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Miljøprojekt

LCA and the working environment

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Preface

This report was prepared within the Danish LCA methodology and consensus creation project during the period from 1997 to 2003. The report is one out of five technical reports to be published by the Danish Environmental Protection Agency and dealing with key issues in LCA. The reports were prepared as background literature for a number of guidelines on LCA, planned to be published by the Danish Environmental Protection Agency during the autumn of 2003. The reports present the scientific discussions and documentation for recommendations offered by the guidelines. The reports and guidelines developed within the project are presented in the overview figure below.

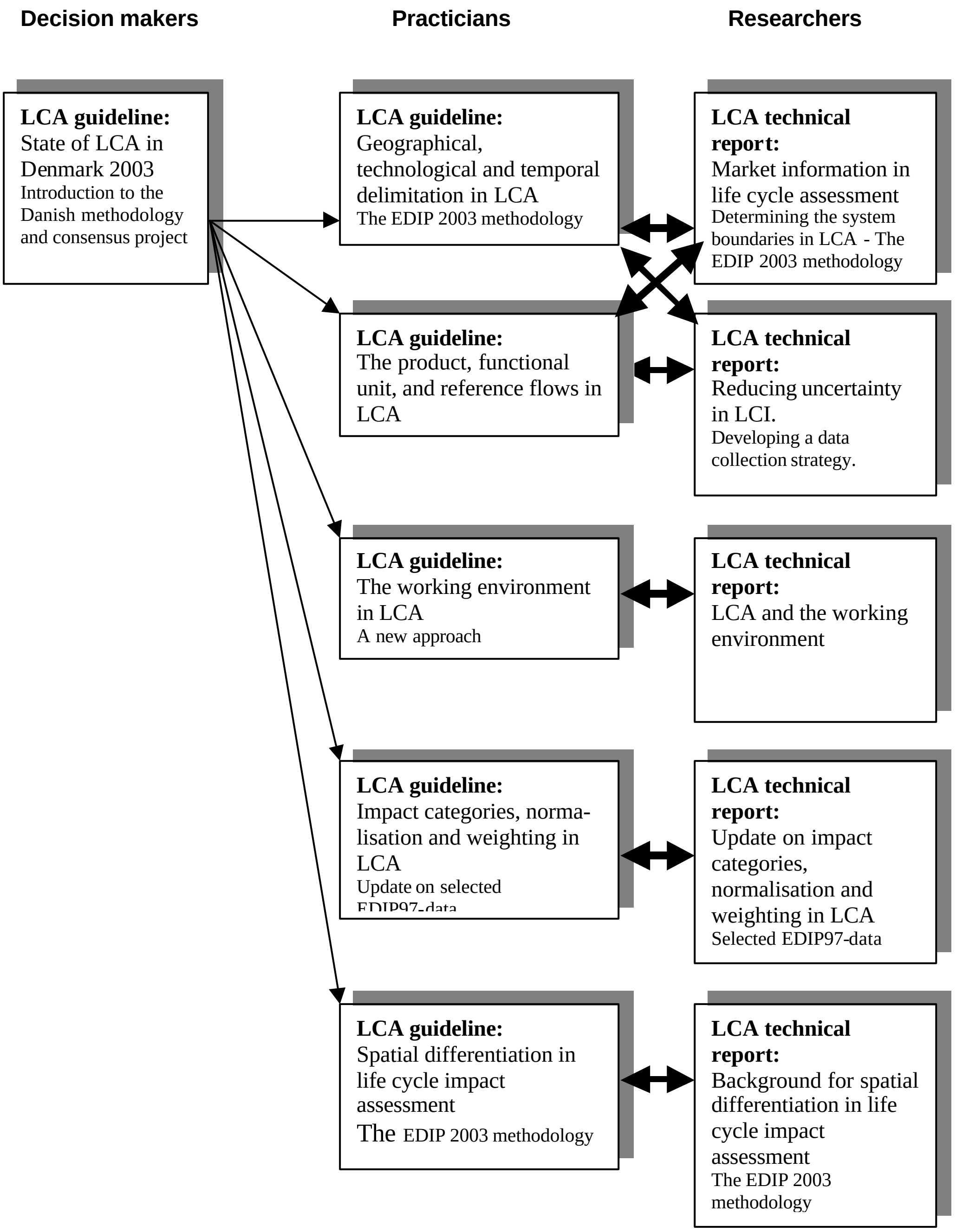
A primary objective of the guidelines has been to provide advice and recommendations on key issues in LCA at a more detailed level than offered by general literature, like the ISO-standards, the EDIP reports, the Nordic LCA project and SETAC publications. The guidelines must be regarded as a supplement to and not a substitution for this general literature.

It is, however, important to note that the guidelines were developed during a consensus process involving in reality all major research institutions and consulting firms engaged in the LCA field in Denmark. The advice given in the guidelines may thus be considered to represent what is generally accepted as best practice today in the field of LCA in Denmark.

The development of the guidelines and the technical reports was initiated and supervised by the Danish EPA Ad Hoc Committee on LCA Methodology Issues 1997-2001. The research institutions and consulting firms engaged in the development and consensus process are:

COWI, Consulting Engineers and Planners (Project Management)
Institute for Product Development, the Technical University of Denmark
FORCE Technology (until 1/1-2004 dk-TEKNIK ENERGY & ENVIRONMENT)
The Danish Technological Institute
Carl Bro
The Danish Building Research Institute
DHI - Water and Environment
Danish Toxicology Institute
Rambøll
ECONET
National Environmental Research Institute

Guidelines and technical reports prepared within the Danish LCA-methodology and consensusproject



Summary and conclusions

The report consists of two parts, i.e. a main report and an Appendix.

The main report is a description of a new methodology for working environmental aspects in LCA, including an extensive database. It is suggested to replace the methodology that was developed in the original EDIP project. The new methodology is based on two types of Danish statistical information regarding economic sectors, i.e. information on the amounts being produced (in weight units) in a number of sectors, and information on the number of reported work-related diseases and damages in the same sectors. By combing the statistics it is possible to establish a figure for working environment impacts per produced unit that can be used together with information on the impacts in the external environment.

The following impact categories are included in the assessment of the working environment:

- Fatal accidents
- Total number of accidents
- CNS function disorder
- Hearing damages
- Cancer
- Muscolo-sceletal disorders
- Airway diseases (allergic)
- Airway diseases (non-allergic)
- Skin diseases
- Psycho-social diseases

In contrast to the original EDIP methodology the new method doesnot include assessment of single processes in the companies. The main advantage of this is that it becomes much easier to collect and process the necessary information for a working environmental LCA. Another advantage is that the uncertainty in combining information from very different sources is avoided. Finally, it is possible to establish the same type of information for other countries, thereby facilitating the development of an even more extensive database.

The main limitation when using a sector assessment is that the level of detail cannot be increased beyond the level allowed by the basic statistical information. Assessment of specific processes is outside the scope of the methodology, and only larger companies can be expected to possess a set of statistics that can replace the average information from the whole sector. The method is, thus, not well suited for assessing the effect on the overall results following changes in the choice of specific processes or materials in a single company.

The established database covers about 80 economic sectors that are divided into four groups, i.e. raw material production (e.g. energy resources, metals, paper, etc.), production of intermediates and components (e.g. wood products, plastics, ceramics, metal products, etc.), production of final products (e.g. furniture and various electromechanical products) and transportation. The database is at present not integrated in the EDIP PC tool, but is available in the form of a spreadsheet.

The report also describes how comparable information can be derived from companies whose activities are not included in the database. This type of information is most often significantly less detailed, but can be used to indicate the relative importance of a given activity.

It is concluded that the new methodology and the associated database can be used to make life cycle assessments of the working environment. This is demonstrated in a case study of an office chair, in which the magnitude of the actual impacts is examined along with the relative importance of the single activities. It is also possible to get an overview of which activities that are most important for each of the impact categories included in the methodology.

The data format in the case study matches that for the other impact categories in the EDIP methodology, i.e. it is possible to make an impact assessment and subsequently normalise the results.

The Appendix describes the process of developing the new method. The main content of the Appendix is a description of the methods for working environmental LCA that were available at the start of the project. The descriptions were presented together with practical experiences at a mid-project workshop, where about 65 LCA practitioners and working environmental professionals participated.

The discussions at the workshop showed that there is a large interest in working environmental LCA at least in Denmark and Scandinavia, but also that the existing methodologies did not fulfil the requirements from the audience. Some criticism was voiced, especially regarding the lack of precision and usability of the methods in relation to the time that is necessary to produce the results.

It is the hope that the new methodology will serve the primary purpose of including the working environment in LCA, i.e. to avoid environmental improvement of products and products systems at the expense of the working environment. It is also the hope that the basics of the methodology will gain international acceptance, thereby increasing the usefulness for all LCA practitioners and at the same time help improve the working environment also outside Denmark.

Sammenfatning og konklusioner

Dette Miljøprojekt består af to dele, en hovedrapport og et bilag.

Hovedrapporten indeholder en beskrivelse af en ny metode til at inddrage arbejdsmiljø i LCA, inklusive en omfattende database. Metoden foreslås som et alternativ til den metode, der blev udviklet i det oprindelige UMIP-projekt. Den ny metode er baseret på to danske statistiske kilder vedrørende henholdsvis hvor meget, der – målt i vægt - produceres i en række økonomiske sektorer (brancher), og hvor mage arbejdsskader og –ulykker, der anmeldes i de samme brancher. Ved at kombinere de to statistiske kilder er det muligt at beregne, hvor stor arbejdsmiljøbelastningen er per produceret enhed. Denne information har samme format som de oplysninger, der generelt bruges i livscyklusvurderinger og det er således muligt at foretage en integreret miljø- og arbejdsmiljøvurdering.

Følgende typer af belastninger indgår i vurderingen:

- Dødsulykker
- Arbejdsskader/ulykker
- Kræftsygdomme
- CNS-funktionssvækkelse
- Psykiske lidelser
- Høreskader
- Hudsygdomme
- Luftvejssygdomme, ikke-allergiske
- Luftvejssygdomme, allergiske
- Bevægeapparatskader

Den nye metode indeholder i modsætning til den oprindelige UMIP-metode ikke en vurdering af enkeltprocesser på virksomhedsniveau. Den største fordel ved dette er, at det er langt lettere at indsamle og bearbejde data i en arbejdsmiljø-LCA. En anden fordel er, at den potentielle usikkerhed ved at kombinere en branche- og procesvurdering undgås. Endelig skal det fremhæves, at det er muligt at fremskaffe lignende informationer fra en række andre lande, og det er dermed også muligt at etablere en mere bredt dækkende database.

Den største ulempe ved kun at bruge en branchevurdering er, at der ikke kan opnås et højere detaljeringsniveau, for eksempel ved at gennemføre processpecifikke vurderinger, end de grundlæggende statistiske informationer tillader. Dette er ikke en ulempe i sig selv men kan medføre, at det er svært at lave en præcis fortolkning af resultaterne i nogle tilfælde.

Databasen, der er blevet udviklet i projektet, dækker ca. 80 brancher eller processer. Disse kan inddeles i fire typer: Råvareproduktion (f.eks. energiråvarer, metaller og papir), produktion af mellemprodukter og komponenter (f.eks. plastgranulat, kemiske produkter, keramik og trævarer), produktion af færdigvarer (f.eks. møbler og elektromekaniske produkter) og transport. Metoden og databasen kan integreres i UMIP's PC-værktøj, men foreligger for øjeblikket kun i form af en regnearks-fil.

Rapporten beskriver endvidere, hvordan den samme type af information kan etableres for processer, der ikke er inkluderet i databasen. Dette sker på baggrund af offentligt tilgængelige oplysninger fra (større) virksomheder. Resultatet er ikke så detaljeret som for den øvrige del af databasen, men kan bruges til at indikere den relative vigtighed af en given aktivitet.

Det konkluderes i rapporten, at den nye metode sammen med databasen kan bruges til at lave arbejdsmiljø-LCA. Dette demonstreres i en enkelt case – arbejdsmiljø-LCA af en kontorstol. I casen beregnes den samlede belastning over livsforløbet. Endvidere vurderes det hvilke aktiviteter, der er af størst betydning i det samlede billede såvel som for de enkelte belastningstyper.

Rapportens appendiks beskriver i grove træk, hvordan den nye metode er blevet udviklet. Hovedvægten i appendiks er en beskrivelse af de metoder til arbejdsmiljø-LCA, der var tilgængelige ved projektets start. Disse beskrivelser blev – sammen med praktiske eksempler – præsenteret på en midtvejs-workshop, hvor der deltog 65 LCA-praktikere og arbejdsmiljøprofessionelle fra Skandinavien og Holland.

Diskussionerne på workshoppen viste, at der er stor interesse for arbejdsmiljø-LCA, specielt i Danmark, Sverige og Norge. Workshoppen viste også, at de eksisterende metoder ikke var tilfredsstillende, specielt ikke når resultaterne blev vejet op mod det relativt store tidsforbrug, som metoderne kræver.

Den nye metode betyder, at en arbejdsmiljø-LCA kan gennemføres på væsentligt kortere tid end i den oprindelige UMIP-metode. Det er håbet, at den nye metode kan opfylde det primære formål med at inddrage arbejdsmiljø i LCA, nemlig at undgå forringelser i arbejdsmiljøet som følge af miljømæssige forbedringer af produkter og produktsystemer. Det er også håbet, at den grundlæggende metode vil få international udbredelse, således at anvendeligheden bliver endnu større for LCA-praktikere, samtidigt med at den kan bruges til at forbedre arbejdsmiljø også uden for Danmarks grænser.

1 Introduction

The present report gives an overview and a discussion of a new methodology for including the working environment in the general EDIP-LCA methodology. The new methodology is seen as a good alternative the methodology that was described in EDIP97[1] but only was tested to a limited degree.

The main reason for including the working environment in LCA is the same as for EDIP97, i.e. to give a possibility to examine whether environmental product improvements are implemented on the expense of a deteriorated working environment.

The method has therefore been developed in order to make it possible to perform a general assessment of the changes in working environmental impacts that are induced by changes in the choice of materials and processes. This knowledge can subsequently be combined with more specific knowledge about potential hazards in relevant sectors and form the basis for a dialogue between the actors in a product chain. WE-LCA can thus be seen as a natural component in the efforts for development of products with less impact on the environment and human health.

It is, however, not possible to examine or protect against deterioration as a consequence of company-specific changes, e.g. an increased tempo or efficiency, by using the developed LCA-methodology. For this purpose, work place assessments for each employee is a better suited tool that WE-LCA cannot replace.

The main reason for suggesting the new methodology is that with the new approach and the accompanying database it is much less demanding in terms of time and resources to include the working environment in LCA. Furthermore, the methodology is built on statistical information which - at varying levels of detail - is available in most countries. It is therefore our hope that the working environment will be a natural part of many LCAs, both in Denmark and in other countries.

1.1 The development process

The development of the new methodology has been performed in three phases:

- Phase 1: Review of existing methods for working environmental LCA. As a part of the consensus-process that has been an integrated part of the

[1] "EDIP97" is in the present report a common denominator for the methodology descriptions that can be found in Hauschild and Wenzel: Environmental Assessment of Products. Volume 2: Scientific background. Chapman & Hall, 1997 (Danish version: Hauschild (ed.): Baggrund for Miljøvurdering af produkter, Miljøstyrelsen/Dansk Industri 1996), Wenzel, Hauschild and Rasmussen: Miljøvurdering af produkter, Miljøstyrelsen/Dansk Industri 1996, and in Broberg og Rasmussen: Arbejdsmiljø fra vugge til grav, Arbejdsmiljøfondet 1996.

