mining workers is 35.6. Therefore, the YLL results can be calculated as follows:

$$\mathrm{YLL}_{(\mathrm{airbag,mining})} = \sum_i^n \mathrm{fatality}_i \times \mathrm{lost\ years}$$

$$= (9.10\mathrm{E}-10) \times (70-35.6) = 3.13\ \mathrm{E}-08\ \mathrm{yr}$$

$$\mathrm{YLL}_{(\mathrm{ECU,mining})} = \sum_i^n \mathrm{fatality}_i \times \mathrm{lost\ years}$$

$$= (8.09\mathrm{E}-09) \times (70-35.6) = 2.78\ \mathrm{E}-07\ \mathrm{yr}$$

YLD calculation

According to the Industry Performance Report 2007 – 2008 (Government of Western Australia Department of Mines and Petroleum, 2008), the most common accident type in the mining industry that cause serious injuries is overexertion or strenuous movements. They can lead to sprain or strain. Moreover, Polinder *et al.* (2007) present a table on the overview of disability weights and duration of health state for injuries in the Global Burden of Disease (GBD). The table lists the severity weight for vertebral column fractures / dislocations / sprain / strain is 0.2666 and the duration of disability is 0.140 years.

$$\mathrm{YLD}_{(\mathrm{airbag,mining})} = \sum_i^n \mathrm{severe\ injuries}_i \times \mathrm{the\ severity\ factor} \times \mathrm{duration}$$

$$= (1.18\ \mathrm{E}-08) \times 0.266 \times 0.140 = 4.39\ \mathrm{E}-10\ \mathrm{yr}$$

$$\mathrm{YLD}_{(\mathrm{airbag,mining})} = \sum_i^n \mathrm{severe\ injuries}_i \times \mathrm{the\ severity\ factor} \times \mathrm{duration}$$

$$= (3.45\ \mathrm{E}-07) \times 0.266 \times 0.140 = 1.28\ \mathrm{E}-08\ \mathrm{yr}$$

DALYs calculation

In summary, in terms of the equation 1, the DALYs due to the mining industry can be calculated as follows.

$$\mathrm{DALYs}_{(\mathrm{airbag,mining})} = \mathrm{YLL} + \mathrm{YLD}$$

$$= (3.13\ \mathrm{E}-08) + (4.39\ \mathrm{E}-10\ ) = 3.24\mathrm{E}-08\ \mathrm{yr}$$

$$\mathrm{DALYs}_{\ (\mathrm{ECU,mining})} = \mathrm{YLL} + \mathrm{YLD}$$

$$= (2.78\ \mathrm{E}-07) + (1.28\ \mathrm{E}-08) = 2.91\mathrm{E}-07\ \mathrm{yr}$$

7.2.3 Deaths in electricity production industry to DALYs

YLL calculation

The modified world life expectancy, 70 years, is applied again. It is hard to find the average death age of electricity generation workers. However, from the fatal occupational injuries report (United States department of labor, 2011), the average death age of all kinds of industrials is 45.5. Therefore, the YLL results can be calculated as follows:

$$\mathrm{YLL}_{(\mathrm{airbag,electricity})} = \sum_{i}^{n} \mathrm{fatality}_i \times \mathrm{lost\ years}$$

$$= (1.41\mathrm{E}-07) \times (70-45.5) = 3.5 = 3.45\ \mathrm{E}-06\ \mathrm{yr}$$

$$\mathrm{YLL}_{(\mathrm{ECU,electricity})} = \sum_{i}^{n} \mathrm{fatality}_i \times \mathrm{lost\ years}$$

$$= (1.58\mathrm{E}-06) \times (70-45.5) = 3.87\ \mathrm{E}-05\ \mathrm{yr}$$

DALYs calculation

In summary, in terms of the equation 1, the DALYs due to the electricity generation industry can be calculated as follows:

$$\mathrm{DALYs}_{(\mathrm{airbag,electricity})} = \mathrm{YLL}_{(\mathrm{airbag,electricity})} = 3.45\ \mathrm{E}-06\ \mathrm{yr}$$

$$\mathrm{DALYs}_{(\mathrm{ECU,electricity})} = \mathrm{YLL}_{(\mathrm{ECU,electricity})} = 3.87\ \mathrm{E}-05\ \mathrm{yr}$$

It should be mentioned that because the serious lost time injuries data could not be found in the electricity generation industry. Therefore, the DALYs results here only include the YLL part.

8. Results and interpretation

The results of the S-LCA case study is presented in table 8 below. As discussed before, DALYs is a negative indicator and should be minimized. Therefore, the use of (–) is aimed to show that the DALYs results are reduced thanks to the saved life years and the prevented severe injuries.

Table 8. Comparing life years saved and life years lost.

	YLL (yr)	YLD (yr)	DALYs (yr)
LIFE YEARS SAVED	(-) 2.21E-03	(-) 9.76E-03	(-) 1.20E-02
Emissions during the life cycle			
Airbag			1.04E-06
ECU			2.14E+00
Total			2.14E+00
POTENTIAL life years lost			2.14E+00
Mining			
Airbag	3.13E-08	4.39 E-10	3.24E-08
ECU	2.78E-07	1.28 E-08	2.91E-07
Total	3.09E-07	1.33 E-08	3.22E-07
Electricity generation			
Airbag	3.45E-06	-	3.45E-06
ECU	3.87E-05	-	3.87E-05
Total	4.21 E-05	-	4.21 E-05
Pyrotechnical materials production			
Total	0	0	0
LIFE YEARS LOST	4.24 E-05	1.38 E-08	4.24 E-05

From the table 8, two main results can be noted.

Firstly, the life years saved is much higher than the life years lost. The table shows that there are more drivers' lives can be saved than the workers' lives lost in the mining industry and electricity generation industry. Meanwhile, there are more severe injuries which can be prevented from traffic accidents than serious injuries happened in the mining industry and electricity generation industry.

Secondly, the potential life years lost is prominent in the table, especially as a result of the emissions during the life cycle of an ECU. After looking into the inventory data, the reason is because the screw component and the resistor component in the PCB board emit some amounts of 2,3,7,8-TCDD, 0.201 g and 1.41 g respectively. Even though the amounts of the dioxin emissions in the study seem not to be large, dioxin has extremely high toxicity potentials, equivalent to1.90E+09 1,4 DCB when it enters air compartment. This, as a result, gives high HTPs values of the screw component and the resistor component, which leads to high potential life years lost in the end.

As stated by WHO (2011), 2,3,7,8-TCDD, i.e. dioxin, is very toxic and can lead to both reproductive and developmental problems. Its tolerable daily intake is only 1- 4 picogram per kg bodyweight (Farland *et al.*, 2000). The already known emission sources include a wide range of manufacturing processes, such as smelting, the processes of some herbicides and pesticides industry and chlorine bleaching of paper pulp. Besides, some natural processes, such as forest fires and volcanic eruptions, can emit dioxin as well (WHO, 2011).

The inventory data of the two previous master thesis shows that the production site of the screw component is in Germany and the production site of the resistor component is in Malaysia and Taiwan. The potential life years lost does not mean that there will be certain number of people die or suffer from severe disease, because there are too many uncertainties regarding the fate, exposure and effect of the dioxin emissions. In addition, the dioxin emission is not unique for the screw and the resistor suppliers of Autoliv since the emission sources exist in a variety of manufacturing processes. However, the figure still signals that Autoliv company can pay attention to the manufacturing processes involving those dioxin emissions and take actions to try to reduce the amounts.

9. Discussions

9. 1 The uncertainties of the results

First of all, as mentioned in the goal and scope chapter, there are several assumptions made in this study. All those assumptions could reduce the reliability of the results.

Secondly, some choices in the thesis study could also affect the final results. For instance, all the fatality and the serious lost time data in the mining industry are obtained from the Government of Western Australia Department of Mines and Petroleum because of the rich mining resources in the region and the transparent records. In reality, mining industry in other countries and regions, such as developing countries, may have much less advanced mining technology and safety awareness. The deaths/kg metal mining and the serious lost time injuries/ kg metal mining may be higher in those countries and regions. However, the thesis study is aimed to obtain some rough numbers to evaluate whether the main objective of an Autoliv's driver airbag system, which is to save lives and prevented severe injuries, is justified.

9.2 Data quality

The collection data can be sorted into three groups, which are (1) data from the two previous master studies, (2) data from scientific papers as well as governmental databases, (3) data from the Autoliv company.

With regard to the data from the two previous master studies, since their inventory data is gathered from Autoliv's inner database as well as suppliers, and their theses have been approved by Chalmers, this group of data is regarded as reliable.

With regard to data from scientific papers and governmental databases, their data is more exposure to critical reviews from researchers and academicians. Therefore, this type of data is regarded as very reliable.

With regard to the figures about the saved lives and the prevented severe injuries, after contacting the life cycle manager in Autoliv, it turns out that the two figures are calculated in terms of NHTSA's estimation approaches. Thus, they could be trustful considering the well-established method used to derive them.

However, it is noticeable that most collected data are generic data, except for the site specific data obtained from the two previous master thesis studies. The heavy use of generic data could reduce the accuracy of the results. But as mentioned before, the thesis study is aimed to gain some rough numbers to evaluate whether the main objective of an Autoliv's driver airbag system is justified. Whether more site specific data is required can then be decided in light of the results of this study.

9. 3 The feasibility of the UNEP/SETAC framework

One significant and interesting issue can be discussed here is the usefulness of the UNEP/SETAC framework. Except for the four general steps included in both E-LCA and S-LCA, i.e. goal and scope, life cycle inventory analysis, life cycle impact assessment, and results and interpretation, the UNEP/SETAC framework does not provide much additional help for the case study.