LCA-methodology development project, a workshop was held following this first phase of the project. The results of the review and a summary of the discussions at the workshop are presented in Appendix A to the present report. A short summary of the workshop is also given in section 1.1.1.
- Phase 2: Testing of the EDIP methodology for working environmental LCA
- Phase 3: Refining and supplementing the EDIP-methodology and database.

1.1.1 The first workshop

At the first workshop in the project, the Phase 1- review of existing methods were presented and discussed with the about 65 persons present at the workshop. The general conclusions from the discussions at the workshop were that

- The existing methods for assessing working environmental impacts are not sufficiently precise
- The methods include a limited number of impacts
- The methods are very resource demanding, and
- There are more suitable tools for identification of improvement opportunities in the working environment

These conclusions can be transformed into a demand for a methodology that give a broad and yet precise overview of the working environmental impacts in a life cycle perspective without being too demanding in terms of resources. Whether the method should or would be used for improvements at the company level was an open question at the workshop.

In addition to these conclusions the project group felt that there was an imminent need for an operational method if the working environment should survive in present and future LCA developments.

As a result of these considerations the project group aimed at developing a method that would satisfy some, but not all, of the requirements stated above. More explicitly, the project group recognised that the demand for a high degree of precision could not be met at the same time as the demand for a less resource demanding method which was operational at the end of the project period.

1.1.2 Phase 2: Testing of the EDIP-methodology

The two main elements in the EDIP97 methodology, i.e. the process and the sector[2] assessment, are described in some detail in the Appendix. The basic idea behind the methodology is that for internal processes at a company, specific data are established using the process assessment, while for external processes the sector assessment is applied. The two different kinds of

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[2] The terms ”sector” and ”sub-sector” are throughout the report used to describe economic activities at different levels of detail, i.e. economic sectors are divided into a number of sub-sectors, see for example Table 1.1. However, the two terms do not describe a fixed level of detail. It should also be mentioned that the term ”branches” can be used to describe both sectors and sub-sectors.

information can subsequently be aggregated by further data treatment, using the working/exposure time per functional unit as the common denominator.

The data for the sector assessment can be expressed in a simple formula:

$$\text{Impacts per "functional unit"} = \frac{\text{Number of injuries/damages in sector}}{\text{Amount produced in sector}}$$

As an example, the impacts from producing one kWh in Denmark can be calculated by dividing the total number of impacts in the electricity producing sector with the total amount of electricity being produced.

However, at the end of EDIP97 development, only a limited number of data were available for WE-LCA, i.e. data on electricity production, transportation, and steel production.

In order to be able to test the EDIP-methodology, the first step was to extend the database for working environmental LCA. How to establish new data for the EDIP97 method is not described in detail in the reports, but supply statistics in combination with information on work-related accidents and damages was seen to be a main element in the development of the few sector-related data in the original database. It was also stated in the reports that the sector assessment methodology was best suited for large and homogenous productions.

The problem in using supply statistics was experienced by the project team already during the first efforts towards extending the database. Here, Statistics Denmark were asked to provide supply statistics for the plastic processing sectors, i.e. the sectors with the following NACE-codes:

Table 1.1. NACE-codes for plastic processing sectors in Danish statistics

Activity	NACE-code
Production of plastic products	252
Production of sheets, films, tubes, hoses and other profiles	2521
Production of sheets, films and other flat plastics	252110
Production of plastic tubes and hoses	252120
Production of plastic bars and profiles	252130
Production of plastic packaging	252200
Production of building articles	2523
Production of plastic sanitary articles	252310
Production of plastic building components	252390
Production of other plastic products	2524
Production of plastic office- and school products	252410
Production of table service and kitchen equipment	252420
Production of other plastic products	252490

A given company is in the statistics identified by the NACE-code that covers the main economic activity. This means that companies in other sectors also can be processing plastics, e.g. the chemical industry, toy producers, insulation companies, automotive and electronics industry etc. On the other hand the sectors in Table 1.1 may also have other activities than processing of plastics.

The information from Statistics Denmark showed that it was only possible to establish supply statistics on the four-digit NACE-code level, i.e. NACE-codes 2521, 2522, 2523 and 2524. In comparison, the statistics from the Danish Labour Inspectorate can be established on a five-digit NACE-code level, giving a possibility for an increased level of detail.

Furthermore, it turned out that the imported amounts in the supply statistics are allocated to both companies making their own imports and wholesale dealers, e.g. regional offices of multinational plastic producers, that subsequently sell the imported plastics to companies in all sectors. As about half of the amount of plastic raw material is imported by wholesale dealers, the actual amounts being processed in each of the four four-digit NACE-codes can only be calculated with a high degree of uncertainty.

In conclusion, the sector method described in EDIP97 is not well suited for handling sectors with a wide variety of products being produced, the main problems being achieving a sufficient level of detail as well as precision. It should be mentioned in this context that the above mentioned problems probably will be even more pronounced in sectors where there is both a Danish production and an import of raw materials, e.g. the steel industry.

It was therefore decided at the second phase of the project to develop an alternative method for sector assessments in the third phase of the project. The following chapters describe in detail the new sector assessment method that is suggested to replace both the sector and the process assessment methods in EDIP97.

1.2 About the new method

The new methodology can be seen as a simplification of the methodology outlined in EDIP97. This simplification was not intended *a priori* in the project, but emerged as an operational solution to many of the problems that were identified during the review and testing of the old methodology.

The main difference between the old and the new method is that the new method is a sector assessment which is purely based on statistical information whereas the old methodology relied on both statistical and process/company specific information.

One practical implication of this is that it is not necessary to collect information on specific processes at the company level, thereby significantly reducing the necessary amount of work. Instead, most - if not all - of the information can be extracted from the database that has been established. The method is thus (almost) fully operational, also for LCA practitioners without a thorough knowledge of working environmental impacts. Seen in view of the minor attention that has been given to the working environment in LCA so far, this is regarded as a significant progress.

At the same time it must be recognised that some level of detail is lost when excluding the process assessment and also that there are some inherent uncertainties in the new method. Therefore, the present methodology should not be regarded as final, but rather as temporary solution allowing the working environment to be included in LCA without having to start from the beginning in every LCA.

Meanwhile, detailed information on the working environment can still be collected on the company level and be the basis for improvement efforts.

Several tools for this, especially work place assessments, are already available and may prove to be of great value when establishing product related information.

2 The new methodology

In short, the new methodology is a sector assessment method; i.e. it uses different kinds of statistical information from economic sectors to produce product specific information regarding the working environmental impacts per functional unit.

The procedure for performing LCA-calculations including the working environment does not differ from the general procedure in LCA, and the description of the methodology therefore has its main focus on how the database has been developed and how the associated uncertainties can be handled.

The first sections (2.1-2.3) in the chapter describe the development of the general database, while section 2.4 describes the development of the database for those sectors, where the general methodology could not be applied.

2.1 Statistical sources

The general methodology uses two types of statistical information to derive the database:

- Statistics on work-related accidents and reported diseases from the Danish Labour Inspectorate (Arbejdstilsynet), and
- Statistics on the amounts of produced goods in Denmark (Varestatistikken).

2.1.1 Work-related injuries and damages

In Denmark, all notified occupational accidents and occupational diseases are recorded by the Registry of Occupational Injuries, which is a part of the Danish National Labour Inspection Service.

The registers contain information that identifies the reports and the injured persons and enterprises involved. This information describes the work function, the accident event/the exposure sources that led to the occupational disease, the type of injury, a diagnosis, and a number of other background factors.

Danish employers are required to notify all occupational accidents and cases of toxic injury which results in one or more days' absence from work. In addition, doctors and dentists are required to notify all work-related diseases, even merely suspected cases.

An "occupational accident" is an injury sustained by persons on account of their work, where the event causing the injury

- occurs suddenly and unexpectedly
- is an out of the ordinary occurrence
- results in immediate injury

Likewise, an “occupational disease” is an injury sustained by persons on account of their work, or on account of the conditions under which work takes place

- where the disease arises after a period of exposure
- where exposure takes place during everyday work
- where - as is often the case - the disease gradually becomes more and more serious.

However, some diseases may manifest themselves suddenly even though they may be due to long-term exposure.

All occupational diseases occurring to persons performing work in the service of Danish employers and at Danish workplaces in Denmark, are included. But when it comes to occupational accidents only persons employed at Danish workplaces in Denmark *on land* are included, leaving out the accidents occurring at sea or in the air.

Even though the accidents and diseases are sorted and registered into respectively 15 and 18 different categories only the result of 9 categories are published. The published ones are:

Accidents:

- Fatal accidents
- Total number of accidents

Diseases:

- CNS function disorder
- Hearing damages
- Cancer
- Muscolo-sceletal disorders
- Airway diseases (allergic)
- Airway diseases (non-allergic)
- Skin diseases
- Psycho-social diseases

The statistical information on work-related damages and injuries can be assumed to be most precise (or statistically representative) for those sectors where the reporting is most intensive, simply because large numbers can be taken as an indication of a large economic activity and/or a relatively high impact in the working environment.

As a consequence, it is suggested that the statistics on work-related injuries and damages is used to select the sub-sectors for which the calculations can be performed with a relatively high degree of prediction power. The procedure should ideally exclude calculations for sub-sectors, where the reported number of damages and injuries is small, for example less than 15 per year, but this rule of thumb must be disregarded in some cases, where more representative data cannot be found.

2.1.2 Produced amounts

The information on the produced amounts can be derived from the Danish statistics on goods production (Varestatistik for Industri), which is published four times a year, the last publication for each year containing aggregate information for the whole year.

The Danish statistics on goods production is based on a questionnaire produced by Statistics Denmark. The questionnaire is sent out to all industrial companies with more than 10 employees and includes questions of what the company produces, the value of the produced goods and some kind of quantity unit for it (tons, meters, pieces etc.). Value is the only parameter that is common for all the trades. By combining the result from the questionnaires with the statistics for the foreign trade, it is thus possible to convert all the amounts of produced goods to a weight unit, no matter what they prior was given in.

The uncertainty introduced by this procedure which is described in detail in section 2.3.3-2.3.5 depends on the homogeneity of the products being produced in the sector. For one sector, production of steel, it has been possible to compare the results of the calculations using the outlined methodology to the actual production as stated by Jernkontoret (Jernkontoret, 1998). A comparison for the years 1996 and 1997 is shown below.

Table 2. Comparison of produced and calculated amounts for two years in the steel producing sector.

	Steel Production	
Year	Calculated	Actual production
1996	703 kton	739 kton
1997	777 kton	786 kton

The statistical information in the publication series is for many sectors grouped in a way that directly matches the information on work-related injuries and damages for the same sectors. Examples are:

- Production of iron and steel
- Production and first processing of aluminium
- Production and first processing of lead, zinc, and tin
- Production of rubber and rubber goods
- Production of basic plastics

For other sub-sectors it is more difficult to establish a direct relation between the two types of information that is required by the methodology, for example processing of iron, steel and plastics. With a careful examination of the products groups in the goods statistics, however, it should be possible to establish the information also for such sub-sectors with a relatively high degree of precision. Consultation with professional statisticians, e.g. in Statistics Denmark, is very helpful in these cases as the Agency possesses the basic statistical information as well as the key for allocation of product groups to economic sectors.

2.2 Combining the statistics

By combining the two statistical sources it is possible to relate the working environmental impacts to the unit processes commonly used in LCA and thereby create an operational tool for including the working environment in LCA. Before it can be done, however, some assumptions and intermediate calculations have to be established.

A basic assumption in the methodology is that the added value from a given activity is directly related to amount of produced or processed material. At the specific sector level, the results will be an average of many companies, and the information is therefore comparable with respect to representativity to that regarding work-related damages and injuries which is also an average from many companies within a given sector. The assumption is however not always valid at the company level, e.g. companies using highly technological processes to produce small products (example: contact lenses) will differ significantly from companies using comparatively low-level technology to produce mass products (example: packaging products).

The main prerequisite for performing and using the calculations is that the products or production in specific sectors can be described in relatively precise terms. This is not always possible on the overall sector level, and when extending the results from one sub-sector to another, it is therefore necessary to assume that the sub-sector activities for which the information is available are representative for the whole sector.

It should also be borne in mind, that the products being produced in sectors with a large number of accidents and injuries also tend to be more heterogeneous, the building industry being an obvious exception from this rule of thumb. Thus, in the first and second steps in the following procedure there will always be a trade-off between the specificity of information in the two types of statistics. The practical problems in choosing relevant sectors is, however, not very big as one or both statistical sources in general set the limits on the level of detail that can be achieved.

2.3 The five step procedure

The procedure used in establishing the database can be described in five steps:

1. Selection of sectors
2. Specifying the production in the sector
3. Calculating the total weight of the products
4. Accounting for the working environmental impacts
5. Calculating the working environmental impacts per weight unit

2.3.1 Selection of sectors

The first step is selecting sectors and sub-sectors with a significant number of work-related accidents and diseases. By choosing sectors with a significant impact on the working environment the statistical uncertainty regarding the number of impacts is reduced.

An important criterion is that the sector can be characterised by one or more unit processes that are of interest in relation to LCA. The sector "Production of plastics packaging" (NACE-code 252200) will thus comprise processing of almost all types of plastics using extrusion, injection moulding etc., but it is not possible to achieve a higher level of detail. Another example is the sector "Production and first processing of lead, zinc and tin" (NACE-code 274300) which - as the title indicates - comprise both production and processing of all three materials.

2.3.1.1 The choices made by the project group

The project group identified from the working environmental statistics about 80 sectors with a product profile that was assumed of general interest in relation to many product LCA's. Only a few of these sectors were not suited for the calculations in the methodology, e.g. because the amount of produced goods was not available due to confidentiality like in the case of rock wool. Other sectors like electricity production and transportation required slightly different calculation methods because of differences in the physical units for these sectors (kWh, ton-kilometres).

The full database is documented in Appendix 1 to the report. Each sector is described by the NACE-code for the main economic activity and one or a few keywords for the products being produced within the sector is given.

When using the database in specific LCA case studies, it may not always be possible to find information about the impacts from specific processes or materials. In such cases, it should be examined whether it is possible to use the procedure outlined in the following paragraphs. If this for one reason or another is not possible, it is recommended that the LCA practitioner uses the information from a sector with a working environmental profile which is assumed to be similar to the sector in question. Another option is to omit the impacts from the given activity. No matter which option is chosen, it is important to address the associated uncertainty when reporting.

2.3.2 Specifying the production in the sector

The second step is to identify in the goods statistics the products that are being produced in the selected sectors. The products are identified by an 8-digit code, which is unequivocally related to an economic sector. As an example, products made in the sector "Production and first processing of lead, zinc and tin" (NACE-code 274300) all start with the numbers 78 (lead), 79 (zinc) and 80 (tin), respectively.

It is strongly suggested that this step - and the subsequent calculations in paragraphs 2.3.3 is performed by a professional statistician from a governmental statistical agency with access to the basic statistics given by the companies.

2.3.3 Calculating the total weight of the produced amount in a sector

The third step is to produce an aggregate of the produced amounts (in tons) for all goods in the chosen sectors. The basic information in the good statistics is exemplified in Table 2.3.