Firstly, not all concepts suggested by UNEP/SETAC have been used in the case study, such as stakeholder category and subcategories.

Secondly, the indicator applied in the case study, i.e. DALYs, is not included in the long list of the social indicators contained in the UNEP/SETAC framework. The goal of the study could not be fulfilled by choosing any of the indicators contained in the UNEP/SETAC framework.

However, it should be mentioned that one really useful concept suggested by the UNEP/SETAC framework is the “prioritization step”. Considering that some activities and processes are known not to have high social impacts, and that data on social impacts is sometimes scarce, there is a clear merit in being able to prioritize and not necessary include all process in a certain life cycle.

In summary, the UNEP/SETAC framework to some extent can help carry out an S-LCA study since it guides what should be done for each step and suggests the prioritization step. However, because S-LCA is not as standardized as E-LCA, the framework could not help much with regard to how to convert a variety of life cycle inventory data to the indicators used in the life cycle impact assessment. Besides, what indicators should be used is more variable and more case specific in S-LCA than in E-LCA. Therefore, the UNEP/SETAC framework could not guide much in this sense.

10. Conclusions

In summary, two conclusions can be come up with after conducting the S-LCA case study.

First of all, the calculation results show that the main objective of an Autoliv driver airbag system, which is to save lives and prevented severe injuries, seem to be justified because the number of life years saved is larger than the number of life years lost. However, there is a doubt regarding the fulfillment of the objective of the company Autoliv, which are the dioxin emissions during the production of the screw components and the resistor components. Therefore, it is vital for the company Autoliv to check the involved manufacturing processes and see if the emissions could be avoided.

Secondly, the UNEP/SETAC framework did not help much for the case study. How to guide more S-LCA case studies in the future is an issue that needs help from various scholars and organizations.

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Appendix 1 - Generic Analysis

The appendix 1 is available on the Life Cycle Initiative's website (2009). Subcategory indicator from Global Reporting Initiative (GRI) is abbreviation of the indicator from the GRI framework (LA: labor practices and decent work; HR: human right; PR: product responsibility).

Stakeholder categories	Subcategories	Indicator	Unit of measurement
Worker	Freedom of Association and Collective Bargaining	Evidence of restriction to Freedom of association and Collective bargaining	Semi-quantitative
		Evidence of country/sector/ organization or factory non respect or support to freedom of association and collective bargaining	Quantitative, semi-quantitative, qualitative
		GRI: HR5 Operations identified in which the right to exercise freedom of association and collective bargaining may be at significant risk, and actions taken to support these rights	Semi-quantitative, qualitative
	Child Labour	Percentage of children working by country and sector	Quantitative semi-quantitative, qualitative
		GRI HR6 Operations identified as having significant risk for incidents of child labor, and measures taken to contribute to the elimination of child labor	Semi- Quantitative

	Fair Salary	Living Wages by country	Quantitative
		Minimun wage by country	Quantitative
		Non poverty wage by country	Quantitative
	Working Hours	Excessive Hours of work	Quantitative
	Forced Labour	Commodity that are at high risk of having being produce using forced labour	Quantitative, semi-quantitative
		Percentage (estimate) of forced labour by region	Quantitative
		GRI HR7 Operations identified as having significant risk for incidents of forced or compulsory labor, and measures taken to contribute to the elimination of forced or compulsory labor	Quantitative, semi-quantitative, qualitative
	Equal opportunities/ Discrimination	Women in the Labor force participation rate by country	Quantitative, semi-quantitative, qualitative
		Country gender index ranking	Semi-quantitative
	Health and Safety	Occupational accident rate by country	Quantitative,
	Social Benefits/Social Security	Social security expenditure by country and branches of social security (eg. Healthcare, sickness, maternity)	Quantitative, Semi-Quantitative

		GRI LA3 Benefits provided to full-time employees that are not provided to temporary or part-time employees, by major operations	Quantitative
Consumer	Health & Safety	Quality of or number of information/signs on product health and safety	Quantitative, Semi-Quantitative
		Presence of consumer complaints (at national, sectorial, organizational level)	Quantitative, Semi-Quantitative
		GRI PR2 Total number of incidents of non-compliance with regulations and voluntary codes concerning health and safety impacts of products and services and type of outcomes	Quantitative, Semi-Quantitative, Qualitative
	Feedback Mechanism	Presence of feedback mechanisms (e.g. after sale services) (by organization or sector/country)	Quantitative, Semi-Quantitative, Qualitative
		Number of consumer complaints at the sector level	Quantitative, Semi-Quantitative, Qualitative
	Consumer Privacy	Country ranking related to regulations on data-sharing	Semi-Quantitative
		Country ranking related	Semi-Quantitative

		to strength of laws protecting privacy against organizations and government	
		Country ranking related to the strength of regulatory powers to investigate privacy-related complaints	Semi-Quantitative
	Transparency	Presence of a law or norm regarding transparency (by country and/or sector)	Semi-Quantitative, Qualitative
		Sector transparency rating; number of organizations by sector which published a sustainability report	Quantitative, Semi-Quantitative, Qualitative
	End of life responsibility	Strength of national legislation covering product disposal and recycling	Semi-Quantitative
Local community	Access to material resources	Changes in land ownership	Quantitative
		Levels of industrial water use	Quantitative
		Extraction of material resources	Quantitative
		Percent of population (Urban, Rural, Total) with Access to Improved Sanitation Facilities	
	Access to immaterial resources	Patent filings	Quantitative
		Freedom of expression in country of operation	Qualitative, Semi-Quantitative
		Levels of technology transfer	Semi-Quantitative
	Delocalization and Migration	Forced evictions stemming from economic development	Quantitative
		Description of causes for	Qualitative,

		and treatment of internally displaced persons	Semi-Quantitative
		International Migrants as a Percentage of Population	Quantitative
	Cultural Heritage	Cultural Heritage in Urgent Need of Safeguarding	Qualitative
		Prevalence of Racial Discrimination	Qualitative, Semi-Quantitative
	Safe & healthy living conditions	Burden of Disease by Country	Quantitative
		Pollution Levels by Country	Quantitative
		Presence/Strength of Laws on Construction Safety Regulations by Country	Qualitative, Semi-Quantitative
	Respect of indigenous rights	Human Rights Issues Faced by Indigenous Peoples	Qualitative, Semi-Quantitative
		Prevalence of Racial Discrimination	Qualitative, Semi-Quantitative
		Indigenous Land Rights Conflicts/Land Claims	Qualitative, Semi-Quantitative
	Community engagement	Freedom of Peaceful Assembly and Association	Qualitative
		Transparency of Government Policymaking	Semi-Quantitative
		Public Trust of Politicians	Semi-Quantitative
	Local employment	Unemployment Statistics by Country	Quantitative
		Poverty and Working Poverty by Country	Quantitative
		Presence of Local Supply Networks	Semi-Quantitative
	Secure living conditions	State of Security and Human Rights in Country of Operation	Qualitative

		Strength of Public Security in Country of Operation	Semi-Quantitative
Society	Public commitments to sustainability issues	Existence of (legal) obligation on public sustainability reporting	Semi-Quantitative
		Engagement of the sector regarding sustainability	Qualitative, Semi-Quantitative
	Contribution to economic development	Economic situation of the country/region (GDP, economic growth, unemployment, wage level, etc.)	Qualitative/quantitative
		Relevance of the considered sector for the (local) economy (share of GDP, number of employees in relation to size of working population, wage level, etc.)	Qualitative, Quantitative
	Prevention & mitigation of armed conflicts	Is the organization doing business in a region with ongoing conflicts?	Qualitative, Semi-Quantitative
		Is the organization doing business in a sector that features linkages to conflicts, e.g. where the depletion of resources allows significant profits (e.g. extractive industries, forestry, fishery)?	Qualitative, Semi-Quantitative
		Is the organization doing business in a sector otherwise linked to the escalation or de-escalation of conflicts (e.g. conflict escalation	Qualitative, Semi-Quantitative

		by massive pollution, de-escalation by trade beyond conflict boundaries)?	
	Technology development	Sector efforts in technology development	Qualitative
		Research and development costs for the sector	Quantitative
	Corruption	Risk of corruption in the country and/or sub-region	Semi-quantitative (corruption index)
		Risk of corruption in the sector	Qualitative (corruption index)
Value chain actors	Fair competition	National law and regulation	Qualitative, Semi- Quatitative
		Sectoral regulation	Qualitative, Semi- Quatitative
		Sectoral agreement	Qualitative, Semi- Quatitative
		Sector is present in consumer unions	Qualitative, Semi- Quatitative
	Promoting social responsibility	Industry code of conduct in the sector	Semi-quantitative
	Supplier relationships	None	
	Respect of intellectual property rights	General Intellectual Property Rights and related issues associated with the economic sector	Qualitative, Semi-Quantitative

Appendix 2 - Specific Analysis

The appendix 2 is available on the Life Cycle Initiative's website (2009). Subcategory indicator from Global Reporting Initiative (GRI) is abbreviation of the indicator from the GRI framework (LA: labor practices and decent work; HR: human right; PR: product responsibility).

International Labor Organization (ILO) convention also provides relevant standards for labor regarding indicators (C138: Minimum Age Convention, 1973; C182: Worst Forms of Child Labour Convention, 1999).