Table 2.3. Example of basic statistical information used in the calculation of produced amounts in a sector.

Product	Amount in tons	Value in 1000 DKK
Rigid PVC-tubes, seamless	?	150.000
Rigid PVC-tubes, with seam	22.400	287.400
Flexible PVC-tubes, with seams	5.902	103.494
Flexible PE-tubes, seamless	1.904	24.473
Rigid PE-tubes, seamless	10.533	210.291
Rigid tubes of condensation plastics	?	17.296
Sum	40.739 + ?	792.954

When information on the weight of the products was not available, e.g. as indicated by the questionmarks in Table 2.3, additional information from the foreign trade statistics was used to calculate the weight of the production. Information from the companies to be used in the foreign trade statistics must contain information on the weight and the value of exported products. The average value per weight unit of the export was thus used to calculate the (missing) weight of the total production in the goods statistics of a given product by the following equation:

$$\text{Total production of product (in kg)} = \frac{\text{Value (in kr)}}{\text{Average value per weight unit (kr/kg)}}$$

With the additional information from the foreign trade statistics the weight of the produced amount in a sector can be calculated by simple addition. The resulting figure (in tons) is the best estimate of the total amount of products being produced in a given economic sector.

2.3.4 Accounting for the working environmental impacts

The forth step is not a calculation, but simply accounting for the work-related injuries and damages for the activities in the same sector as the produced volume was calculated for. As described earlier, the Danish Labour Inspectorate kindly provided this information.

2.3.5 Calculating the impacts per functional unit (weight)

The fifth and final step is to calculate the working environmental impacts per functional unit by dividing the information from step 4 with he information from step 3. The result of this calculation is a figure for the number of work-related accidents and injuries per produced tons.

2.4 Supplementing the database

Although the published database is extensive, a LCA practitioner may have additional needs when making an LCA - a need which cannot always be covered by using the methodology outlined in the previous sections. Therefore, methods for supplementing the database are outlined in the following paragraphs, including some examples.

The examples are included in the database, but it is stressed that they differ significantly in quality from those developed by the general methodology.

2.4.1 Danish electricity production

One of the products most commonly used in LCA is electricity and it is a common finding that use of electricity causes significant environmental impacts. The case studies in EDIP97 showed that electricity production also has a significant impact in the working environment, and it is therefore of great interest to make a reliable inventory for electricity production.

The inventory for electricity production (e.g. 1 kWh) was produced by calculating figures for production of each of the raw materials (e.g. coal, oil and natural gas) necessary to produce 1 kWh in Denmark and add these to the figures for the production at the Danish power plants.

In the context of Danish electricity production the impacts associated with coal production are very important. However, it was not possible within the frames of the project to establish an average set of figures on coal production by using information from all the countries supplying coal to Denmark. Instead, American statistics regarding the amounts of coal produced and the injuries associated with this were obtained from the Mine Safety and Health Administration (MSHA) which is a part of the United States Department of Labour. The production statistics comprise both open mines and pit mines, and the statistics on accidents include all persons involved in coal production from the mine to the production plant. It should be noted that these statistics excludes work-related diseases.

When interpreting LCAs in which electricity plays a role, it should thus be remembered that the impacts from electricity production most probably are underestimated. Firstly, the only impacts considered are accidents. Secondly, American coal production is probably associated with fewer accidents (and other impacts) than production in less developed countries like East European countries, South Africa and South America. No efforts have been devoted to describe the differences between the coal producing countries.

2.4.2 Danish transportation

Transportation is often regarded *a priori* as a key issue in many LCAs but the results rarely reflect the alleged importance. With respect to the working environment, transportation is also interesting, mainly because of the risk of accidents but also because of the general working conditions in the sector.

In this project, the number of working environmental accidents is calculated for transport by truck, ship and railway. Key figures for amounts of transported goods were found in publications from Statistics Denmark and the Danish Ministry of Transport. These key figures are published every year and an average from 1995 to 1997 was used for the calculations.

2.4.2.1 Units used

The unit used for describing working environmental impacts in truck and railway transportation is “impacts per tonne-kilometre” (e.g. the number of accidents caused by the transportation of one tonne one kilometre), which is the same unit being used in calculations of environmental impacts. For transport by ship only the total weight of goods being transported can be found, and the impacts are therefore calculated per tonne transported, not per tonne-kilometre.

2.4.2.2 Transport by truck

The amount of tonne-kilometres transported by truck used in the calculations is the national and international transportation with Danish trucks. This information matches the reported number of accidents and diseases connected to these transports. The information includes both transportation on the road and handling of goods in terminals.

2.4.2.3 Transport by railway

In the calculations for transport by railway, only transported amounts within Denmark are considered. This information corresponds to the number of accidents and injuries reported to the Danish Labour Inspectorate, assuming that Danish railway workers do not ride the trains to other countries.

2.4.2.4 Transportation on ships

For transportation on ships, the amounts loaded in Danish harbours are considered in the calculations. This information is matched with the number of accidents and injuries reported to the Danish Maritime Authority. In doing so, a potential error is introduced because of the following three factors. Firstly, it is not known how much of the loaded goods that is transported with foreign ships. Secondly, the number of reported accidents and injuries comprise all Danish ships, irrespective their routes. This means that accidents on Danish ships sailing on foreign routes are included in the number. Thirdly, the number of accidents and injuries used in the calculation comprises both trade and passenger ships, simply because the latter most commonly transport goods as well as passengers at the same time. The magnitude of the potential error has not been estimated.

2.4.3 Production outside of Denmark

Production of basic raw materials like primary metals do not take place in Denmark and it is therefore necessary to find other data sources from relevant countries or companies. Most often the information on working environmental impacts will be in the format "Accidents/injuries per 100.000 working hours", "Lost time injury frequency rate" or "Combined Lost time and Medically treated injury frequency rate". Usually, the figures are aggregated and averaged for a number of production facilities or for the sector as a whole in a given country.

In order to reach the data format used in the general methodology this information must be related to the production efficiency, i.e. produced amount per man-hour. These figures can in many cases be derived from annual reports from relevant companies, and the final calculations can be performed without significant problems. One should however be aware that by using company specific statistics, other types of uncertainties are introduced, e.g. regarding the representativity of the information.

2.4.3.1 Nickel production as an example

As an example, the magnitude of the working environmental impacts can be derived from the annual reports from WMC, an Australian producer of metals, fertilisers and other products.

The combined "Lost time and Medically treated injury frequency rate" (LMI) was in average for all WMC operations 30.7 per million hours worked in 1996-1997. For the nickel operations, the average figure was 34.7 with a range from 6.1 to 54.0 in different operations.

The production in 1996-1997 was 47.600 tonnes and the labour productivity was stated to be 37 tonnes of nickel metal produced per employee in the same year. Assuming that each employee works 2000 hours per year, the LMI per tons nickel can then be calculated to

$((34.7 * 10^{-6})*2000/37) \approx 1.9 * 10^{-3}$ injuries per tons nickel.

There were two fatal accidents in the nickel operations in 1997 in WMC. With a production volume of 48.000 tonnes the number of fatal accidents per kg nickel can be calculated to 2/48.000 kg $\approx 4*10^{-5}$ fatality per kg nickel.

It is also possible to derive the corresponding figures for 1996 by combining the information in the WMC Annual Report from 1996 and 1997:

- Production volume: 46712 tonnes
- Labour productivity: 30 tonnes/employee per year (equal to 15 kg/hour)
- LMI: 37.6/1.000.000 hours
- Working time: 2000 hours/year
- One fatal accident

From this information it can be calculated that the LMI per kg nickel = $(37.6*10^{-6})*2000/30 \approx 2.5$ injuries$*10^{-3}$/ tons nickel. The number of fatal accidents per kg nickel can be calculated to 1/47.000 $\approx 2*10^{-5}$ fatality per tons nickel.

It is obvious that using information from one company alone is associated with uncertainties. It can be seen from the figures that the number of injuries per kg nickel has decreased from 1996 to 1997. The decrease is caused by an improvement in productivity (23%) and a decrease in the LMI-index (7%).

There is thus a variance of at least 25% from one year to another with respect to LMI. For fatal accidents, the incidence rate may vary even more, from zero to $1*10^{-4}$ fatal accidents per tons nickel (or even more). The number of injuries and accidents, especially fatal accidents, that is derived in this way should therefore be used only as a crude measure, until a more reliable average can be established.

Besides the variations described above, additional uncertainties are associated with the number of working hours per year per employee and the production volume. In the example, parts of the nickel operation were shut down during periods of time. The number of working hours may therefore be overestimated. At the same time, the intermediate product “Nickel in concentrate” was sold at the international spot market in order to limit stock piling. It is however not possible to deduct from the annual reports if this is reflected in the overall statistics.

The largest uncertainty is associated with the unknown representativity of the company used in the example. This is discussed further in section 2.4.4.

2.4.3.2 Gold as an example

WMC is also a gold producer. In 1997, 529 employees produced 21.838 kg (770.305 ounces) of gold. The Lost time and Medically treated injuries (LMI) per million hours was 48.2 in the gold production. Assuming that each employee worked 2000 hours in 1997, the figure for injuries per kg gold can be calculated: $(529*2000*(48.2*10^{-6}))/21.838 \approx 2.3$ injuries per tons gold.

In 1996, the Lost time and Medically treated Injuries per million hours in the gold operation was 68.7. The number of employees was 876 and the production was 22.787 kg. Using the same procedure and assumptions as for 1997, the corresponding figures can be calculated to 5 injuries per ton gold, i.e. twice as many injuries as in 1997.

No fatal accidents were reported for the gold operations in 1997, while there in 1995 were three fatalities and one fatality in 1996 in gold production in WMC operations. It is therefore suggested to calculate an average value, i.e. for the years 1995-1997 1.33 fatal accidents were observed in average. Using this average, an estimate of the number of fatal accidents per tons gold can be calculated to $1.33/22.312 \approx 6 * 10^{-2}$ fatal accident per ton gold. It should be noted that the average production is calculated using only information from 1996 and 1997.

2.4.3.3 Copper and uranium as an example

At WMC there is an integrated production of copper and uranium and the working environmental impacts are reported as one figure for both productions.

It is however possible to allocate the impacts according to the economic value of the two products and thereby achieve a figure for each of the materials. The necessary data and the calculation procedure is outlined in some detail in the following:

- Copper production = 86.882.000 kg
- Average copper price = US$ 1.02 per pound (US$ 2.24/kg)
- Uranium production = 1.758.000 kg
- Average uranium price = US$ 13 per pound (US$ 28.6/kg)
- LMI = 38.9 per million hours
- Number of employees = 839
- Number of annual working hours per employee = 2000

The basic formula for allocation of the injuries is:

$$\text{Injuries per tons Cu} \approx \frac{\dfrac{\text{Number of injuries} \cdot (\text{Value Cu})}{((\text{Value Cu}) + (\text{Value U}))}}{\text{Produced amount of Cu (in tons)}}$$

Entering the above figures gives the following formula:

$$\text{Injuries per tons Cu} \approx \frac{\dfrac{(839 \cdot 2000 \cdot (38{,}9 \cdot 10^{-6})) \cdot (1{,}95 \cdot 10^{8})}{((1{,}95 \cdot 10^{8}) + ((5 \cdot 10^{7}))}}{86.882}$$

$$\text{Injuries per tons Cu} \approx 6 \cdot 10^{-4}$$

Using the same procedure and the same basic data, the number of injuries per kg uranium can be calculated:

$$\text{Injuries per tons U} \approx \frac{\dfrac{(839 \cdot 2000 \cdot 38{,}9 \cdot 10^{-6}) \cdot (5 \cdot 10^{7})}{((1{,}95 \cdot 10^{8}) + ((5 \cdot 10^{7}))}}{1758}$$

$$\text{Injuries per tons U} \approx 7{,}5 \cdot 10^{-3}$$

2.4.3.4 Steel production as an example

The figures for Danish steel production in the database have been supplemented with figures on Swedish steel production. Sweden produces a large amount of crude steel from both virgin and recycled materials and at the same time the Swedish procedure and traditions for registration of work-related injuries are fairly similar to the Danish procedure.

The information on the amounts of produced steel (4.91 million tons) was obtained from "Jernkontoret" - the Swedish Steel Producers Association (www.jernkontoret.se). The information on work related injuries was obtained from ISA – the Swedish Agency for work related injuries (ISA, 1996).

The figures from the two sources are not fully comparable, because Jernkontoret specifies the total number of employees as well as the total production of steel in Sweden, including the production in sectors outside the NACE-code for this process (271000). It is not possible to distribute neither the number of employees nor the amounts produced on sub-sectors. In contrast to the information from Jernkontoret, the ISA-statistics on work related injuries only concern the employees in the specific sector.

To account for this difference in the basic statistics the production figures from Jernkontoret have been reduced with a factor 1.54, reflecting the relation between the number of persons producing the steel in the production statistics (21.000 persons) and the number of persons employed in the sector included in the ISA-statistics (13.663 persons). The basic assumption behind this is that the frequency of injuries and accidents is the same in the primary sector (NACE-code 271000) and the other sectors producing steel.

2.4.4 Representativity, completeness and precision

2.4.4.1 Representativity

It is obvious that the figures for nickel gold, copper and uranium production are associated with a large uncertainty regarding their representativity for use in LCA. The most prominent example is probably that it can be assumed that there are large differences between the working environment in industrialised countries and in developing countries. When using information from industrialised countries, it is therefore almost certain that they will be an underestimate of the average working-related injuries at the Global level.

The figures on steel production are assumed to be representative for modern steel production. There may however still be large differences between single companies in Sweden and there will probably be even larger differences to countries with less modern production facilities and less focus on the working environment.

The outlined procedure for establishing inventory data is very simple once relevant data sources have been identified, and it is often possible to obtain data for several years from the same source and thereby produce more reliable averages for the given company or country. It will often also be possible to obtain information from several companies and countries and thereby establish ranges for the working environmental impacts per produced unit.

2.4.4.2 Completeness

It should be noticed that the information from the specific producer (WMC) only regards the number of accidents and injuries and not reported damages and diseases following (long-term) exposure. It is a well known fact that employees in the mining industry are exposed to high levels of e.g. noise and hazardous chemicals and it can therefore be expected that a more detailed examination of the health records at the company will show a relatively high incidence rate. This information was not available to the project group, but may eventually be obtained from official statistical sources.

2.4.4.3 Precision

Based on the previous paragraphs it can be concluded that the precision in the inventories for productions outside of Denmark is relatively low. The most serious concern is that reported diseases and damages are not included in the inventory and the overall impacts from this type of production are significantly underestimated.

In the end, the need for precision will always be balanced by the resources needed to provide the information. It is therefore suggested that the figures derived from foreign sources primarily are used as a first indicator in a LCA. If e.g. nickel mining and further production proves to be important in the LCA, LCA consultants or companies are advised to seek more precise information from the actual supplier or to establish a broader overview of the working environmental impacts.

2.5 The resulting database

The resulting database from the calculations is presented in Chapter 9. The 80 sectors in the database are grouped according to the following headlines:

- Production of raw materials (e.g. crude oil, gas, electricity, iron, gold, gravel, wood, paper and cardboard).
- Processing and production of final goods (e.g. wood products, chemical products, plastic products, etc. with a further division into more detailed product categories)
- Production and assembly of final goods (e.g. pumps, refrigerators, chairs, stoves, etc.)
- Transportation (railway, ship, truck)

It should be noted that the general headlines reflect a wide variety in the state of the products. The production within a sector may thus comprise both semi-manufactured goods for further processing, components for assembly with other components into final products and final consumer products.

With the 80 unit processes in the database the need for information can be covered in some detail for many of the LCAs that are being made today. One should however be aware that the database is not homogenous with respect to the activities taking place inside and outside Denmark. This is discussed further in section 2.4.4. This is especially the case for the production of virgin metals, where the only impacts described are the number of accidents.

Furthermore, the impacts have generally been calculated using company-specific information with an unknown representativity.

Another example is production of coal, where average American conditions have been used for the calculations. Again, the level of detail with respect to the working environmental impacts is low compared to the other sectors in the database, and the representativity is unknown.

3 The methodology in relation to the ISO 14040-series

The discussion of the methodology in relation to the ISO 14040-series in the following chapters is based on the assumption that the assessment of the working environment is an integrated part of the EDIP method. It can be used as the starting point for the definition of goal and scope for a study including the working environment, and it can also be used when interpreting the results and how they were derived.

The discussion is mainly based on the accepted standard EN ISO 14040 (1997), but includes elements from the ISO 14041 standard (Goal and scope definition and inventory analysis), and the draft standards ISO14042 (Life cycle impact assessment) and ISO 14043 (Life cycle interpretation).

3.1 Practical remarks regarding the use of the methodology

The method for assessment of working environmental impacts in LCA is developed to function along with the other impact categories addressed in the EDIP LCA-method.

In practice this is reflected in the developed database, the aim of which has been to produce information on working environmental impacts for many of the unit processes in EDIP.

The easiest way to include the working environment in EDIP is by integrating the database on working environmental impacts in the existing PC-tool. This has not been possible within the project period, but may be possible in connection with a general update of the PC-tool and the methodology.

Meanwhile, it is suggested that assessment of the working environment in LCA is done either by having the practitioner entering the data manually into the PC-tool or by making a spreadsheet in which the calculations can be done.

When this has been done it is possible to include the working environment in the interpretation of the results of a LCA using the general EDIP method.

The following chapters give a realistic picture of the pros and cons of the developed methodology with respect to the four elements in an LCA:

- Goal and scope definition
- Inventory analysis
- Impact assessment, and
- Interpretation

The discussion does not cover all elements in equal detail, but focuses on those that are assumed to be the most interesting seen from the point of view of the LCA practitioner and the decision-maker.

4 Goal and scope definition and inventory analysis

The international standards ISO 14040 and ISO 14041 states that “The goal and scope of an LCA shall be clearly defined and consistent with the intended application” (ISO, 1997/1999).

As the discussion in the present report does not consider specific applications some of the elements in the standard are only addressed very briefly while other elements are discussed in detail because they are of general importance.

4.1 Goal of the study

The specific goal of a LCA study does not necessarily change when the working environment is included in the impact assessment. It will, however, often be necessary to state explicitly to what extent the assessment of the working environment will be taken into account when the goals of the study are to be met.

4.2 Function, functional unit and reference flow

Assessment of the working environment should be done by using the same functional unit as for the other parts of methodology. Thus, including the working environment should have no effect on the definition of the functional unit or the reference flow.

4.3 System boundaries

Ideally, the system boundaries for the LCA should be the same whether or not the working environment is included, i.e. the same unit processes are included. It should, however, be observed that some processes often are omitted from the LCA because they are assumed to have only a minor environmental impact. It is at present not known whether this assumption also is true for the working environmental impacts, and a previous omission of a process from the system boundaries should therefore be reconsidered.

One important difference from a general LCA is that the working environmental impacts in the use phase of a product can not be included, neither for the general consumer nor in professional settings. The reason for this is it is not possible to allocate the impacts in a given sector to specific products. As an example, muscolo-sceletal disorders in office workers can very seldom be attributed to a specific chair, table, personal computer or mouse, but are rather the result of an interaction between the general office layout, the specific furniture, the tasks to be done, the organisation of the work and the worker.

It should also be observed that precise information on many processes can not be found in the database. Instead, it is recommended that the practitioner use data for a process that resemble the actual process as much as possible. The choice of process should be addressed in the LCA report.

4.3.1 Description of the data categories

The data categories are described in section 2.1.1. These categories are available in Danish working environmental statistics, but may have a different format or be less detailed in other countries.

In order to reduce the number of data (and impact) categories, nine different kinds of accidents have been integrated into two headings, i.e. "Total number of accidents" and "Fatal accidents". This loss of detail is considered to be of minor importance as the primary aim is to establish an overview of the impacts as such and not to distinguish between e.g. injuries and sprains to arms and legs.

4.3.2 Criteria for inclusion of inputs and outputs

The criteria for inclusion of inputs and outputs is not a specifically related to working environmental impacts. In short, the present methodology and the database is developed to be used with the other parts of the EDIP-methodology, i.e. the life cycle should be covered as far as possible (the number of unit processes) with as detailed as impact assessment as possible (the number of impact categories).

In the end, the choice of which in- and outputs to include is made by balancing the necessary efforts with the additional information that can be obtained. For the moment being it is recommended that assessment of the working environment follows the assessment of the other impact categories, i.e. it is assumed that the processes included in the LCA generally will cover the working environment satisfactory. If experience shows that this is not always the case, it will be very straightforward to include additional processes with a significant impact on the working environment but with only minor impact on the environment.

4.4 Data quality requirements

The ISO 14040 standard series states that "Data quality requirements specify in general terms the characteristics of the data needed for the study. Data quality requirements shall be specified to enable the goals and scope of the LCA study to be met."

The following paragraphs highlights the most important issues that should be taken into account when defining the data quality requirements and subsequently be addressed in a LCA report where the methodology has been used.

4.4.1 Time-related coverage

As for all other inventory and assessment data in LCA, the methodology aims at using as recent data as possible. However, in order to minimise statistical variations an average of the information for the previous three years (1995-1997) has been used when establishing the database.

4.4.2 Geographical coverage

The database that is developed for use in the method is almost exclusively based on Danish statistics. The primary reason for this is that with a limited budget the project group considered it more important to collect Danish information on a broad range of sectors rather than collecting information on a few selected sectors from a broader range of countries.

This must be kept in mind when interpreting the results, i.e. the practitioner and the commissioner must know that the results reflect the impacts as if all unit processes had taken place in Denmark.

This is obviously not the case for very many products, and the lack of an international database must at present be regarded as a major flaw in the method. On the longer term, however, it is suggested that comparable information from other countries is produced using the same procedure. The statistics on goods production is uniform from one country to another and the calculation of the amount of produced goods in a given sector is relatively straightforward. The statistics on occupational accidents and injuries vary from country to country, but will most often include common elements. When combining information from different countries it should however always be stated how an aggregation of the information has been performed.

4.4.3 Technology coverage

As the database was established using information on whole sectors, the figures can be assumed to describe average conditions with respect to the technological level.

The range used to calculate average conditions must be assumed to be very broad. There is little doubt that the working environmental impacts per kilo product will be different if small/light products (e.g. nails and screws) are compared to big/heavy products (e.g. railroad tracks). In order to minimise the potential error, a database has been established for different product types from different sub-sectors where possible.

The effect of changing from old fashioned to modern technology cannot be assessed using the methodology. Introduction of new and more efficient technology commonly reduces the working time per produced unit and - accordingly - also the impacts per produced unit. There is, however, a risk that more efficient technology may increase the impacts on the musculo-sceletal system through an increased amount (or intensity) of monotonous and repeated work. It is also possible that the use of more efficient technology can change the psycho-social working environment in a negative direction, e.g. by people working alone instead of in teams.

4.4.4 Precision, completeness and representativity of the data

4.4.4.1 Precision and completeness

As indicated in the previous paragraphs the described methodology is a compromise between the demand for precise information on a given unit process on one hand and the demand for a broad database on the other.

It is evident that the precision will be low when information on the sector level is used. The ideal situation is to have sectors with a large and uniform output (one or very few products), but this can only be achieved in a very few cases. Instead, an iterative process had to be applied, the first iteration being to identify sectors with a suitable number of reported occupational accidents and diseases.

This approach made it possible to establish a broad database in a batch process. The project group selected a number of "interesting" sectors, and the possibility of calculating production volumes for these sectors were discussed with a statistician from the Statistics Denmark. Some of the selected sectors were excluded following the discussions while others were defined slightly different. The database is therefore considered to be almost complete with respect to the number of processes for which the requested information can be derived. It may, however, be possible to establish similar information for other processes, e.g. production of food products, if a special need arise.

4.4.4.2 Representativity

The representativity has also been discussed in the previous paragraphs. It is obviously a drawback that only Danish working environmental conditions are addressed in the database, but also here a compromise had to be made in the project. This time the compromise was made between the demand for a broad database (many processes) and the possibility of establishing more (international) data sets for a few processes, thereby being better able to discuss the representativity.

Data sources similar to those used in the present methodology can be found in most industrialised countries, and it is therefore possible to establish the same information from other countries, at least with respect to some of the impact categories addressed by Danish statistics..

Establishing information from other countries will improve the usefulness of the method significantly. It will not only be possible to compare the working environmental impacts for a given economic activity, but it will perhaps also be possible to establish the requested information for processes that are assessed with a great uncertainty by using Danish figures.

4.4.4.3 Missing information

The major problem in using data from other countries is that there are differences in the way the working environmental impacts are reported. Many countries only report the number of accidents and/or the number of muscolo-sceletal injuries, while incidents of cancer, allergy, hearing damages etc. are not reported. The database is thus not complete in these cases, and the importance of the missing information should be considered in the interpretation of the results.

The present database emerged as a result of a batch process and it is therefore not possible to pinpoint the most problematic data sets by using a formal methodology. It is however obvious that the production of many raw materials is limited in Denmark and the assessment of this part of the life cycle is therefore associated with an inherent uncertainty. The following examples can illustrate the problem:

- The most common plastic raw materials (e.g. PE, PP, PVC, PS and PET) are not produced in Denmark. In order to establish a figure for plastic production, the average impacts per kilo produced product in the Danish chemical industry (sector 232000) was used. Information from the same sector in other countries may prove to be more differentiated, allowing a calculation of the impacts in the plastics processing sector as a whole or - more ideally - for production of specific plastics.

- Production of iron and steel (sector 271000) is described in two ways. Firstly by using information from one Danish company, which uses recycled steel as the main raw material, secondly by using average Swedish data, primarily for production of virgin steel. The latter set of data only contain information on accidents, but it is worth noticing that the accident frequency is twice as high in Denmark as in Sweden. Other countries also have a larger number of steel-producing companies using both iron ore and recycled steel as raw material. Again, it would be interesting to be able to discriminate between different countries and different processes.

- Production and processing of lead, zinc and tin is contained under one heading in the developed database. Although the world wide production volume is low compared to plastic and steel production, it may be possible to pinpoint countries where the production volume is sufficiently high to enable more precise calculations.

4.4.4.4 Company statistics

Besides the possibility of establishing information based on national statistics it may also be possible to use company specific information. This option can especially be utilised in companies with a large and uniform product output and with a detailed statistical material on the working environmental impacts.

4.4.5 Consistency and reproducibility of the method

The method and the database are developed to provide as consistent and reproducible results as the basic statistical information allows. It is obvious that the methodology will give the same results once the system boundaries and the in- and outputs have been established. It is also obvious that the interpretation and use of the results is strongly dependent on how well the geographical and technological conditions are related to the basic statistical data.

4.4.6 Sources of data and their representativity

The data sources and their representativity is discussed previously in the report under the headings time-related coverage, geographical coverage and technology coverage.

It can be concluded from these discussions that the data sources are representative for average Danish conditions in selected sectors. If data from one sector is used to describe the conditions in another sector, e.g. when information on production of ceramic household products is used to describe the production of advanced technical ceramics, the representativity becomes uncertain. The two economic activities may have a number of common features with respect to the impacts in the working environment (e.g. by using the same type of basic raw materials and the same basic processes), but the specific choice of materials and processes will most often be very different for the two activities.

4.4.7 The uncertainty of the information

The described procedure is assumed to produce results with a low variability but a relatively high uncertainty.

One main reason for the low variability is that the Danish statistics are collected and processed by central authorities, securing that the basic data are available. Furthermore, the information is averaged over three years (1995-1997), securing that accidental or temporary variations become less significant.

The relatively high uncertainty is ascribed to the methodology as a whole. It is not possible to add any precision to the basic information, and the uncertainty of the study must therefore be thoroughly discussed in the interpretation. Guidelines for the interpretation of the working environmental LCA can be found in Chapter 6.

The only option for decreasing the uncertainty is considered to be a methodology using process specific information. This option is discussed in more detail in section 7.4.

4.5 Allocation procedures

Allocation procedures is often a very important element in LCA, i.e. the choice of allocation procedure can change the results significantly.

In EDIP97, some but not much attention was given to special problems when allocating the impacts in the working environment. The main recommendation was that the working time was used when possible to allocate the impacts between multi-output processes. If this was not possible the weight of the products was suggested as allocation parameter.

In the new method, product weight is used to allocate the impacts in a given sector. It is thus inherent in the method that two products will have exactly the same impacts if they are produced within the same sector and have the same weight, e.g. one kilo of polystyrene have the same working environmental impacts as one kilo of polycarbonate.

This is not very satisfactory, but the level of detail in the basic statistics does not allow a more precise assessment. It may be possible as a future improvement to use company specific information in order to achieve the desired level of detail, but in doing so a number of other uncertainties are introduced. Firstly, the use of company statistics will require an intensified use of allocation procedures, e.g. by using value as the basis for allocation. Secondly, the statistical basis (i.e. the production volume and the number of occupational accidents and injuries) is often relatively small on the company level, introducing a significant uncertainty regarding the data quality.

This allocation procedure is for example used when supplementing the database with information from foreign companies, e.g. raw material producers, using integrated processes in their production (see the example in section 2.4).

4.6 Aggregation over the life cycle

4.6.1 Historical remarks

Exposure time was used in EDIP97 and working time in the IVF method to aggregate impacts from different processes in the life cycle. The choice is reasonable because it gives the possibility of relatively precise assessments if a process assessment methodology is used.

In practice, both of the described process assessment methods are very time consuming and this fact caused the development of the sector assessment method in EDIP97. In order to be able to aggregate information derived from both the process and sector assessment, the sector assessment in EDIP97 also had to be related to the exposure.

In the EDIP97 sector assessment, the calculation of exposure time is based on information on the average number of accidents and injuries per year or per million working hours in a given sector as well as assumptions regarding the number of employees that are exposed to noise, chemicals etc. in a given sector. This information must subsequently be converted to damages per functional unit (e.g. per ton material) in a number of calculation steps, taking total production volumes, total number of employees and average working time in the sector into consideration.

These calculations were only examplified to a very limited extent in EDIP97, but were in the present project proven through case studies on plastics and steel to pose a large number of practical problems.

4.6.2 Aggregation in the present methodology

In the present methodology, only a sector assessment is performed. This means that the information from all unit processes in the developed database can be easily aggregated over the life cycle, i.e. there is no demand for collection of additional information, once the basic statistical information has been collected.