Stakeholder categories	Subcategories	Indicator	Unit of measurement
worker	Freedom of Association and Collective Bargaining	Employment is not conditioned by any restrictions on the right to collective bargaining	Qualitative, Semi-Quantitative
		Presence of unions within the organization is adequately supported (Availability of facilities to Union, Posting of Union notices, time to exercise the representation functions on paid work hours)	Qualitative, Semi-Quantitative
		Copies of collective bargaining negotiations and agreements are kept on file	Semi-Quantitative
		Workers are free to join unions of their choosing	Qualitative, Semi-Quantitative
		Employee/union representatives are invited to contribute to planning of larger changes in the company, which will affect the working conditions	Semi-Quantitative
		GRI LA5 Minimum notice period(s) regarding significant operational changes, including whether it is specified in collective agreements	Semi-quantitative
		Workers have access to a neutral, binding, and independent dispute resolution procedure	Qualitative
	Child Labour	Absence of working children under the legal age or 15 years old	Quantitative, semi-quantitative,

		(14 years old for developing economies)	qualitative
		Children are not performing work unauthorized by the ILO conventions C138 and C182 (hazardous work)	Quantitative, semi-quantitative, qualitative
		Records on all workers stating names and ages or dates of birth are kept on file	Semi-quantitative
		Working children younger than 15 and under the local compulsory age can attend school	Quantitative, semi-quantitative, qualitative
	Fair Salary	Lowest paid worker, compared to the minimum wage	Quantitative, Semi-quantitative
		The lowest paid workers are considering their wages meets their needs	Quantitative/Semi -quantitative
		Presence of suspicious deductions on wages	Qualitative, Semi-Quantitative
		Regular and documented payment of workers (weekly, bi-weekly)	Qualitative, Semi-Quantitative
	Working Hours	Respect of contractual agreements concerning overtime	Semi-Quantitative
		Clear communication of working hours and overtime arrangements	Semi-Quantitative
		The organization provides flexibility	Qualitative, Semi-Quantitative
	Forced Labour	Workers voluntarily agree upon employment terms. Employment contracts stipulate wage, working time, holidays And terms of resignation. Employment contracts are comprehensible to the workers and are kept on file	Quantitative, Semi-quantitative
		Birth certificate, passport, identity card, work permit or other original documents belonging to the worker are not retained or kept for safety reasons by the organization neither upon hiring nor during	Semi-quantitative

		employment	
		Workers are free to terminate their employment within the prevailing limits	Semi-Quantitative
		Workers are bonded by debts exceeding legal limits to the employer	Quantitative, Semi-Quantitative
	Equal opportunities/Discrimination	Presence of formal policies on equal opportunities	Qualitative， Semi-Quantitative
		GRI HR4 Total numbers of incidents of discrimination and actions taken	Quantitative, Qualitative
		GRI LA 13 Composition of governance bodies and breakdown of employees per category according to gender, age group, minority, group membership, and other indicators of diversity	Quantitative, Semi-Quantitative
		GRI LA 14 Ratio of basic salary of men to women by employee category	Quantitative, Semi-Quantitative
	Health and Safety	Number/ percentage of injuries or fatal accidents in the organization by occupation	Quantitative
		Presence of a formal policy concerning health and safety	Semi-Quantitative
		Adequate general occupational safety measures are taken. - Preventive measures and emergency protocols exist regarding accidents & injuries. - Preventive measures and emergency protocols exist regarding pesticide & chemical exposure - Appropriate protective gear is required in all applicable situations. -	Qualitative, Semi-Quantitative
		Number of (serious/non-serious) Occupational Safety and Health Administration (OSHA) violations reported within the past 3 years and status of violations	Quantitative, Semi-quantitative

		GRI LA8 Education, training, counselling, prevention and risk control programs in place to assist workforce members, their families, or community members regarding serious diseases.	Qualitative, Semi-quantitative
	Social Benefits/Social Security	List and provide short description of social benefits provided to the workers (eg. Health insurance, pension fund, child care, education, accommodation etc.)	Qualitative
		Evidence of violations of obligations to workers under labour or social security laws and employment regulations	Quantitative, Semi-quantitative, Qualitative
		Percentage of permanent workers receiving paid time-off	Quantitative, Semi-Quantitative
Consumer	Health & Safety	Number of consumer complaints	Quantitative, Semi-quantitative
		Presence of Management measures to assess consumer health and safety	Qualitative
		Quality of labels of health and safety requirements	Qualitative, Semi-Quantitative
	Feedback Mechanism	Presence of a mechanism for customers to provide feedback	Quantitative, Qualitative and semi-quantitative
		Management measures to improve feedback mechanisms	Quantitative, Qualitative, Smi-quantitative
		GRI PR5 Practices related to customer satisfaction, including results of surveys measuring customer satisfaction	Quantitative, Qualitative, Smi-quantitative
	Consumer Privacy	Strength of internal management system to protect consumer privacy, in general	Qualitative, Semi-Quantitative
		Number of consumer complaints related to breach of privacy or loss of data within the last year	Quantitative
		Number of complaints by	Quantitative

		regulatory bodies related to breach of consumer privacy or loss of data within the last year	
	Transparency	Non-compliance with regulations regarding transparency	Qualitative, Semi-Quantitative
		Consumer complaints regarding transparency	Qualitative, Semi-Quantitative
		Publication of a sustainability report	Qualitative, Semi-Quantitative
	End of life responsibility	Level of management attention to end-of-life impacts	Qualitative, Semi-Quantitative
		Do internal management systems ensure that clear information is provided to consumers on end-of-life options (if applicable)	Semi-Quantitative
Local community	Access to material resources	Has the organization developed project-related infrastructure with mutual community access and benefit	Qualitative, Semi-Quantitative
		Strength of organizational risk assessment with regard to potential for material resource conflict	Qualitative, Semi-Quantitative
		Does the organization have a certified environmental management system	Semi-Quantitative
	Access to immaterial resources	Annual arrests connected to protests of organization actions	Quantitative
		Do policies related to intellectual property respect moral and economic rights of the community?	Qualitative, Semi-Quantitative
		Presence/strength of community education initiatives	Qualitative, Semi-Quantitative
	Delocalization and Migration	Number of individuals who resettle (voluntarily and involuntarily) that can be attributed to organization	Quantitative
		Strength of organizational policies related to resettlement (e.g. due diligence and procedural safeguards)	Qualitative, Semi-Quantitative

		Strength of organizational procedures for integrating migrant workers into the community	Qualitative, Semi-Quantitative
	Cultural Heritage	Strength of Policies in Place to Protect Cultural Heritage	Qualitative, Semi-Quantitative
		Presence/Strength of Organizational Program to include Cultural Heritage Expression in Product Design/Production	Qualitative, Semi-Quantitative
		Is Relevant Organizational Information Available to Community Members in their Spoken Language(s)?	Semi-Quantitative
	Safe & healthy living conditions	Management oversight of structural integrity	Qualitative, Semi-Quantitative
		Organization efforts to strengthen community health (e.g. through shared community access to organization health resources)	Qualitative, Semi-Quantitative
		Management effort to minimize use of hazardous substances	Qualitative, Semi-Quantitative
	Respect of indigenous rights	Organization Operates in a Region where there is Land Rights Conflict with Indigenous Groups	Semi-Quantitative
		Strength of Policies in Place to Protect the Rights of Indigenous Community Members	Qualitative, Semi-Quantitative
		Annual Meetings Held with Indigenous Community Members	Quantitative
		Response to Charges of Discrimination against Indigenous Community Members	Qualitative, Semi-Quantitative
	Community engagement	Strength of written policies on community engagement at organization level	Qualitative, Semi-Quantitative
		Diversity of community stakeholder groups that engage with the organization	Qualitative, Semi-Quantitative

		Number and quality of meetings with community stakeholders	Quantitative, Qualitative, Semi-Quantitative
		Organizational support (volunteer-hours or financial) for community initiatives	Quantitative
	Local employment	Percentage of workforce hired locally	Quantitative
		Strength of policies on local hiring preferences	Qualitative, Semi-Quantitative
		Percentage of spending on locally-based suppliers	Quantitative
	Secure living conditions	Management policies related to private security personnel	Qualitative, Semi-Quantitative
		Number of legal complaints per year against the organization with regard to security concerns	Quantitative
		Number of casualties and injuries per year ascribed to the organization	Quantitative
Society	Public commitments to sustainability issues	Presence of publicly available documents as promises or agreements on sustainability issues	Qualitative, Semi-Quantitative
		Complaints issued related to the non fulfillment of promises or agreements by the organization by the local community or other stakeholders at OECD contact points or Global Reporting Initiative.	Qualitative, Semi-Quantitative
		Presence of mechanisms to follow-up the realisation of promises	Quantitative, Semi-Quantitative
		The organization has pledged to comply with the Global Compact principles and has engaged itself to present yearly Communication On Progress	Semi-Quantitative
		Implementation/signing of Principles or other codes of conduct (Sullivan Principles, Caux	