Information from other data sources, e.g. foreign trade statistics or company specific information, will most often not provide information on exactly the same impact categories as in the developed database. This problem is discussed further under impact assessment (section 5**).**

5 Impact assessment

5.1 Introduction to Life Cycle Impact Assessment

According to ISO (ISO/FDIS 14042:(E), 1999), the purpose of Life Cycle Impact Assessment (LCIA) is “to assess a product system’s life cycle inventory analysis (LCI) to better understand their environmental significance”. LCIA can, for example, be used to

- Identify and assist the prioritisation of product system improvement opportunities
- Characterise or benchmark a product system and its unit processes over time
- Make relative comparisons among product systems based on selected category indicators, or
- Indicate environmental issues where other techniques can provide complementary environmental data and information useful to decision-makers.

Within this framework, the methodology for working environmental assessment can be seen as a possibility for broadening the perspectives of an LCA by including knowledge about some of the impacts that directly affect humans, i.e. the people working to produce the products that are being investigated in the LCA.

5.2 The elements in Life Cycle Impact Assessment

In general, LCIA can be divided into a number of steps:

- Selection of impact categories, category indicators and models
- Classification (Assignment of Life Cycle Inventory (LCI) results)
- Characterisation (Calculation of category indicator results)
- Optional elements and information
    - Normalisation (relative proportion of category indicators to a reference value)
    - Grouping
    - Weighting
    - Data quality assessment

In the following sections, the developed methodology is described in relation to these general steps.

5.3 Selection of impact categories, category indicators and models

5.3.1 Selection of impact categories

The following impact categories have been selected for inclusion in the assessment:

- Fatal accidents
- Total number of accidents
- Reported injuries, diseases and damages
    - Hearing damages
    - Cancer
    - Muscolo-sceletal disorders
    - Airway diseases (allergic)
    - Airway diseases (non-allergic)
    - Skin diseases
    - Psycho-social diseases
    - CNS function disorder

The basic statistical information gives the possibility of dividing the total number of accidents into a number of specific categories, e.g. sprains and wounds. The benefits from doing so is however offset by the amount of work necessary to compile and process the information, and the possibility is thus not utilised in the current methodology.

5.3.2 Category indicators

The developed methodology is more simple than the EDIP97 methodology in the impact assessment step, simply because the impacts have been related to specific materials and processes already at the inventory level.

In the methodology, the inventory results, the category indicators and the category endpoints are the same. This is an inherent feature of the methodology, the reason being that the basic information is collected and processed at the national system level.

This methodology is thus not strictly in accordance with the final draft ISO 14042 standard which prescribe impact assessment in the above steps (section 5.2). However, Udo de Haes *et al.* (1999) acknowledges that the choice of the indicator at endpoint level may open new possibilities for a science-based aggregation.

If the choice of indicator at endpoint level is regarded as a problem, it could theoretically solved by using the procedure in EDIP97, i.e. that exposure time is used to aggregate the impacts from different parts of the life cycle. The major requirement in doing so is that assumptions should be made regarding exposure time in different sectors.

This is probably not very difficult, but will introduce additional uncertainties as the assumptions must be based on whatever relevant and available information that can be found. Under all circumstances the only profit from doing so is that the methodology will become more in line with the ISO 14042 requirements. There will be no additional important information with respect to the working environment as the final results ideally (and hopefully also in practice) should be the same.

It should be remarked at this point, that one of the important ideas behind using exposure time as the aggregation factor in EDIP97 was to accommodate the different data formats in the sector and the process assessment methods. As the process assessment methodology is not included in the present methodology, this need no longer exists.

5.3.3 Models

The model chosen for data collection and -treatment is entirely based on precisely defined statistical information. As described in other sections, the chosen model has its limitations with respect to both precision and general requirements in the ISO standards. At the same time it should be recognised that the model gives the possibility of including new and relevant issues in an LCA, and the choice should primarily be regarded as a first step towards a more detailed assessment methodology.

5.3.4 Assignment of LCI results (Classification)

As described earlier, the LCI results are the same as both the category indicators and the category endpoints.

This is a logical consequence of the close relationship between the governmental demand for decision support regarding working environmental issues and the available statistics on working environmental impacts.

The difference between assessing working environmental impacts and environmental impacts can thus be seen as the result of a long tradition for governmental interest in the working environment (The Danish Labour Inspectorate was founded more than 100 years ago as opposed to the natural environment (the Danish EPA was founded less than 30 years ago). During this period of time, assessment of the working conditions have changed considerably and the management tools that can be used for data collection and handling have been focused on creating an overview at the sector level rather than establishing precise information for single companies.

It should be remarked that there is additional statistic material available, e.g. in the form of exposure measurements for a number of chemicals and processes. The measurements are however relatively old, and it will be very difficult to relate the measurements to the processes that are actually included in the system boundaries. The information may however be useful in the sensitivity analysis or in the interpretation of the results as it can be used to pinpoint some of the processes within an economic sector which have a high potential for causing the impacts in the category endpoints.

5.3.5 Classification of category indicator results (Characterisation)

The remarks given in the previous section also apply to the characterisation element in LCIA.

5.4 Normalisation

The aim of the normalisation step in EDIP is to give an overview of the relative importance of the single effect categories. This is done by relating the actual (calculated) impact to the average impact caused by a person in the relevant geographic area.

In the present methodology, the basis for the normalisation is easily identified as the total number of reported working environmental accidents and damages in Denmark, distributed evenly on the number of Danes in the same period of time. As for the other calculations, the normalisation factors in Table 5.1 have been calculated as a three-year average for 1995-1997.

The procedure is thus simple, using the total number of accidents and work-related diseases as reported to the Danish Labour Inspectorate and dividing with the number of inhabitants in Denmark.

Table 5.1 . Normalisation factors for working environmental impacts.

	Person equivalents, PE	Worker equivalents
Basis for normalisation Effect category	Danish population	Danish work force
Fatal accidents	$1.54 * 10^{-5}$	$3.06 * 10^{-5}$
Accidents	$9.69 * 10^{-3}$	$1,92 * 10^{-2}$
Cancer	$3.54 * 10^{-5}$	$7.02 * 10^{-5}$
Psycho-social damages	$1.40 * 10^{-4}$	$2,77 * 10^{-4}$
CNS-function disorders	$6.37 * 10^{-5}$	$1,26 * 10^{-4}$
Hearing damages	$4.56 * 10^{-4}$	$9.06 *10^{-4}$
Airway diseases, non-allergic	$1.00 * 10^{-4}$	$1,99 * 10^{-4}$
Airway diseases, allergic	$7.93 * 10^{-5}$	$1,57 * 10^{-4}$
Skin diseases	$3.12 * 10^{-4}$	$6,19 * 10^{-4}$
Muscolo-sceletal disorders	$1.44 * 10^{-3}$	$2,85 * 10^{-3}$

The normalisation reference or person equivalent can be interpreted in the way that if every Dane was working, one out of a hundred persons would experience an accident at work every year.

The normalisation reference for the working environment is comparable to the normalisation reference for other environmental impacts, e.g. the contribution of an average Dane to acidification is calculated by dividing the total Danish contribution to acidification with the number of inhabitants in Denmark.

When performing the normalisation step, i.e. using the person equivalent, it is possible to examine both how the working environment differs between products and how important the working environment is in comparison with the impacts in the natural environment.

In Table 5.1, another set of normalisation factors, “The worker equivalents”, is found. This set of figures show the probability for an average worker of experiencing an accident or report a work-related disease in a year. The only difference between the two sets of factors is that the worker equivalent is calculated using the number of employed persons in Denmark. The worker equivalent is suggested for use in specific working environmental LCAs, where absolute figures may give more suitable information than when using the Danish population as the normalisation reference. It should however be stressed that when the worker equivalent is used in normalisation, comparisons with other effect categories can not be made.

5.5 Grouping

Grouping is according to ISO/FDIS 14042:(E) “assigning impact categories into one or more sets. It may involve sorting which is descriptive or ranking which is prioritising”.

Grouping is an optional element in LCIA and is not included in the general EDIP methodology as described in EDIP97.

No efforts have been devoted to describe a grouping procedure for assessment of working environmental impacts in the present methodology.

Seen in view of a lacking weighting procedure (see section 5.6), the development of procedures for either grouping or weighting of working environmental impacts could provide useful information for decision-makers. At the moment, the results of the assessment are presented without any kind of prioritisation, and the decision-maker must therefore use (subjective) values in the interpretation.

5.6 Weighting

The normalisation procedure for the working environment gives information on which effects that will be most frequently observed in the life cycle of a product. However, the most frequently observed effects are not necessarily the most problematic, e.g. fatal accidents must be regarded as more serious than hearing damages.

To account for this, the general EDIP methodology introduces an optional impact assessment step, namely weighting. The weighting of the impacts in the natural environment is done by using political targets for reduction in emissions.

This is however only possible to a limited degree for the working environment as the only specified target is that the number of fatal accidents shall be reduced to zero before year 2005. In addition, the Danish minister of labour has identified a number of other impacts that are of special concern and therefore should be reduced or totally avoided by year 2005:

- Hearing damages
- Occupational exposure to carcinogenic substances and work-related damages to the central nervous system caused by exposure to solvents or heavy metals
- Injuries to children and adolescents at work
- Damages to health caused by psycho-social risk factors at work
- Sickness or serious annoyances caused by an unsatisfactory indoor climate
- Damages and injuries caused by lifting of heavy burdens or by monotonous repeated work

No specific goals have been specified for these impacts and it is also not possible to relate all the concerned impacts to the effect categories used in the methodology.

It is therefore suggested that the weighting step be excluded from the assessment of working environmental impacts for the moment being. As a consequence, when comparing impacts in the natural environment to impacts in the working environment, this should be done following the normalisation step.

5.6.1 Suggestion for future development

In future developments of the methodology, alternative weighting methodologies should be considered, e.g. weighting by using economic indicators.

One way of rating the injuries could be the “Injury table” issued by the Danish National Board of Industrial Injuries. The table is used to determine the size of the indemnity when a person suffers a compensation-eligible occupational injury. The table rates a wide variety of injuries in percent of full disablement and can therefore be used as a weighing tool.

However, there may be a problem with the difference in level of detail. The impact categories in the assessment is often less detailed than the “Injury table”. An example is the impact category “Muscolo-sceletal disorders” which covers a wide range of injuries with different levels of seriousness that are rated differently in the injury table. Another example is the impact category “Hearing damages” which only includes reduction in hearing but which can render the victim 5 - 75 % disable according to the “Injury table”.
This means that one either have to increase the level of detail in the impact categories or somehow make an average over the different rates in the injury table.

The data basis to make the impact categories more detailed is available and by studying what kind of injuries they consists of, it would be possible to use the “Injury table” as a weighing tool. The “Muscolo-sceletal disorders” category could thus be divided into the different types of accidents, which could be given a percent rate. Since the number of accidents of each type is known it would be possible to estimate a percentage rate for the impact category.

One last problem remains due to the fact that not all registered injuries are compensation-eligible. However, this would not shift the balance since the accidents that are not compensation-eligible are minor accidents that would not weigh as much as those which are compensation-eligible.

6 Interpretation

6.1 Introduction

Interpretation of the results of a LCA should according to the ISO 14040-series (ISO/CD 14043-2, 1998) be "a systematic technique to identify, qualify, check and evaluate information from the results of the life cycle inventory analysis and/or impact assessment of a product system, and present them in order to meet the requirements of the application as described in the goal and scope of the study".

The standard is still a draft and it may be changed significantly. At the same time, there is very limited experience with the use of the new methodology as only one case has been described. It is therefore chosen firstly to describe the possibilities and limitations of the present methodology in general terms and – in a subsequent chapter – to describe the findings of the case and how they can be interpreted.

6.2 Why include the working environment in LCA?

The objective of including the working environment in LCA is most often stated to be the desire to be able to make products with less environmental impacts without increasing the impacts in the working environment. The following guidelines for interpretation are aimed at LCAs with this goal.

6.3 What can the working environmental LCA tell the practitioner?

The described methodology has a relatively low degree of precision with respect to specific materials and processes. The developed database is however so broad that it is now possible to cover a large part of the life cycle with respect to working environmental impacts as demonstrated in the case study.

The first option that emerges is to pinpoint the most important activities in the product system and examine these in more and more detail. As in a LCA of the natural environment, some typical patterns for products and product systems can be seen.

6.3.1 Energy consuming products

In products or product systems using electricity during the use, this will presumably be a very dominant factor with respect to working environmental impacts. A closer examination will reveal that the impacts from coal mining is the dominant factor in electricity consumption (at least in Denmark). An even closer scrutiny will reveal that underground mining is much worse that open cut mining. On the same level of detail, the database will show that there are large variations from country to country. Going back to the basic statistical sources it can be seen that there are large variations between the mines in a country, and also that there are considerable variations from year to year in a given mine.

The possibilities for reduction of the working environmental impacts that can be drawn from this stepwise examination can be summarised as follows:

- Reduce the electricity consumption of the product
- Change the product's energy source from electricity to oil - or perhaps even better - natural gas, or
- Change the fuel for electricity production from coal to natural gas or oil
- Increase the efficiency in electricity production
- Import coal from the countries with least working environmental impacts in the coal mines
    - Coal from open mines
    - Coal from specific mining operators with a high working environmental standard
    - etc.

The recommendations regarding electricity consumption are thus in line with those that can be obtained from a general LCA. It can also be seen that the results can be interpreted at different levels of detail and thereby meet the needs of different decision-makers, from the product developer to the electricity producer.

6.3.2 Non-electricity consuming products

Most of the common consumer products do not consume electricity during use. In this type of products, the working environmental impact profile will therefore be different.

For products with a short life, e.g. packaging for food products, the impacts will mainly be related to the production steps before the use phase. For products with a long life, e.g. an office chair, the product may have an impact both during its production and its use. As explained earlier, the methodology does not give the possibility of distributing the impacts in a given process, e.g. office work, on the multitude of products used to perform the work. In conclusion, the methodology is best suited to assess the impacts during the production steps.

It will be a general finding that the heavier a product, the more working environmental impacts will be the result. More precisely, this will be the case if the product is made of a single material or if the proportion of the used materials do not change from a lightweight product to a heavy product. This conclusion is also in line with the general findings in LCA. One should, however, be aware that this finding is inherent in the methodology because of the basic assumptions. Another inherent implication is that differences in the working environmental impacts between two or more producers of similar products, e.g. cartons for milk packaging, can not be identified by using the method.

The possibility of distinguishing between products is better when different materials are used in products fulfilling the same function. One such example is paper bags and plastic bags used for transportation of consumer goods from the supermarket to the home. A LCA of these simple products will reveal large differences in the working environmental impacts as well as in other effect categories. The difference in working environmental impacts reflects the average working conditions through the two life cycles.

The same possibility is not present if bags made of polyethylene and polypropylene are compared. Information on the working environmental impacts as well as production volume has been collected on the sector level, and the resulting impact per kilo material is exactly the same for the two products. This finding is probably in good accordance with the actual impacts in a given company.

For more complicated products, e.g. office chairs, the results from a working environmental LCA can point to the materials and processes with the highest potential for impacts. This knowledge may be used by the producer when choosing a supplier, e.g. by having the suppliers answering a questionnaire with general questions concerning the management of the working environment (is the working environment included in the environmental management system?) and specific questions on materials and processes (e.g. are carcinogenic substances being used in the production, or does the noise level exceed 85 dB in the production process?)