		Round Table, UN principles, etc.)	
	Contribution to economic development	Contribution of the product/service/organization to economic progress (revenue, gain, paid wages, R+D costs in relation to revenue, etc.)	Qualitative, Quantitative
	Prevention & mitigation of armed conflicts	Organization's role in the development of armed conflicts	Qualitative, Semi-Quantitative
		Disputed products	Quantitative, Semi-Quantitative
	Technology development	Involvement in technology transfer program or projects	Qualitative, Semi-Quantitative
		Partnerships in research and development	Qualitative, Semi-Quantitative
		investments in technology development/ technology transfer	Quantitative
	Corruption	Formalised commitment of the organization to prevent corruption, referring to recognised standards.	Qualitative, Semi-Quantitative
		The organization carries out an anti-corruption program	Qualitative, Semi-Quantitative
		The organization installs or co-operates with internal and external controls to prevent corruption	Qualitative, Semi-Quantitative
		Written documents on active involvement of the organization in corruption and bribery; convictions related to corruption and bribery	Qualitative, Semi-Quantitative
		Financial damages	Quantitative
Value chain actors	Fair competition	Legal actions pending or completed during the reporting period regarding anti-competitive behavior and violations of anti-trust and monopoly legislation in which the reporting organization has been identified as a participant. (GRI SO7)	Qualitative, Quantitative, Semi-Quantitative
		Membership in alliances that	Qualitative,

		behave in an anti-competitive way	Semi-Quantitative
		Documented statement or procedures (policy, strategy etc.) to prevent engaging in or being complicit in anti-competitive behavior	Qualitative, Semi-Quantitative
		Employee awareness of the importance of compliance with competition legislation and fair competition.	Quantitative, Semi-Quantitative
	Promoting social responsibility	Presence of explicit code of conduct that protect human rights of workers among suppliers	Semi-Quantitative
		Percentage of suppliers the enterprise has audited with regard to social responsibility in the last year	Quantitative
		Membership in an initiative that promotes social responsibility along the supply chain	Semi-Quantitative
	Supplier relationships	Absence of coercive communication with suppliers	Qualitative, Semi-Quantitative
		Sufficient lead time	Qualitative, Semi-Quantitative
		Reasonable volume fluctuations	Qualitative, Semi-Quantitative
		Payments on time to suppliers	Semi-quantitative
	Respect of intellectual property rights	Organization’s policy and practice	Qualitative, Semi-Quantitative
		Use of local intellectual property	Quantitative, Semi-Quantitative Quantitative

Appendix 3 - The three attribution methods

The appendix 3 is from the paper: Estimating the Lives Saved by Safety Belts and Air Bags (Glassbrenner, 2003). The appendix 3 shows the restraint configurations, the equations for the three attribution methods and the corresponding notations.

Method	Restraint	Lives saved
Belt-maximizing	Seatbelt	$\sum_{\mathrm{belt(i)=1}} \frac{\mathrm{e_i(belt)F_i}}{1-\mathrm{e_i(used)}}$
	Airbag	$\frac{\mathrm{e(bag \mid belt)}}{1-\mathrm{e(bag \mid belt)}} \sum_{\substack{\mathrm{belt(i)=1} \\ \mathrm{bag(i)=1}}} \mathrm{F_i} + \frac{\mathrm{e(bag)}}{1-\mathrm{e(bag)}} \sum_{\substack{\mathrm{belt(i)=0} \\ \mathrm{bag(i)=1}}} \mathrm{F_i}$
Restraint-neutral	Seatbelt	$\sum_{\substack{\mathrm{belt(i)=1} \\ \mathrm{bag(i)=0}}} \frac{\mathrm{e_i(belt)F_i}}{1-\mathrm{e_i(belt)}} + \sum_{\substack{\mathrm{belt(i)=1} \\ \mathrm{bag(i)=1}}} \frac{\mathrm{e_i(belt)}}{\mathrm{e_i(belt)+e(bag)}} \frac{\mathrm{e_i(system)F_i}}{1-\mathrm{e_i(system)}}$
	Airbag	$\frac{\mathrm{e(bag)}}{1-\mathrm{e(bag)}} \sum_{\substack{\mathrm{belt(i)=0} \\ \mathrm{bag(i)=1}}} \mathrm{F_i} + \sum_{\substack{\mathrm{belt(i)=1} \\ \mathrm{bag(i)=1}}} \frac{\mathrm{e(belt)}}{\mathrm{e_i(belt)+e(bag)}} \frac{\mathrm{e_i(system)F_i}}{1-\mathrm{e_i(system)}}$
Bag-maximizing	Seatbelt	$\sum_{\substack{\mathrm{belt(i)=1} \\ \mathrm{bag(i)=1}}} \frac{\mathrm{e_i((belt \mid bag))F_i}}{1-\mathrm{e_i((belt) \mid bag)}} + \sum_{\substack{\mathrm{belt(i)=1} \\ \mathrm{bag(i)=0}}} \frac{\mathrm{e_i(belt)F_i}}{1-\mathrm{e_i(belt)}}$
	Airbag	$\mathrm{e(bag)} \sum_{\mathrm{bag(i)=1}} \frac{\mathrm{F_i}}{1-\mathrm{e_i(used)}}$

Notation	Definition
e(bag)	the effectiveness of air bags, i.e. 14%
e(bag | belt)	the residual effectiveness of air bags, i.e. 11%
R	the set of all restraint configurations
In the remaining definitions, i denotes a restraint configuration	
F_i	the fatality count for i
belt(i)	1 if a belt is used in i, and 0 otherwise
bag(i)	1 if a bag is present and the occupant is over 12 in i, 0 otherwise
e_i(belt)	the effectiveness of the belt in I
e_i(system)	e_i(belt) if bag(i)=0, otherwise the effectiveness of the belt-bag system in i
e_i(used)	the effectiveness of the restraint (belt, bag, or belt-bag) used in i
e_i(belt | bag)	$\frac{e_i(\text{system}) - e(\text{bag})}{1 - e(\text{bag})}$ when bag(i)=1, otherwise undefined

Restraint Configurations	
Coordinate	**Values**
Vehicle type	passenger car; light truck or van
Seating position	driver, right front passenger, front center, rear outboard, rear center
Belt type	3-point, 2-point, lap
Belt used?	yes, no
Air bag?	yes, no
Age	5-12, 13 or older

Appendix 4 – Human toxicity potentials of 182 substances related to the initial emission compartments and impact categories

The appendix 4 is from the paper: Priority assessment of toxic substances in life cycle assessment. Part I: Calculation of toxicity potentials for 182 substances with the nested multi-media fate, exposure and effects model USES-LCA (Huijbregts *et al.* 2000). The unit of the human toxicity potentials is 1-4 $DCB_{eq.}$

No	Name	air	water	soil
Metals				
1	Antimony	6.70E+03	5.10E+03	8.90E+03
2	Arsenic	3.50E+05	9.50E+02	3.20E+04
3	Barium	7.60E+02	6.30E+02	3.60E+02
4	Beryllium	2.30E+05	1.40E+04	1.30E+04
5	Cadmium	1.50E+05	2.30E+01	2.00E+04
6	Chromium III	6.50E+02	2.10E+00	5.10E+03
7	Chromium VI	3.40E+06	3.40E+00	8.50E+03
8	Cobalt	1.70E+04	9.70E+01	2.40E+03
9	Copper	4.30E+03	1.30E+00	9.40E+01
10	Lead	4.70E+02	1.20E+01	3.30E+03
11	Mercury	6.00E+03	1.40E+03	5.90E+03
12	Methyl-mercury	5.80E+04	1.50E+04	2.00E+04
13	Molybdenum	5.40E+03	5.50E+03	6.20E+03
14	Nickel	3.50E+04	3.30E+02	2.70E+03
15	Selenium	4.80E+04	5.60E+04	2.90E+04

16	Thallium	4.30E+05	2.30E+05	2.00E+06
17	Tin	1.70E+00	1.70E-02	1.30E+01
18	Vanadium	6.20E+03	3.20E+03	1.90E+04
19	Zinc	1.00E+02	5.80E-01	6.40E+01
Inorganic				
20	Ammonia	1.00E-01	x	x
21	Hydrogen sulphide	2.20E-01	x	x
22	Hydrogen chloride	5.00E-01	x	x
23	Nitrogen dioxide	1.20E+00	x	x
24	Sulphur dioxide	3.10E-01	x	x
25	PM10	9.60E-02	x	x
Non- aromatics				
26	Acrylonitrile	3.40E+03	7.10E+03	4.90E+05
27	Acrolein	5.70E+01	5.90E+01	2.30E+02
28	1,3-Butadiene	2.20E+03	7.00E+03	3.10E+03
29	Carbon disulfide	2.40E+00	2.40E+00	3.60E+00
30	Ethylene	6.40E-01	6.50E-01	7.80E-01
31	Formaldehyde	8.30E-01	3.70E-02	2.30E+00
32	Propylene oxide	1.30E+03	2.60E+03	2.20E+05
Aromatics				
33	Benzene	1.90E+03	1.80E+03	1.50E+04
34	Toluene	3.30E-01	3.00E-01	3.50E-01
35	Styrene	4.70E-02	8.50E-02	4.80E-02
36	Phenol	5.20E-01	4.90E-01	1.90E+00

37	Ethyl-benzene	9.70E-01	8.30E-01	7.50E-01
38	m-Xylene	2.70E-02	3.40E-01	3.80E+00
39	o-Xylene	1.20E-01	4.20E-01	5.00E+00
40	p-Xylene	4.30E-01	3.50E-01	3.00E+00
41	Butylbenzyl-phtalate	1.00E+01	8.60E-02	3.10E-01
42	Di(2ethylhexyl)-phtalate	2.60E+00	9.10E-01	1.80E+00
43	Dibutyl-phtalate	2.50E+01	5.40E-01	1.30E+00
44	Diethyl-phtalate	3.20E-01	1.40E-01	5.70E-02
45	Dihexyl-phtalate	7.00E+03	1.40E+04	1.20E+03
46	Diisooctyl-phtalate	3.10E+02	1.80E+01	3.20E+01
47	Diisodecyl-phtalate	4.60E+01	1.90E+01	1.10E+02
48	Dimethyl-phtalate	2.10E+02	7.20E+00	2.80E+01
49	Dioctyl-phtalate	1.90E+01	6.30E+00	8.60E+00
50	Phtalicanhydride	4.10E-01	1.10E-04	1.00E-02
Polycyclic aromatic				
51	Naphtalene	8.10E+00	5.60E+00	4.80E+00
52	Anthracene	5.20E-01	2.10E+00	5.10E-01
61	Carcinogenic PAHs	5.70E+05	2.80E+05	7.10E+04
Halogenated non-aromatics				
62	Dichloro-methane	2.00E+00	1.80E+00	2.40E+00
63	Trichloro-methane	1.30E+01	1.30E+01	1.40E+01
64	Tetrachloro-methane	2.20E+02	2.20E+02	2.20E+02
65	1,2-Dichloro-ethane	6.80E+00	2.80E+01	1.30E+03
67	1,1,1-Trichloro-ethane	1.70E+01	1.70E+01	1.60E+01