6.3.3 Comparisons using company specific information and average values

The lack of detail in the database can to some extent be counterweighted by the possibility of comparing the performance of a company with the average of the entire industry. In practice, this is done by collecting the information given to the Labour Inspectorate regarding work related injuries and accidents for e.g. a five-year period and relate this information to the produced volume in the same period. The latter information is best collected by using input-data for the company, i.e. how many kilos of raw materials was bought in the period.

It is obvious that this type of comparison is associated with a large uncertainty, especially for small companies with a very low number of accidents and injuries. For larger companies, the comparison may however provide useful information.

6.3.4 Comparisons on the societal level

When LCA of the working environment is used in life cycle decision-making on the societal or political level, the present methodology has both advantages and disadvantages.

The advantage of the methodology is that it is possible to examine the difference in working environmental impacts between the systems investigated. As indicated many places in the report, the products under examination must be different with respect to the material composition in order to see differences other than those introduced by differences in weight. If, however, the examined products differ with respect to material composition, it may be possible to observe a difference in working environmental impacts, not only with respect to the number of injuries and accidents, but also with respect to their nature. A shift from product A to product B may for example increase the expected number of hearing damages while the number of reported cancer incidents presumably will be smaller.

The main disadvantage of the methodology lies in the basics of the methodology, i.e. that average data are used to describe sectors with a large variation in the output of materials and products. Decision-makers must be aware of these shortcomings if unjustified decisions are to be avoided.

In relation to communication of working environmental conditions at the company level, at least two tools are seen as more operational than working environmental LCA. Work place assessments give an overview of the impacts of a given process at at specific company and provide a prioritisation of the efforts that potentially can minimise these impacts. A certified working environmental management system like OHSAS 18001 ensures that a company fulfils all legal requirements and that the company is devoted to a continuous effort to prevent working place injuries on both the short and long term.

7 Comparison of methods

The present method differs significantly from the method described in EDIP97, the major difference being that the present method is a sector assessment without the possibility of examining specific processes at the company level. The advantages and disadvantages of this are discussed several places in the previous chapters and are summarised in the following.

7.1 Advantages of the present method

7.1.1 An extensive database

The present method is a sector assessment that is based exclusively on statistical information. This approach has allowed the development of a database regarding Danish working environmental impact. The database is fully documented in the report and gives thus the possibility of including working environmental impacts in LCA without having to collect and process information from scratch.

This is judged to be a major step forward as one of the obstacles in both general and working environmental LCA is the need to collect and process information from a large number of processes. A very crude conclusion is that there are no longer any excuses for not including the working environment in an LCA. The final choice of whether to include the working environment or not is however still up to the commissioner of the LCA study.

7.1.2 A uniform database

The database has to a very large extent been developed in a batch process using information from the Danish Labour Inspectorate and the Danish Statistical Agency. This means that the level of detail and precision is equal for all processes for which the information has been derived in this way.

7.1.3 Possibilities for international development

Both the methodology and the development of a database allow for an internationalisation of the method, i.e. it is possible for practitioners in other countries to develop national databases by using the same procedure.

There will of course be differences from one country to another as a consequence of different ways of reporting working environmental impacts on the sector level. This should, however, not be a great obstacle since the number of impact categories could be in- or decreased to meet the goal of the LCA. The most natural approach would be to include a discussion of the national differences in the sensitivity analysis and thereby secure that the life cycle overview is not lost.

7.2 Disadvantages of the present method

The major disadvantage of the present methodology is that the level of detail is relatively low. This is an inherent feature of the methodology that is caused by the level of detail in the basic statistical information.

7.2.1 Only an sector assessment

The methodology described is purely a sector assessment. This is in contrast to the method described in EDIP97 in which the methodology was a mixture of a process assessment and a sector assessment.

Including a process assessment increases the level of detail in some parts of the assessment and makes it possible to compare the activities in a given company or process to the rest of the life cycle. At the same time, however, mixing the two different approaches introduces additional uncertainties regarding aggregation over the life cycle as the data format in the two methods can only be made comparable by using a number of assumptions regarding exposure time. It is not possible to compare the uncertainty introduced by the two approaches.

7.2.2 No company specific information

The present methodology does not require any special efforts at the company level. This means that no improvement options can be identified at the company level.

It is, however, debatable whether the process assessment in EDIP97 is suitable for identification of improvement options. It is recognised that by following a product through the process line at a company some of the important working environmental impacts are identified and - to some extent - also quantified.

7.2.2.1 Work Place Assessments

In Denmark, Work Place Assessments (WPA) are mandatory in all companies with more than five employees. Every process is examined in order to find out whether it causes a working environmental impact. The examination is not restricted to a limited number of parameters like noise or chemical exposure, but should give a broad overview of all types of working environmental impacts, e.g. including psycho-social impacts and indoor climate.

The WPA approach is judged to give more detailed information on the working environment for single employees than the process assessment in EDIP97.

Another possibility for establishing product related information is to use the screening methodology suggested in EDIP97 and in MUP (Schmidt *et al*, 1994). The screening focuses on exposure to chemicals and may be used to identify the processes with the largest potential for many of the impacts that are examined in the sector assessment.

If exposure to hazardous chemicals (and other stressors in the working environment) is avoided or minimised it should ideally be reflected in a better working environmental profile. This is not possible when using a sector assessment based on statistical information from large economic sectors
.

7.3 Comparison with international methods

7.3.1 The IVL-method

The present methodology is very similar to that developed by IVL in Sweden (Antonsson, 1999), the major difference being in the calculation procedure. The advantage of the present methodology in relation to the IVL-method is that it is possible to establish information on a more detailed level, i.e. for more sub-sectors including those where some of the economic output is measured in “pieces”, “m^2”, “drums”, etc.

7.3.2 The IVF-method

The method developed by IVF is exclusively a process assessment methodology with the inherent advantages and disadvantages associated with this type of assessment.

There is little doubt that the IVF method can provide relatively precise results at the company/process level, but the method is also very demanding in terms of resources (man time). This is prohibitive for the inclusion of working environment in LCA on the short term, but on the longer term the method can provide a very useful insight to working environmental impacts in the life cycle perspective.

7.4 Future developments

With the present methodology and the associated database a number of new possibilities have emerged.

7.4.1 PC-program

First of all, the necessary efforts in including the working environment in LCA have been reduced significantly. It is thus possible for LCA practitioners to use the developed database along with information on other impact categories without significant problems. The one remaining problem is that the present methodology and the database is not included in the EDIP PC-program, and it is suggested that the present methodology is included when the next updating of the PC-programme take place.

7.4.2 International collaboration

Secondly, the present methodology opens up for a broader international collaboration on working environment in LCA. The developed methodology is based on statistical information, part of which is well known and easily accessible on the national level (the goods statistics). Statistics on working environmental impacts probably differs more from one country to another, but it should still be possible to establish comparable information for many countries and thereby improve the number of application areas as well as the precision in working environmental LCA.

7.4.3 Process assessments

Process assessments are judged to give more precise results than sector assessments and they will therefore probably be the tool for the future.

It is recommended that future developments in working environmental LCA focus on establishing internationally acceptable methods for process assessment. The two main problems that should be addressed are the format of a common database and the possibilities for development of an internationally accepted impact assessment methodology.

With respect to the format of the database a major step forward would be to develop a format that could be used to integrate results from the new sector assessment method and the process assessment method outlined by IVF (and to some extent also in EDIP97). In doing so it would be possible to gradually improve the precision in working environmental LCAs as a consequence of obtaining more information on the specific process level.

With respect to the impact assessment methodology, one of the first tasks in this context should an investigation of the possibilities of using economic parameters, e.g. the willingness to pay for avoiding the potential impacts, as the guiding principle in the weighting procedure.

8 Case study: An office chair

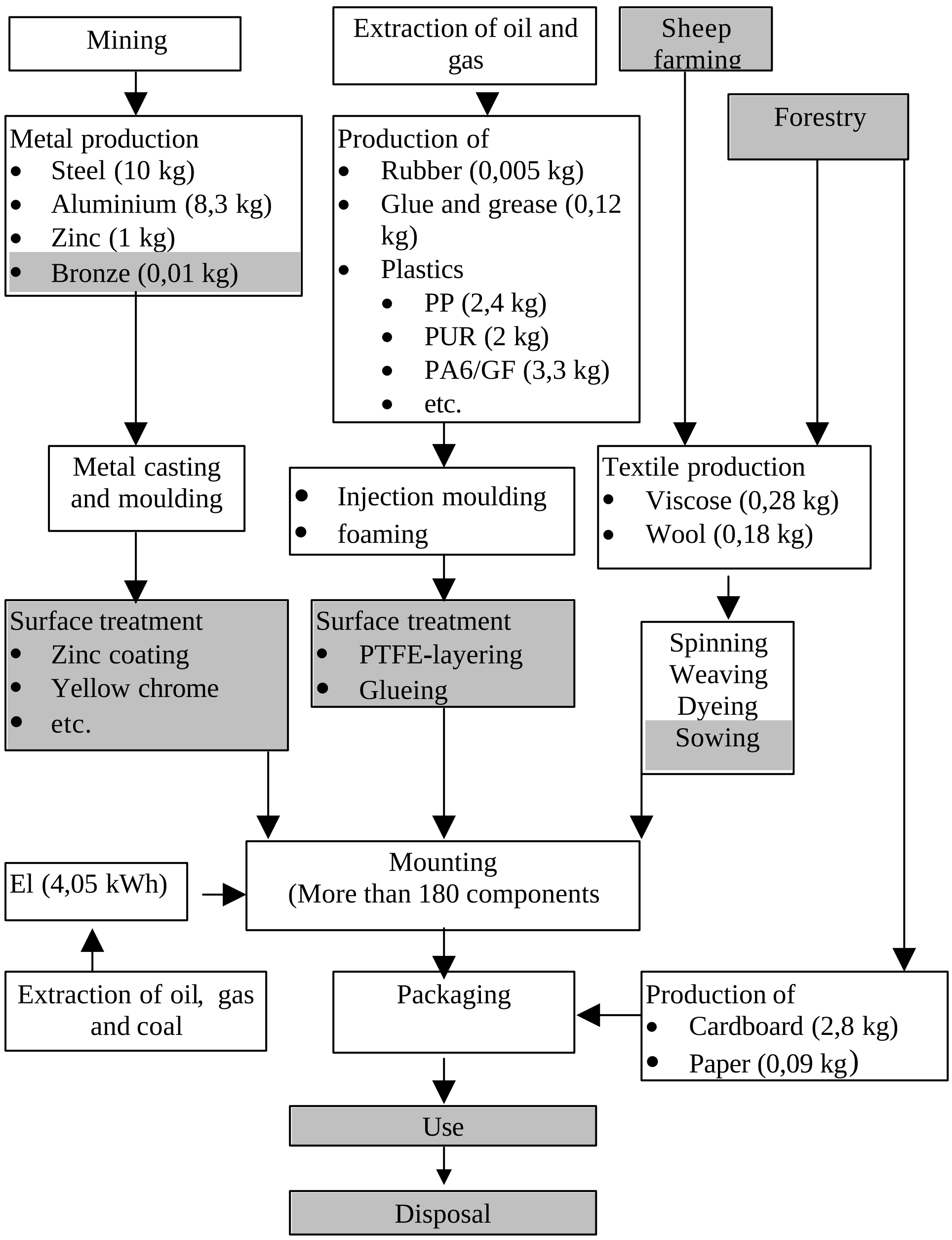
The chosen case – an office chair – has also been used in other parts of the LCA-method development and consensus project. One of the reasons for choosing this case is that large parts of a LCA has already been performed, e.g. much of the necessary information was available also for the working environmental part of the LCA. No further data collection was performed in the present project.

8.1 Making a flowchart

The starting point for the LCA is a component list for the product with information on material type, weight and applied processes (e.g. surface treated or injection moulded). In order to create a better overview of the comprehensive list of components, it is suggested as a first step that a flowchart for the generic material types (plastics, steel, metals, paper, etc.) is established.

The flowchart for the office chair is shown in Figure 1. The shaded boxes show the activities that could not be included in the calculations because of missing information. This is for example the case for forestry and surface treatment because the developed database does not contain data on these processes. Extraction of energy for transportation is also not included because the actual consumption was not calculated in the basic information for the study.

Figure 1. Flow chart for an office chair. Shaded areas indicate that the requested information could not be found in the database.



8.2 Aggregation from the component list

The component list gives information on the amount of materials used in the product. Table 8.1 shows an excerpt from the component list for the office chair. In the calculations it is assumed that the seat and back of the office chair will be replaced three times in the lifetime of the chair. The additional consumption of materials for this is included in the above figures.

Table 8.1. Excerpt from the component list for the office chair.

Number	Name	Material	Amount (in g)
1	Glider EGO f. back	Aluminium	450,0
1	Screw spec. 3 x 7	Steel	1,4
1	Catch EGO f. right	Steel	55,0
1	Spring EGO f. catch	Stainless steel	2,2
1	Screw, mach. M3x6	Steel	0,4
1	Trigger chip EGO	POM	2,6
1	Stop EGO f. back tilt.	Zinc	73,0
2	Brake block f. back tilt	Rubber	0,8
2	Bearing EGO upper	POM	0,6
1	Top cover	ABS	62,0
...	...	...	...

The office chair is made from more than 180 components that can be aggegated with respect to the basic material type and the weight (Table 8.2).

Table 8.2. Material content in the office chair.

Material	Aggregated from	Weight
Steel	Steel, stainless steel, sintered steel	9830,7 g
Aluminium		6413,0 g
Zinc		941,7 g
Bronze*		10,4 g
Rubber		4,4 g
Basic chemicals	Glue and grease	97,0 g
Plastics	POM, PA6, PA66, ABS, PP, polyester and PUR w. melamine	8205,9 g
Viscose/wool		462,4 g
Total		25965,5 g
Packaging		
Paper		18,3 g
Cardboard		2820,0 g
Plastics	PP and PA6	85,1 g
Total		2923,4 g

* Not included in the calculations

The data in Table 8.2 are used as the basic input for the calculations of the impacts from raw material production. The main aggregation is that different types of steel and plastics are found under one heading for each material as it is not possible to make further discrimination with regard to raw material production in the database. When dealing with plastic production, it should be observed that one kilo of primary plastic as a rule of thumb requires two kilos of raw materials. For convenience, it can be assumed that the raw materials are evenly distributed between oil and natural gas, i.e. one kilo of each per kilo plastic.

The component list is also used to specify the amounts of material that are processed further before becoming actual components. This is explained in section 8.4.

8.3 Energy and transportation

The impacts from production of energy raw materials and transportation are also included in the assessment.

The overall consumption of oil, gas and coal for energy production and material feedstock has been used for the calculations as no detailed information for the single materials was available. Production of electricity is only considered for the assembly process at the producers as this was the only process for which this information was available.

For transportation, only national transportation in Denmark is considered and it is assumed that all transportation is performed by truck. Transportation between earlier parts of the supply chain is not considered, but the extra transportation associated with replacement of seats and backs of the chair is included in the calculations.

The aggregated figures for consumption of energy raw materials and transportation are shown in Table 8.3.

Table 8.3. Energy and transportation data.

	Amount
Energy raw material	
* Coal	32,102 kg
* Oil	26,4 liter
* Natural gas	18,8 m^3
* Electricity	4,05 kWh
Transportation	26038 kg-km

8.4 Matching the aggregated information with the database

An integrated part of aggregating the data in the component list is to find sectors in the database, for which the activities match those in the life cycle. Table 8.4 shows the sectors that were chosen to match the activities in the life cycle of the office chair, both with regard to raw material production and the subsequent production steps.

Table 8.4. Sectors included in the calculations.

Material	Amount	NACE-code	Description
Steel	9830,7 g	271000	Danish iron- and steel works
	692,5 g	287400	Production of screws, springs etc.
	9138,2 g	287590	Production of other finished metal products
Aluminium	6413,0 g	274200	Production of aluminium
Zinc	941,7 g	274300	Production of lead, zinc and tin
Bronze*	10,4 g		
Rubber	4,4 g	251300	Production of rubber products
Glue/grease	97,0 g	241300/241 400	Production of basic chemicals
Plastics	8291,0 g	241600	Production of basic plastics
	8201,7 g	252490	Production of other plastic products
	85,1 g	252200	Production of plastic packaging
Viscose/wool	462,4 g	171000	Spinning
	462,4 g	172000	Weaving
Office chair	25965,5 g	361110	Production of chairs and sitting furniture
Paper and cardboard	2838,3 g	212100	Production of paper and cardboard packaging
Coal	32,102 kg	-	Extraction of coal
Oil	26,4 liter	-	Extraction of oil
Natural gas	18,8 m^3	-	Extraction of natural gas
Electricity	4,05 kWh	401000	Electricity production
Transportation	26038 kg-km	-	Road transportation

* Not included in the calculations

Production of bronze is not included in the calculations because no sector in the database matches this activity directly. The potential error in this omission is however very small as the amount of bronze in the office chair is almost negligible. If an increased level of detail is requested, bronze could be included by using other processes, e.g. a combination of production of copper and production of lead, zinc and tin.

For steel and plastics, a number of sectors have been used to describe the life cycle, thereby giving the possibility for a more detailed assessment. For plastics, the life cycle starts with extraction of oil and natural gas, followed by production of basic plastics and ending with production of plastic packaging and production of other plastic products. For steel, the life cycle starts with production of steel and subsequently a division into production of screws and production of other steel products.

8.5 The calculations

The next step in the procedure is to multiply the information in Table 8.4 with the impacts per ton material that can be found in the database. It is of course important to remember to include upstream processes for all materials. It is also important to observe that the units must match each other, e.g. weight is stated in tons.

The calculations can most easily be performed in a spreadsheet. One way of doing this is to make four columns with information on material, process, NACE-code and weight for each of the flows identified in the component list and the flow chart. Subsequently, ten columns containing the headings of the effect categories are entered. In each of the cells in the matrix is entered a formula of the type "=(A*B)", where "A" refers to the cell containing the weight of the component or material flow, and "B" refers to the cell where information on the relevant impact per weight unit can be found.

It can be difficult to get an overview of the information in the complete spreadsheet, and in the next section it is suggested to aggregate some of the information as an optional step in the procedure. The suggested types of aggregation are simple additions of processes and activities that can be combined under a relevant heading. In practice, this will require simple spreadsheet management, e.g. by making a new worksheet where formulas of the type "= (E10 + F10 + J10)" are used for adding the same kind of impacts from different activities.

8.6 Creating a better overview

The information resulting from the calculation outlined in section 8.5 gives the most detailed overview on the sector level when the impacts are calculated, i.e. all sectors that are involved in the life cycle are represented in the table. For more complex products the number of material and process combinations is often so high that it is difficult to create a graphic overview. It is therefore suggested that the information is further aggregated by adding the life cycle impacts from groups of components, e.g. plastic components, steel components, etc. It should be noted that the examples given in the next section are only suggestions. In principle, the method gives the possibility for all kinds of aggregation, and the final choice is left to the practitioner.

As an example all processes involved in the production of plastic components are found under five headings in Table 8.4, i.e. “Extraction of oil”, “Extraction of natural gas”, “Production of primary plastics”, “Production of plastic components” and “Production of plastic packaging”. These can be aggregated under one heading, “Production of plastics (components)”. The same can be done for the other basic materials used for the office chair as well as for energy production and transportation, thereby reducing the number of headings to a more manageable number, about 10. This overview is shown in Table 8.5.

Another possibility (not demonstrated here) is to group the activities in relation to the phases in the life cycle where they take place. As an example, the impacts from production of steel, plastic, aluminium, viscose etc. can be added under one heading “Production of raw materials”. Another example is that production of screws, finished metal products, plastic packaging, other plastic products etc. can be added under the heading “Production of components”. Together with similar information on production of energy resources, transportation and assembly it is thus possible to create an overview of the relative importance of the different life cycle phases.

Table 8.5. An example of a spreadsheet with aggregated information.

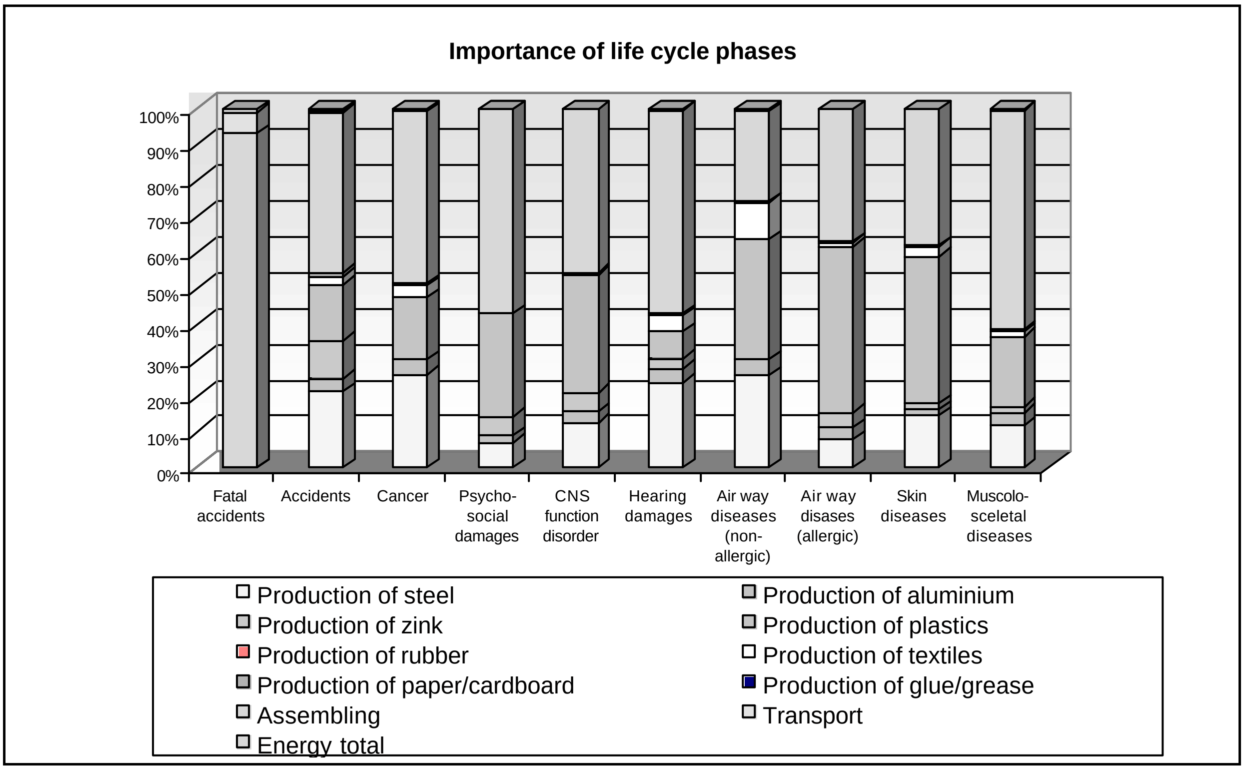
				Accidents and diseases per chair								
Material	**Weight (gram)**	**Life cycle process**	**Fatal accidents**	**Accidents**	**Cancer**	**Psycho-social damages**	**CNS function disorder**	**Hearing damages**	**Air way diseases (non-allergic)**	**Air way disases (allergic)**	**Skin diseases**	**Muscolo-sceletal diseases**
Steel	9830,7	Production of steel	0,0E+00	2,6E-05	1,6E-07	8,7E-08	3,2E-07	1,7E-06	4,4E-07	1,2E-07	6,1E-07	2,9E-06
Aluminium	6413	Production of aluminium	0,0E+00	4,8E-06	2,6E-08	2,6E-08	7,8E-08	2,9E-07	7,8E-08	5,2E-08	7,8E-08	9,4E-07
Zink	941,7	Production of zink	0,0E+00	1,3E-05	0,0E+00	6,9E-08	1,4E-07	2,1E-07	0,0E+00	6,9E-08	6,9E-08	4,1E-07
Plastics	8286,80	Production of plastics	0,0E+00	1,9E-05	1,0E-07	3,7E-07	8,4E-07	5,3E-07	5,8E-07	7,3E-07	1,7E-06	4,8E-06
Rubber	4,40	Production of rubber	0,0E+00	1,8E-08	1,0E-10	0,0E+00	1,6E-10	5,7E-10	1,6E-10	3,6E-10	6,2E-10	1,4E-09
Textiles	462,40	Production of textiles	0,0E+00	3,0E-06	2,0E-08	0,0E+00	0,0E+00	3,2E-07	1,8E-07	1,6E-08	1,2E-07	3,5E-07
Paper/cardboard	2838,30	Production of paper/cardl	0,0E+00	1,4E-06	3,3E-09	3,3E-09	1,5E-08	5,4E-08	3,3E-09	5,0E-09	2,1E-08	1,8E-07
Glue/grease	97,00	Production of glue/grease	0,0E+00	9,5E-09	0,0E+00	8,8E-11	1,8E-10	2,7E-10	3,5E-10	0,0E+00	1,8E-10	6,2E-10
Chair	25965,50	Assembling	1,5E-07	5,6E-05	2,9E-07	7,3E-07	1,2E-06	4,1E-06	4,4E-07	5,8E-07	1,6E-06	1,5E-05
Transportation		Transport	8,8E-09	8,0E-07	2,4E-09	1,2E-09	4,0E-10	2,4E-08	7,2E-09	2,0E-09	2,0E-09	7,8E-08
Energy consumption		Energy total	1,5E-09	2,9E-07	2,7E-10	1,0E-10	6,8E-11	2,8E-09	6,8E-10	6,8E-11	2,9E-10	3,5E-09
		Coal	1,4E-09	2,5E-07	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00
		Oil	3,1E-11	3,6E-09	0,0E+00	0,0E+00	0,0E+00	9,4E-11	0,0E+00	0,0E+00	3,1E-11	3,4E-10
		Natural gas	2,4E-11	2,8E-09	0,0E+00	0,0E+00	0,0E+00	7,2E-11	0,0E+00	0,0E+00	2,4E-11	2,6E-10
		Energy production	3,4E-11	3,5E-08	2,7E-10	1,0E-10	6,8E-11	2,7E-09	6,8E-10	6,8E-11	2,4E-10	2,9E-09

8.7 Creating the graphic overview

It is relatively simple to use the aggregated information in Table 8.5 for a graphic presentation of the results, provided the practitioner has some general experience with spreadsheet management. A number of possibilities are available and some of these are demonstrated in the following figures.

The first suggestion is to make a figure that illustrates the relative contribution from materials/processes to the total impacts from the product – the expected accidents and damages. This overview is presented for the office chair in Figure 2.

Figure 2. The relative contribution of materials and processes to the overall impacts from the office chair.



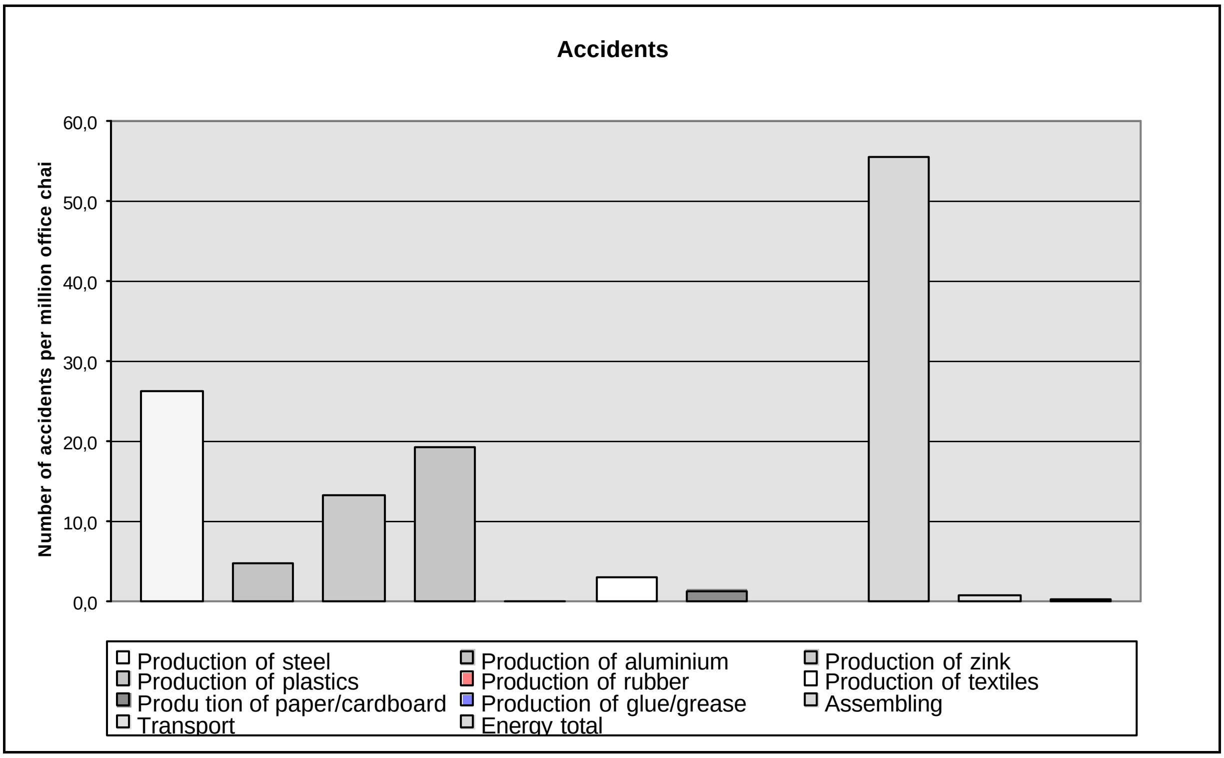
As can be seen from Figure 2, the assembly process is the most important process for many of the impact categories considered by the method. However, both plastics and steel also have a large impact in some categories, e.g. plastics causes more airway diseases than both the assembly process and steel production.

It can also be seen from the figure that transportation only has a significant contribution to one impact category, accounting for about 10% of the expected fatal accidents. For all other impact categories, transportation contributes only with an insignificant part. For energy production, the contribution cannot be observed in the illustration. It should, however, be remembered that the database for production of electricity, especially extraction of coal, is of a poor quality.

Another type of overview can be created by looking at the absolute contribution to the single impacts from each of the materials and processes. An example is shown in Figure 3, where the number of expected accidents per million office chairs is allocated to each of the materials and processes. This overview is often valuable as the database for accidents is the most complete, i.e. this information has been collected for all processes.

It can be seen from the figure that the assembly process is the most important process with respect to the risk of accidents. It can also be seen that steel is more important than plastics. This is not the case for other impact categories as indicated in Figure 2.