67	Trichloro-ethylene	3.40E+01	3.30E+01	3.20E+01
68	Tetrachloro-ethylene	5.50E+00	5.70E+00	6.40E+00
69	Vinylchloride	8.40E+01	1.40E+02	5.20E+02
70	Hexachloro-1,3-butadiene	7.90E+04	8.00E+04	3.00E+04
Halogenated aromatics				
71	Chloro-benzene	9.20E+00	9.10E+00	7.10E+00
72	1,2-Dichloro-benzene	9.10E+00	8.90E+00	7.30E+00
73	1,3-Dichloro-benzene	6.20E+01	7.40E+01	2.50E+02
74	1,4-Dichloro-benzene	1.00E+00	1.10E+00	2.90E+00
75	1,2,3-Trichloro-benzene	1.30E+02	1.30E+02	5.60E+01
76	1,2,4-Trichloro-benzene	1.20E+02	1.20E+02	4.20E+01
77	1,3,5-Trichloro-benzene	1.20E+02	1.20E+02	6.90E+01
78	1,2,3,4-Tetra-chlorobenzene	5.00E+01	1.60E+02	8.00E+01
79	1,2,3,5-Tetra-chlorobenzene	4.60E+01	9.20E+01	1.80E+01
80	1,2,4,5-Tetra-chlorobenzene	3.50E+01	1.80E+02	8.40E+01
81	Pentachloro-benzene	4.10E+02	1.20E+03	4.50E+03
82	Hexachloro-benzene	3.20E+06	5.60E+06	3.30E+07
83	2-Chlorophenol	2.20E+01	7.00E+01	8.30E+00
84	2,4-Dichloro-phenol	9.50E+01	1.60E+01	7.40E+02
85	2,4,5-Trichloro-phenol	8.30E+00	4.50E+01	5.30E+00
86	2,4,6-Trichloro-phenol	1.40E+04	9.10E+03	1.80E+03
87	2,3,4,6-Tetra-chlorophenol	2.90E+02	3.50E+01	3.10E+01
88	Pentachloro-phenol	5.10E+00	7.20E+00	1.50E-01
89	Benzylchloride	3.50E+03	2.40E+03	5.50E+03

90	3-Chloroaniline	1.70E+04	3.50E+03	3.00E+04
91	4-Chloroaniline	2.60E+02	2.90E+03	3.50E+04
92	3,4-Dichloroaniline	2.20E+02	1.30E+02	1.70E+03
93	1-Chloro-4-nitro-benzene	1.20E+03	1.70E+03	2.20E+04
94	Pentachloroni-trobenzene	1.90E+02	9.10E+01	7.20E+01
95	2,3,7,8-TCDD	1.90E+09	8.60E+08	1.30E+09
Pesticides				
96	Acephate	3.10E+00	2.10E+00	2.20E+01
97	Aldicarb	7.20E+01	6.10E+01	5.10E+02
98	Aldrin	1.90E+01	6.00E+03	4.70E+03
99	Anilazine	7.20E-02	2.40E-01	8.00E-02
100	Atrazine	4.50E+00	4.60E+00	2.10E+01
101	Azinphos-ethyl	2.00E+02	4.60E+02	7.60E+02
102	Azinphos-methyl	1.40E+01	2.50E+00	3.90E+01
103	Benomyl	2.10E-02	1.40E-01	4.30E-01
104	Bentazone	2.10E+00	7.30E-01	1.50E+01
105	Bifenthrin	1.90E+01	9.80E+01	2.90E+01
106	Captafol	8.70E+01	5.00E+02	9.60E+02
107	Captan	5.90E-01	5.30E-03	9.70E-02
108	Carbaryl	3.20E+00	4.70E+00	2.10E+01
109	Carbendazim	1.90E+01	2.50E+00	1.40E+02
110	Carbofuran	2.00E+02	5.60E+01	1.40E+03
111	Chlordane	6.70E+03	7.40E+02	2.80E+03
112	Chlorfenvinphos	2.70E+02	8.10E+02	1.20E+03

113	Chloridazon	1.30E-02	1.40E-01	2.20E+00
114	Chlorothalonil	8.40E+00	6.70E+00	9.40E-01
115	Chlorpropham	3.40E-01	1.00E+00	2.10E+00
116	Chlorpyriphos	2.10E+01	4.40E+01	1.40E+01
117	Coumaphos	7.80E+02	1.00E+04	1.10E+04
118	Cyanazine	3.50E+00	6.00E+00	2.40E+01
119	Cypermethrin	1.70E+02	5.50E+00	5.20E+03
120	Cyromazine	3.80E+01	5.40E+00	2.80E+02
121	2,4-D	6.60E+00	3.50E+00	4.70E+01
122	DDT	1.10E+02	3.70E+01	2.70E+02
123	Deltamethrin	1.60E+00	2.80E+00	1.60E-01
124	Demeton	7.10E+01	7.20E+02	5.70E+03
125	Desmetryn	9.50E+01	5.00E+01	6.50E+02
126	Diazinon	5.90E+01	6.60E+01	1.20E+02
127	Dichlorprop	1.10E+00	2.40E+01	4.50E+00
128	Dichlorvos	1.00E+02	3.40E-01	9.70E-01
129	Dieldrin	1.30E+04	4.50E+04	7.60E+03
130	Dimethoate	4.40E+01	1.80E+01	3.20E+02
131	Dinoseb	3.60E+03	1.60E+02	5.60E+02
132	Dinoterb	1.70E+02	2.50E+00	3.60E-01
133	Disulfothon	2.90E+02	3.40E+02	1.70E+02
134	Diuron	2.10E+02	5.30E+01	1.30E+03
135	DNOC	1.60E+02	5.90E+01	2.80E+02
136	Endosulfan	6.70E+00	1.70E+01	2.60E-01

137	Endrin	1.20E+03	6.00E+03	8.40E+03
138	Ethoprophos	1.10E+03	1.80E+03	5.70E+03
139	Fenitrothion	5.90E+00	2.20E+01	1.20E+01
140	Fentin acetate	2.20E+03	8.80E+02	7.20E+01
141	Fentin chloride	8.40E+02	9.60E+02	1.30E+02
142	Fentin hydroxide	8.50E+02	8.70E+02	8.80E+01
143	Fenthion	6.30E+01	9.30E+01	3.00E+01
144	Folpet	2.00E+00	8.60E+00	1.30E+01
145	Glyphosate	3.10E-03	6.60E-02	1.50E-02
146	Heptachlor	4.00E+01	3.40E+03	6.70E+02
147	Heptenophos	2.30E+01	1.30E+00	3.40E+00
148	Iprodione	2.80E-01	1.80E-01	1.80E+00
149	Isoproturon	1.30E+02	1.30E+01	9.60E+02
150	Lindane	6.10E+02	8.30E+02	4.90E+02
151	Linuron	1.40E+01	1.10E+02	1.70E+02
152	Malathion	3.50E-02	2.40E-01	2.60E-02
153	MCPA	1.50E+01	1.50E+01	1.00E+02
154	Mecoprop	1.20E+02	2.00E+02	7.40E+02
155	Metamitron	8.80E-01	1.60E-01	6.50E+00
156	Metazachlor	6.80E+00	1.70E+00	4.90E+01
157	Methabenzthi-azuron	7.10E+00	2.60E+00	5.10E+01
158	Methomyl	6.20E+00	3.30E+00	4.30E+01
159	Methylbromide	3.50E+02	3.00E+02	2.60E+02
160	Metobromuron	5.10E+01	8.00E+00	4.10E+02

161	Metolachlor	2.60E+00	5.50E-01	1.10E+01
162	Mevinphos	1.00E+00	1.10E+01	5.70E+00
163	Oxamyl	1.40E+00	3.60E-01	1.00E+01
164	Oxydemethon-methyl	1.20E+02	7.40E+01	6.10E+02
165	Parathion-ethyl	3.30E+00	3.10E+01	2.90E+00
166	Parathion-methyl	5.30E+01	1.00E+02	2.40E+01
167	Permethrin	8.50E-01	2.30E+01	1.10E+01
168	Phoxim	9.70E-01	1.20E+01	2.50E+01
169	Pirimicarb	3.40E+00	1.70E+00	2.60E+01
170	Propachlor	1.20E+01	1.60E+00	1.50E+01
171	Propoxur	3.70E+01	1.30E+00	2.70E+02
172	Pyrazophos	2.50E+01	5.30E+01	5.10E+01
173	Simazine	3.30E+01	9.70E+00	2.10E+02
174	2,4,5-T	8.90E-01	1.90E+00	5.80E+00
175	Thiram	1.90E+01	3.30E+00	7.90E+00
176	Tolclophos-methyl	6.00E-02	1.00E+00	1.10E+01
177	Tri-allaat	9.70E+00	8.30E+01	5.80E+00
178	Triazophos	2.10E+02	3.20E+02	1.20E+03
179	Tributyltin-oxide	7.50E+03	3.40E+03	3.90E+02
180	Trichlorfon	4.40E+00	3.70E-01	3.30E+01
181	Triuarin	1.70E+00	9.70E+01	1.20E+02
182	Zineb	4.80E+00	1.70E+00	2.00E+01

Appendix 5 – Human toxicity potentials of harmful substances in airbag

The appendix 5 shows the calculation results of the second step of HTPs for the driver airbag, which is to use the specific factor (weighted RCR_{ref}) in the appendix 4 for each selected toxic x substance to calculate their HTP_x.

Label (Total: 1.25E+02 g 1,4-DCB_{eq})		
	Emission to air	**Unit**
Arsenic	1.24E+02	g 1,4 - DCB_{eq}
Copper	8.60E-04	g 1,4 - DCB_{eq}
Hydrogen chloride	2.75E-05	g 1,4 - DCB_{eq}
Hydrogen sulfide	1.76E-07	g 1,4 - DCB_{eq}
Lead	1.32E-03	g 1,4 - DCB_{eq}
Mercury	2.40E-03	g 1,4 - DCB_{eq}
Nickel	7.00E-03	g 1,4 - DCB_{eq}
PAH	1.14E-01	g 1,4 - DCB_{eq}
Phenol	4.56E-06	g 1,4 - DCB_{eq}
Sulphur dioxide	2.06E-03	g 1,4 - DCB_{eq}
Toluene	0.00E+00	g 1,4 - DCB_{eq}
Vanadium	0.00E+00	g 1,4 - DCB_{eq}
Zinc	2.00E-05	g 1,4 - DCB_{eq}

Nut (Total: 6.07E+00 g 1,4-DCB_{eq})		
	Emission to air	**Unit**
Arsenic	5.89E+00	g 1,4 - DCB_{eq}
Hydrogen chloride	1.21E-07	g 1,4 - DCB_{eq}
Hydrogen sulfide	5.46E-08	g 1,4 - DCB_{eq}
Lead	5.82E-02	g 1,4 - DCB_{eq}
Mercury	7.07E-03	g 1,4 - DCB_{eq}
PAH	8.32E-02	g 1,4 - DCB_{eq}
Sulphur dioxide	1.55E-02	g 1,4 - DCB_{eq}
Zinc	1.13E-02	g 1,4 - DCB_{eq}

Cushion (Total: 3.32E+02 g 1,4-DCB_{eq})		
	Emission to air	**Unit**
Chromium III	1.28E-01	g 1,4 - DCB_{eq}
Copper	3.45E+00	g 1,4 - DCB_{eq}
Hydrogen chloride	4.49E-02	g 1,4 - DCB_{eq}
Hydrogen sulfide	4.05E-03	g 1,4 - DCB_{eq}
Lead	2.00E+00	g 1,4 - DCB_{eq}
Mercury	2.07E-01	g 1,4 - DCB_{eq}
Molybdenum	1.63E+00	g 1,4 - DCB_{eq}
Nickel	3.62E+01	g 1,4 - DCB_{eq}
PAH	2.56E+02	g 1,4 - DCB_{eq}

Phenol	7.02E-03	g 1,4 - DCB_{eq}
Sulphur dioxide	2.37E+00	g 1,4 - DCB_{eq}
Toluene	7.04E-04	g 1,4 - DCB_{eq}
Vanadium	2.92E+01	g 1,4 - DCB_{eq}
Zinc	3.99E-01	g 1,4 - DCB_{eq}

Can (Total: 2.48E+02 g 1,4-DCB_{eq})		
	Emission to air	**Unit**
Chromium III	3.22E-04	g 1,4 - DCB_{eq}
Copper	9.02E-01	g 1,4 - DCB_{eq}
Hydrogen chloride	4.97E-04	g 1,4 - DCB_{eq}
Hydrogen sulfide	1.88E-04	g 1,4 - DCB_{eq}
Lead	8.84E-01	g 1,4 - DCB_{eq}
Mercury	2.24E-02	g 1,4 - DCB_{eq}
Molybdenum	9.93E+00	g 1,4 - DCB_{eq}
Nickel	2.35E+02	g 1,4 - DCB_{eq}
PAH	1.02E+00	g 1,4 - DCB_{eq}
Phenol	8.36E-07	g 1,4 - DCB_{eq}
Sulphur dioxide	8.43E-01	g 1,4 - DCB_{eq}
Toluene	1.88E-06	g 1,4 - DCB_{eq}
Vanadium	6.63E-02	g 1,4 - DCB_{eq}
Zinc	9.97E-02	g 1,4 - DCB_{eq}

Cover (Total: 4.41E+01 g 1,4-DCB$_{eq}$)		
	Emission to air	**Unit**
Cadmium	2.93E+01	g 1,4 - DCB$_{eq}$
Chromium III	2.19E-04 0	g 1,4 - DCB$_{eq}$
Copper	7.00E-02	g 1,4 - DCB$_{eq}$
Hydrogen chloride	2.29E-03	g 1,4 - DCB$_{eq}$
Hydrogen sulfide	1.68E-05	g 1,4 - DCB$_{eq}$
Lead	1.59E-01	g 1,4 - DCB$_{eq}$
Mercury	2.39E-01	g 1,4 - DCB$_{eq}$
Molybdenum	2.32E-03	g 1,4 - DCB$_{eq}$
Nickel	1.32E+00	g 1,4 - DCB$_{eq}$
PAH	1.24E+01	g 1,4 - DCB$_{eq}$
Phenol	7.33E-04	g 1,4 - DCB$_{eq}$
Sulphur dioxide	6.09E-01	g 1,4 - DCB$_{eq}$
Toluene	4.94E-07	g 1,4 - DCB$_{eq}$
Vanadium	2.91E-02	g 1,4 - DCB$_{eq}$
Zinc	1.69E-03	g 1,4 - DCB$_{eq}$

Inflator (Total: 7.35E+02 g 1,4-DCB_{eq})		
	Emission to air	**Unit**
Cadmium	6.34E+00	g 1,4 - DCB_{eq}
Chromium III	4.40E-03	g 1,4 - DCB_{eq}
Copper	4.26E+03	g 1,4 - DCB_{eq}
Hydrogen chloride	3.96E-03	g 1,4 - DCB_{eq}
Hydrogen sulfide	1.51E-05	g 1,4 - DCB_{eq}
Lead	1.92E+00	g 1,4 - DCB_{eq}
Mercury	2.54E-01	g 1,4 - DCB_{eq}
Molybdenum	2.82E+01	g 1,4 - DCB_{eq}
Nickel	6.66E+02	g 1,4 - DCB_{eq}
PAH	2.72E+01	g 1,4 - DCB_{eq}
Phenol	1.47E-05	g 1,4 - DCB_{eq}
Sulphur dioxide	4.21E+00	g 1,4 - DCB_{eq}
Toluene	1.93E-06	g 1,4 - DCB_{eq}
Vanadium	5.57E-02	g 1,4 - DCB_{eq}
Zinc	1.34E+00	g 1,4 - DCB_{eq}

Appendix 6 – Human toxicity potentials of harmful substances in ECU

The appendix 6 shows calculation results of the second step of HTPs for the ECU, which is to use the specific factor (weighted RCR_{ref}) in the appendix 4 for each selected toxic substance x to calculate their HTP_x.

Label (Total: 4.01E-03 g 1,4-DCB_{eq})		
	Emission to air	**Unit**
1,2-Dichloro-ethane	1.44E-12	g 1,4 - DCB_{eq}
2,3,7,8-TCDD	2.94E-24	g 1,4 - DCB_{eq}
Ammonia	3.93E-13	g 1,4 - DCB_{eq}
Arsenic	1.35E-06	g 1,4 - DCB_{eq}
Benzene	4.38E-06	g 1,4 - DCB_{eq}
Cadmium	9.12E-08	g 1,4 - DCB_{eq}
Carbon disulfide	2.08E-12	g 1,4 - DCB_{eq}
Carcinogenic PAHs	3.75E-03	g 1,4 - DCB_{eq}
Copper	4.84E-11	g 1,4 - DCB_{eq}
Dichloro-methane	6.02E-15	g 1,4 - DCB_{eq}
Ethyl-benzene	4.80E-10	g 1,4 - DCB_{eq}
Hydrogen chloride	2.48E-06	g 1,4 - DCB_{eq}
Hydrogen sulphide	3.84E-11	g 1,4 - DCB_{eq}
Lead	1.17E-08	g 1,4 - DCB_{eq}
Mercury	3.20E-07	g 1,4 - DCB_{eq}
Nickel	2.30E-04	g 1,4 - DCB_{eq}

PM10	1.10E-06	g 1,4 - DCB_{eq}
Selenium	5.76E-14	g 1,4 - DCB_{eq}
Styrene	1.56E-14	g 1,4 - DCB_{eq}
Sulphur dioxide	1.71E-05	g 1,4 - DCB_{eq}
Zinc	1.09E-10	g 1,4 - DCB_{eq}

Housing (Total: 2.00E+02 g 1,4-DCB_{eq})		
	Emission to air	**Unit**
Carcinogenic PAHs	2.56E+03	g 1,4 - DCB_{eq}
Hydrogen chloride	1.82E-01	g 1,4 - DCB_{eq}
Mercury	3.54E-01	g 1,4 - DCB_{eq}
Sulphur dioxide	5.77E+00	g 1,4 - DCB_{eq}

Cover (Total: 9.00E+00 g 1,4-DCB_{eq})		
	Emission to air	**Unit**
1,3,5-Trichloro-benzene	1.53E-09	g 1,4 - DCB_{eq}
2,3,7,8-TCDD	4.31E+00	g 1,4 - DCB_{eq}
Acrolein	4.70E-08	g 1,4 - DCB_{eq}
Ammonia	3.68E-05	g 1,4 - DCB_{eq}
Arsenic	1.65E+00	g 1,4 - DCB_{eq}
Barium	1.41E-02	g 1,4 - DCB_{eq}
Benzene	7.09E-02	g 1,4 - DCB_{eq}

Beryllium	2.49E-02	g 1,4 - DCB_{eq}
Cadmium	1.89E-01	g 1,4 - DCB_{eq}
Carcinogenic PAHs	1.30E-01	g 1,4 - DCB_{eq}
Chromium VI	-2.08E-04	g 1,4 - DCB_{eq}
Cobalt	2.23E-02	g 1,4 - DCB_{eq}
Copper	1.40E-01	g 1,4 - DCB_{eq}
Ethyl-benzene	6.78E-06	g 1,4 - DCB_{eq}
Formaldehyde	1.31E-05	g 1,4 - DCB_{eq}
Hexachloro-benzene	9.62E-06	g 1,4 - DCB_{eq}
Hydrogen chloride	1.42E-03	g 1,4 - DCB_{eq}
Lead	3.94E-03	g 1,4 - DCB_{eq}
Mercury	1.79E-02	g 1,4 - DCB_{eq}
Molybdenum	4.57E-03	g 1,4 - DCB_{eq}
Naphtalene	1.64E-06	g 1,4 - DCB_{eq}
Nickel	1.63E+00	g 1,4 - DCB_{eq}
Nitrogen dioxide	1.87E-02	g 1,4 - DCB_{eq}
Pentachloro-benzene	3.30E-09	g 1,4 - DCB_{eq}
Pentachloro-phenol	6.61E-12	g 1,4 - DCB_{eq}
Phenol	3.01E-08	g 1,4 - DCB_{eq}
PM10	6.04E-04	g 1,4 - DCB_{eq}
Selenium	9.23E-02	g 1,4 - DCB_{eq}
Sulphur dioxide	1.04E-02	g 1,4 - DCB_{eq}
Thallium	1.87E-02	g 1,4 - DCB_{eq}
Tin	6.64E-08	g 1,4 - DCB_{eq}

Vanadium	6.52E-01	g 1,4 - DCB_{eq}
Zinc	1.67E-03	g 1,4 - DCB_{eq}

Screw (Total: 3.85E+08 g 1,4-DCB_{eq})		
	Emission to air	**Unit**
2,3,7,8-TCDD	3.82E+08	g 1,4 - DCB_{eq}
Acrolein	6.19E-09	g 1,4 - DCB_{eq}
Ammonia	2.30E-05	g 1,4 - DCB_{eq}
Arsenic	1.00E+01	g 1,4 - DCB_{eq}
Benzene	2.07E-02	g 1,4 - DCB_{eq}
Beryllium	4.95E-03	g 1,4 - DCB_{eq}
Cadmium	2.12E+00	g 1,4 - DCB_{eq}
Carcinogenic PAHs	7.18E-02	g 1,4 - DCB_{eq}
Cobalt	3.98E-03	g 1,4 - DCB_{eq}
Copper	1.64E-02	g 1,4 - DCB_{eq}
Dichloro-methane	7.48E-07	g 1,4 - DCB_{eq}
Ethyl-benzene	1.80E-06	g 1,4 - DCB_{eq}
Formaldehyde	4.36E-06	g 1,4 - DCB_{eq}
Hexachloro-benzene	3.84E-06	g 1,4 - DCB_{eq}
Hydrogen chloride	3.69E-04	g 1,4 - DCB_{eq}
Hydrogen sulphide	1.55E-06	g 1,4 - DCB_{eq}
Lead	2.45E-01	g 1,4 - DCB_{eq}
Mercury	1.56E-02	g 1,4 - DCB_{eq}

Molybdenum	8.24E-04	g 1,4 - DCB_{eq}
Nickel	2.11E-01	g 1,4 - DCB_{eq}
Pentachloro-benzene	1.32E-09	g 1,4 - DCB_{eq}
Pentachloro-phenol	2.64E-12	g 1,4 - DCB_{eq}
Phenol	3.74E-09	g 1,4 - DCB_{eq}
PM10	7.93E-05	g 1,4 - DCB_{eq}
Selenium	2.21E-02	g 1,4 - DCB_{eq}
Tetrachloro-methane	2.62E-05	g 1,4 - DCB_{eq}
Thallium	4.82E-03	g 1,4 - DCB_{eq}
Tin	1.93E-08	g 1,4 - DCB_{eq}
Vanadium	9.58E-02	g 1,4 - DCB_{eq}
Zinc	2.81E-01	g 1,4 - DCB_{eq}

PCB (Total: 2.67E+09 g 1,4-DCB_{eq})		
	Emission to air	**Unit**
1,2-Dichloro-benzene	1.44E-05	g 1,4 - DCB_{eq}
1,2-Dichloro-ethane	7.18E-05	g 1,4 - DCB_{eq}
1,3,5-Trichloro-benzene	1.10E-09	g 1,4 - DCB_{eq}
2,3,7,8-TCDD	2.68E+09	g 1,4 - DCB_{eq}
Acrolein	5.43E-06	g 1,4 - DCB_{eq}
Ammonia	4.87E-04	g 1,4 - DCB_{eq}
Anthracene	8.28E-10	g 1,4 - DCB_{eq}
Arsenic	2.80E+01	g 1,4 - DCB_{eq}

Barium	2.08E-01	g 1,4 - DCB_{eq}
Benzene	3.43E+00	g 1,4 - DCB_{eq}
Beryllium	1.92E-01	g 1,4 - DCB_{eq}
Butylbenzyl-phtalate	1.41E-11	g 1,4 - DCB_{eq}
Cadmium	3.65E+00	g 1,4 - DCB_{eq}
Carbon disulfide	7.79E-06	g 1,4 - DCB_{eq}
Carcinogenic PAHs	2.31E+02	g 1,4 - DCB_{eq}
Chloro-benzene	3.99E-12	g 1,4 - DCB_{eq}
Chromium VI	5.30E-01	g 1,4 - DCB_{eq}
Cobalt	3.11E+00	g 1,4 - DCB_{eq}
Copper	1.52E+02	g 1,4 - DCB_{eq}
Dichloro-methane	1.57E-05	g 1,4 - DCB_{eq}
Ethyl-benzene	1.69E-03	g 1,4 - DCB_{eq}
Ethylene	0.00E+00	g 1,4 - DCB_{eq}
Formaldehyde	2.31E-03	g 1,4 - DCB_{eq}
Hexachloro-benzene	2.00E-03	g 1,4 - DCB_{eq}
Hydrogen chloride	1.11E-01	g 1,4 - DCB_{eq}
Hydrogen sulphide	7.74E-04	g 1,4 - DCB_{eq}
Lead	1.78E-01	g 1,4 - DCB_{eq}
Mercury	3.94E-01	g 1,4 - DCB_{eq}
Mevinphos	2.19E-07	g 1,4 - DCB_{eq}
Molybdenum	9.73E-01	g 1,4 - DCB_{eq}
m-Xylene	4.60E-09	g 1,4 - DCB_{eq}
Naphtalene	1.18E-06	g 1,4 - DCB_{eq}

Nickel	6.74E+02	g 1,4 - DCB_{eq}
Nitrogen dioxide	1.35E-02	g 1,4 - DCB_{eq}
Pentachloro-benzene	5.45E-07	g 1,4 - DCB_{eq}
Pentachloro-phenol	3.35E-08	g 1,4 - DCB_{eq}
Phenol	2.43E-06	g 1,4 - DCB_{eq}
PM10	2.74E-02	g 1,4 - DCB_{eq}
Propylene oxide	1.50E-05	g 1,4 - DCB_{eq}
Selenium	7.77E+00	g 1,4 - DCB_{eq}
Styrene	2.27E-08	g 1,4 - DCB_{eq}
Sulphur dioxide	1.28E+02	g 1,4 - DCB_{eq}
Tetrachloro-methane	1.38E-02	g 1,4 - DCB_{eq}
Thallium	9.36E-01	g 1,4 - DCB_{eq}
Tin	1.26E-05	g 1,4 - DCB_{eq}
Vanadium	1.81E+01	g 1,4 - DCB_{eq}
Zinc	9.42E-02	g 1,4 - DCB_{eq}

Appendix 7 - Human toxicity potentials from transportation

The appendix 7 shows the calculation results of HTPs from transportation.

The airbag transportation HTPs		
		Unit
SO_2 emission	9.90E-01	g
Equivalency factor (weighted RCR_{ref})	3.10E-01	
HTPs	3.07E-01	g 1,4 - DCB_{eq}

The ECU transportation HTPs		
		Unit
SO_2 emission	7.69 E+04	g
Equivalency factor (weighted RCR_{ref})	3.10E-01	
HTPs	2.39E+04	g 1,4 - DCB_{eq}

Appendix 8 - Deaths and serious lost time injuries caused by metal mining

Appendix 9 shows the calculation results of deaths and serious lost time injuries caused by kilograms of various metals mining. The fatality data is derived from the Western Australia mining fatality database. The production data is derived from the Western Australian mineral and petroleum statistics digest 2008 report (Government of Western Australia Department of Mines and Petroleum, 2008). The serious lost time data is derived from the email contact from the Government of Western Australia Department of Mines and Petroleum. The production data is derived from Western Australian mineral and petroleum statistics digest 2007-2008 report (Government of Western Australia Department of Mines and Petroleum, 2008).

Metal*	Fatality	Production								Deaths/kg
		2002	2003	2004	2005	2006	2009	Total		
Aluminum	1						1.943 E+06	1.943 E+06	kt	5.15E-10
Gold	7	188.86	187.5	164.42	169.83	163.65		874.26	t	8.01E-06
Iron	5	171.77	194.75	215.85	244.64	249.92		1076.93	Mt	4.64E-12
Nickel	3	183	190.21	174.7	191.71	176.64		916.26	kt	3.27E-09
Copper	1**	62.29	58.78	42.68	83.88	89.47		337.1	kt	2.85E-07
Zinc		218.8	174.55	51.78	57.78	138.84		641.75	kt	5.43E-07
Lead		70.4	56.49	1.17	0.31	74.85		203.22	kt	1.72E-07

<table>
<tr><th>Metal*</th><th>Serious lost time injuries</th><th colspan="2">2007 -2008 production</th><th>Serious lost time injuries/kg</th></tr>
<tr><td>Gold</td><td>75</td><td>139.51</td><td>t</td><td>5.38E-04</td></tr>
<tr><td>Iron</td><td>50</td><td>290.51</td><td>Mt</td><td>1.72E-10</td></tr>
<tr><td>Nickel</td><td>52</td><td>171.05</td><td>kt</td><td>3.04E-07</td></tr>
<tr><td>Copper</td><td rowspan="3">35**</td><td>124.50</td><td>kt</td><td>1.25E-05</td></tr>
<tr><td>Zinc</td><td>25.71</td><td>kt</td><td>2.59E-06</td></tr>
<tr><td>Lead</td><td>197.13</td><td>kt</td><td>1.99E-05</td></tr>
</table>

* Only parts of the metal death rates are calculated because of the accessibility of data. Sliver, silicon, mercury are not included in this table.

**Allocation: copper, zinc and lead together form as base metals. Therefore, it needs allocation method to deal with the fatality data. The method here is to allocate the fatality data in terms of their weight portions.

Appendix 9 – Deaths caused by electricity generation in different countries

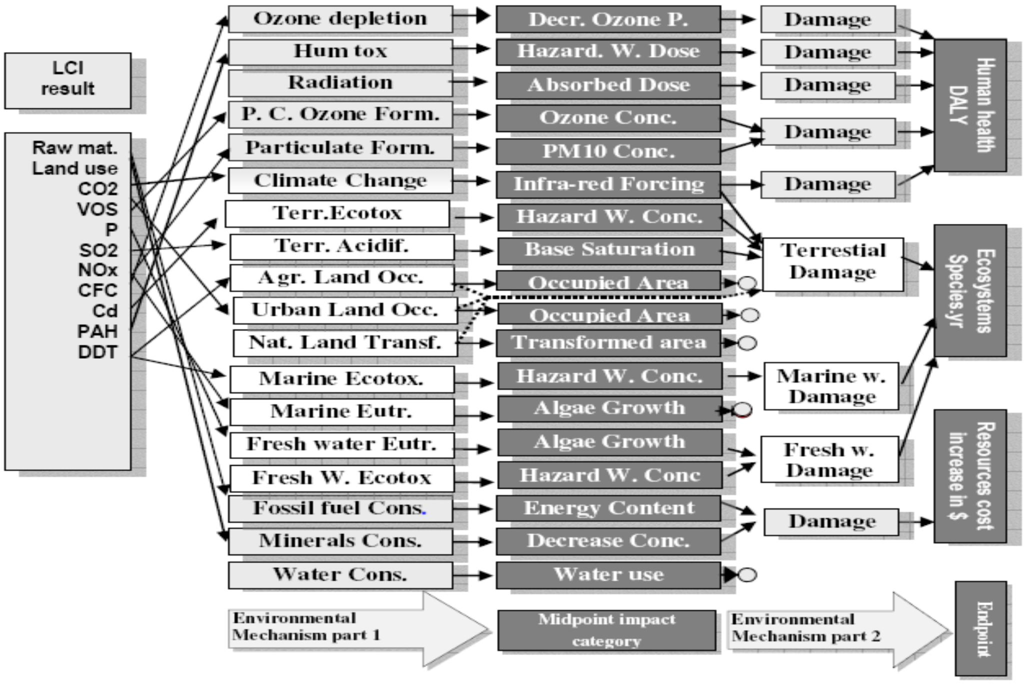
The calculations of deaths caused by electricity generation in different countries is based on table 5 – comparing deaths/TWh for all energy sources and the electricity mix for different courtiers as well as regions based on the International Energy Agency (IEA) database.

Deaths caused by electricity generation in different countries	
Country	Deaths per TWh electricity generation (1TWh=10E+9KWh)
Sweden	3.88
Taiwan	89.6
Uk	60.0
Portugal	48.0
Turkey	55.8
Germany	76.5
Netherland	50.0
Romania	71.1
Italy	36.5
Us	11.1
France	8.77
Canada	30.0
Hungary	35.6
China	220
Japan	51.7
Malaysia	53.6

Slovenia	53.3
India	114
Singapore	19.1
OECD average	60.7
World average	68.8

Appendix 10 - The quantitative connection between midpoint and endpoint categories (the factor Q_{em})

The appendix 8 is from the paper: A life cycle impact assessment method which comprises harmonized category indicators at the midpoint and the endpoint level (Goedkoop *et al.* 2008). It sketches the relations between LCI parameters, midpoint indicators and endpoint indicators.



Midpoint impact category		Endpoint impact category		
Abbr.	Unit	HH(yr)	ED(yr)	RC($/YR)
HT	kg(1,4 - DCB to urban air)	7.0E-7 (I, H, E)*	0	0

*I means individualist, H means hierarchist, and E means egalitarian. They are three types of different perspectives regarding weighting.

Appendix 11- The Estimation of death age for DALYs

A: Average age of drivers in accidents

Average age of drivers in accidents is estimated based on the census from US international safety council (www.census.gov/compendia/statab/2010/tables/10s1077.xls). An interpolation method is used here to calculate the average age of the drivers in accidents. The result shows that the average age estimation for the drivers in fatal accidents is 42.8 years old.

Average age= $\sum$ age when accident $\times$ percentage $= 8 \times 0.5\% + 16 \times 1.2\% + 17 \times 1.9$......+70×6.5%+80×7.4%=42.8

Age group	Drivers in fatal accidents	Age estimation
19 years old and under	9.2	
Under 16 years old	0.5	0.736
16 years old	1.2	0.192
17 years old	1.9	0.323
18 years old	2.7	0.486
19 years old	2.9	0.551
20 to 24 years old	14.9	
20 years old	2.9	0.580
21 years old	3.1	0.651
22 years old	3.1	0.682
23 years old	2.7	0.621
24 years old	3.1	0.744
25 to 34 years old	18.3	5.49
35 to 44 years old	16.4	6.56

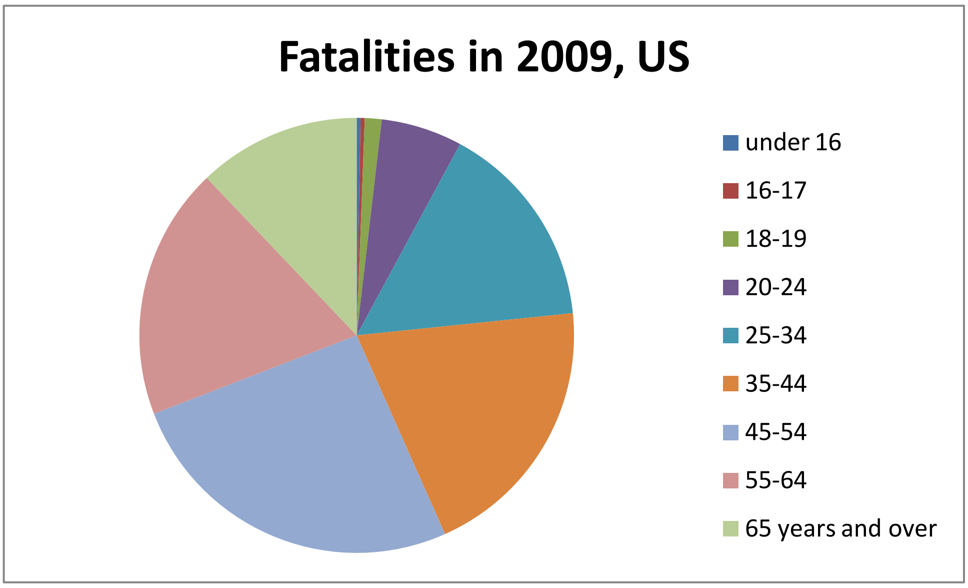
45 to 54 years old	16.1	8.05
55 to 64 years old	11.1	6.66
65 to 74 years old	6.5	4.55
75 years old and over	7.4	5.92
Average age		42.8

B: Average death age of mining workers

Database of Western Australia provides the fatalities by age. After calculation, the average death age of mining workers is 35.6.

C: Average death age of workers in energy industry

The interpolation method is used again to estimate the average death age of workers in electricity industry. The average age is 45.5 after calculations. The fatal occupational injuries data at the year of 2009 is derived from US Department of labor.


Fatalities in 2009, US
under 16
16-17
18-19
20-24
25-34
35-44
45-54
55-64
65 years and over