Figure 3. The contribution of single materials to the overall number of accidents in the life cycle of an office chair.



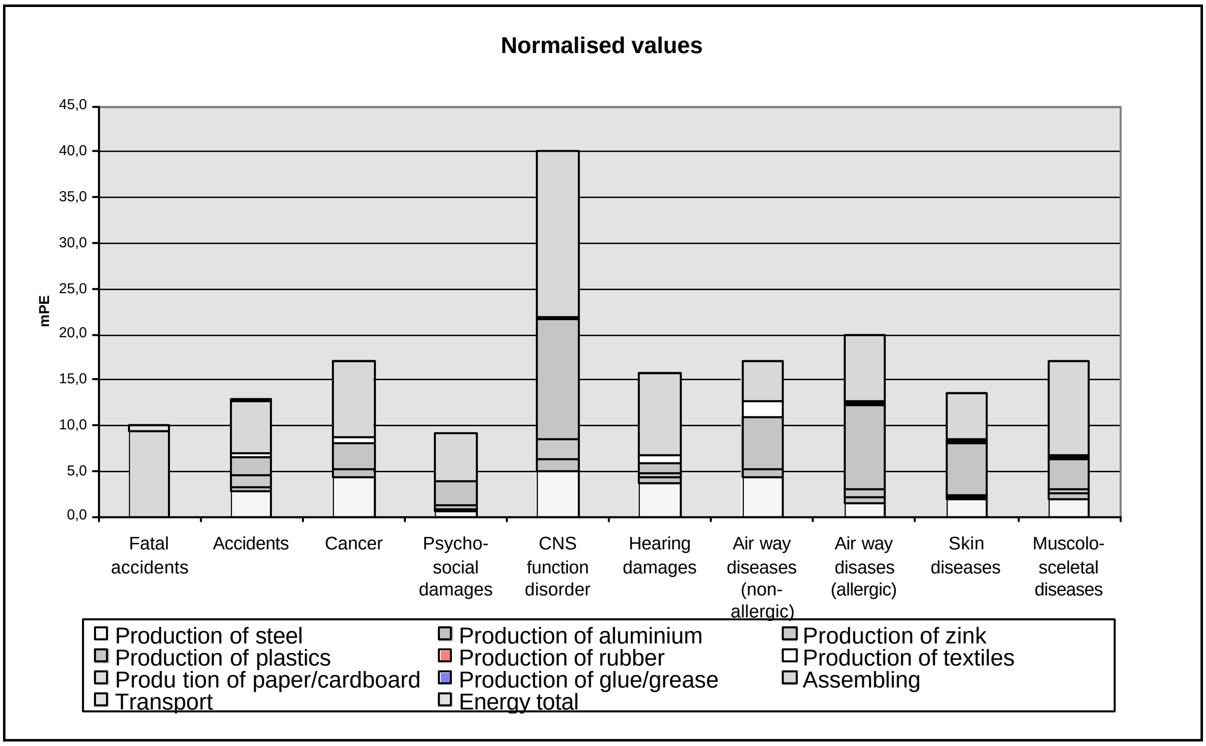
The materials rubber, glue and grease only account for a minor contribution, primarily because of their low weight. Energy production and transportation is also of minor importance.

8.8 Normalisation

The results from the impact assessment can subsequently be normalised in order to gain knowledge on which effects that are most affected by the activities in the life cycle of a product. The normalisation is done by relating the expected number of accidents and damages to the average reporting frequency for an average Danish citizen. In practice, this is done by dividing the number of accidents and damages from the product with the normalisation references given in Table 5.1. With this calculation, the impacts can be stated in person equivalents, i.e. the same unit that is used for other impact categories in the EDIP method (1 person equivalent = 1 PE = 1000 milli person equivalents = 1000 mPE).

Figure 4 shows the normalised impacts from the office chair. It can be seen that the life cycle activities has the most significant effect on CNS-function damage, with an impact that amounts to about twice as much as the other impact categories.

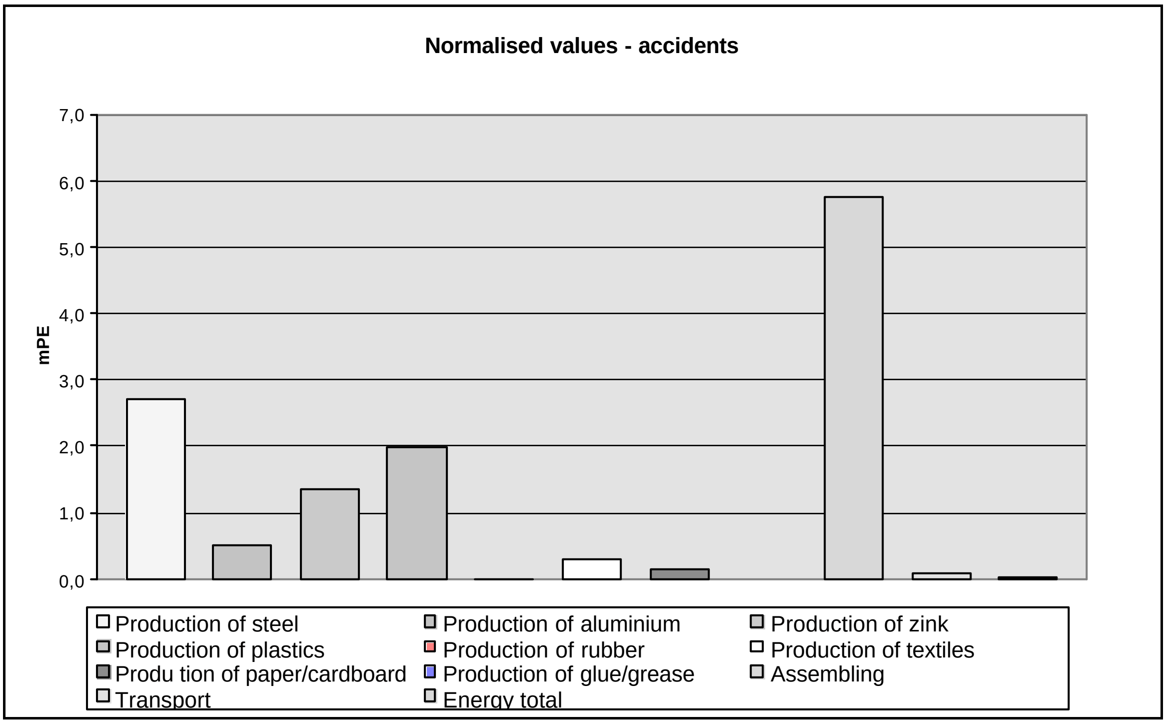
Figure 4. Normalised effects potential for the office chair.



The effect potential measured in milli-person equivalents is an expression of how large a part of the annual impact on an average citizen that is caused by the production of an office chair. With respect to CNS-function damage only 25 chairs can be produced before the average impact is reached, while for skin diseases, 77 chairs can be produced.

The normalised results can be further detailed in the same way as was done in the impact assessment. In Figure 5 is shown how the single activities contribute to the expected accidents. It can be seen that the average annual impact from accidents in the assembly process is reached when each worker has assembled about 170 chairs. With respect to the steel used in the chair, the average annual impact is reached when steel for 370 chairs has been produced and processed into components.

Figure 5. Normalised values for accidents in the life cycle of the office chair.



8.9 Further interpretation

The results emerging from each step in the impact assessment are open for a more detailed assessment and interpretation. For each of the materials used in the product it is thus possible to distribute the impacts on the processes in the life cycle, normally 2-4 processes for each material. In doing so, a more precise assessment of where the largest impacts can be found is obtained. This increase in the level of detail can easily be achieved with the established inventory and may be a better basis for a dialogue between suppliers and producers about how to improve the working environment. In the case of the office chair an obvious choice will be to emphasise the need to avoid organic solvents, as these are a well-known cause of the dominating effect, CNC-function disorder.

A second possibility is to compare the results from an assessment of two different types of office chairs. As indicated in the description of the method, there must be some significant differences between two products in order to make a comparison. As an example, change from one type of plastic to another in a specific component will not change the impacts, unless there is a difference in the weight of the two components. This type of comparison has not been performed in the present project as only information on one office chair has been available.

A third possibility is to compare the results from the working environmental LCA with the results from the other impact categories in a "normal" LCA. With such a comparison the most obvious goal of including the working environment can be fulfilled, i.e. that it is possible to see whether environmental improvement of products are implemented on the expense of the working environment. This comparison with several types of effect categories has not been performed in the present study, as the results from the assessment of the impacts on the natural environment or resource consumption are not known.

The method provides new possibilities to integrate the working environment into LCA. It is, however, emphasized that it is often the conditions at and prioritisations of the single companies that is determining for the prevalence og working-related injuries. A company that has a certified management system for the working environment (e.g. OHSAS 18001) is able to document efforts that go beyond regulatory demands. By choosing such a supplier it is ensured that their working environment is the best possible within the given sector and that there is a possibility for improvement through dialogue.

9 The database

The database that was developed using the sector assessment procedure can be found on the following pages.

As described in the present report, most information in the database has been established by using Danish Statistics concerning reporting of work-related diseases and accidents, respectively the Danish goods statistics. The information that has been derived in this way has a 6-digit DB93-code attached in the second column. DB93 is a Danish nomenclature for sectors, the main principle being a classification of economic activities. The first four digits are identical to those used in the analogous EU Classification system, NACE Rev. 1. The last two digits are Danish sub-divisions, giving an increased level of detail. These two digits may differ from Denmark to other countries.

For a few of the processes in the database, company-specific information has been used. These are characterised in the database by not having a DB93-code attached. The representativity of this information is not known, and the results of life cycle assessments where these processes play a significant role should be interpreted with great caution.

For the database on transportation impacts, it is suggested that the figures in bold are used in the calculations. These figures represent the aggregated impacts from the different transportation modes, e.g. transportation by truck is an aggregation of handling of goods at terminals and the truck transportation itself. In the same way, transport by ship is an aggregation of impacts when handling the goods in land-based terminals and impacts on-board traders.

In total, the database comprises more than 80 unit processes. The information in the present report can not at the moment be found in a computer programme, neither the EDIP PC-tool nor any other commercial programme. It should, however, be a very straightforward procedure to integrate the information in commercial LCA-programs as the data format is comparable to that for other impact categories.

Until the information has been integrated in a computer programme it is suggested that LCA-practitioners create a spreadsheet, where a parallel examination of working environmental impacts throughout the life cycle can be performed. It is judged that a parallel assessment can be performed in a few days when some experience has been achieved. The level of detail – or rather the possibilities for analysing the results - is not so good in a spreadsheet as in a specially designed LCA-programme. Therefore, a skilled spreadsheet manager may be a valuable member of the LCA-team.

	DB-93		Fatal accidents	Accidents	Cancer	Psycho-social damages	CNS function disorder	Hearing damages	Airway diseases (non-allergic)	Airway diseases (allergic	Skin diseases	Muscolo-sceletal diseases
			Accidents and reported diseases per tons product									
Raw material production												
	Energy carriers											
Note 1		Crude oil (1 liter)	1,2E-12	1,4E-10				3,5E-12			1,2E-12	1,3E-11
Note 1		Natural gas (1 Nm^3)	1,3E-12	1,5E-10				3,8E-12			1,3E-12	1,4E-11
		Coal	4,4E-08	7,8E-06				No information on reported diseases				
	401000	Electricity distribution (per kWh)	8,3E-12	8,6E-09	6,7E-11	2,5E-11	1,7E-11	6,6E-10	1,7E-10	1,7E-11	5,8E-11	7,1E-10
Note 2		Electricity production (per kWh, incl. Raw r	1,2E-11	9,3E-09	6,7E-11	2,5E-11	1,7E-11	6,6E-10	1,7E-10	1,7E-11	5,8E-11	7,1E-10
	Metals											
	271000	Basic iron and steel (Denmark)		1,6E-04		1,8E-06	2,0E-05	2,2E-05	2,8E-06		4,6E-07	1,7E-05
Note 3	271000	Basic iron and steel (Sweden)	2,0E-07	1,1E-04				Not directly comparable to Danish statistics				
	274200	Aluminium production		7,5E-04	4,1E-06	4,1E-06	1,2E-05	4,5E-05	1,2E-05	8,1E-06	1,2E-05	1,5E-04
	274300	Lead, zinc and tin production		1,4E-02		7,3E-05	1,5E-04	2,2E-04		7,3E-05	7,3E-05	4,4E-04
	274400	Copper production (Denmark)		2,9E-03								7,2E-04
Note 4		Copper		6,0E-04				No information on reported diseases				
Note 4		Nickel	3,2E-05	1,9E-03				No information on reported diseases				
Note 4		Gold	6,0E-02	3,8E+00				No information on reported diseases				
	Other raw materials											
	141200	Quarrying of limestone, gypsum, chalk	2,3E-07	9,6E-06				2,3E-07		2,3E-07		2,3E-07
	142100	Sand and gravel production		2,4E-06			2,3E-08	1,6E-07	1,1E-07	2,3E-08	4,6E-08	1,6E-07
	201010	Saw milling	8,7E-07	2,2E-04	8,7E-07	8,7E-07	3,5E-06	1,8E-05	1,7E-06	2,6E-06	1,7E-06	2,6E-05
	211200	Manufacture of paper and cardboard	9,2E-07	1,6E-04		1,8E-06	9,2E-07	2,8E-05	9,2E-07	9,2E-07	1,8E-06	1,5E-05
	212100	Corrugated paper and paperboards		4,8E-04	1,2E-06	1,2E-06	5,2E-06	1,9E-05	1,2E-06	1,7E-06	7,6E-06	6,2E-05
	212500	Other articles of paper and cardboard	5,1E-06	9,9E-04		1,5E-05	5,1E-06	8,7E-05	5,1E-06	5,1E-06	1,0E-05	1,1E-04
	265100	Cement		1,6E-05	1,2E-07			3,1E-06	9,5E-07	1,2E-07	2,4E-07	1,1E-06
	266300	Ready-mixed concrete	9,1E-08	6,7E-06				6,3E-07	1,8E-07	9,1E-08		3,6E-07

	DB-93		Fatal accidents	Accidents	Cancer	Psycho-social damages	CNS function disorder	Hearing damages	Airway diseases (non-allergic)	Airway diseases (allergic	Skin diseases	Muscolo-sceletal diseases
			Accidents and reported diseases per tons product									
Intermediates/final products												
	Wood products											
	202000	Veneer sheets, plywood, etc.		2,8E-04	2,8E-06		1,4E-06	6,9E-06	1,4E-06	4,1E-06	5,5E-06	4,6E-05
	203020	Builders' carpentry		8,8E-04	2,1E-06	4,2E-06	7,1E-06	4,7E-05	4,2E-06	9,2E-06	1,8E-05	9,9E-05
	205190	Other wood products		1,2E-03	7,2E-06		7,2E-06	7,2E-05		3,6E-05	3,6E-05	1,1E-04
	Chemical products											
	232000	Refined petroleum products		1,2E-06	3,8E-08		7,6E-08	3,4E-07	3,8E-08			3,0E-07
Note 5	2413-14	Basic organic and inorganic chemicals		9,8E-05		9,1E-07	1,8E-06	2,7E-06	3,6E-06		1,8E-06	6,4E-06
	241600	Plastics in primary forms		2,7E-04		6,2E-06				6,2E-06	3,1E-06	2,5E-05
	245110	Soaps and detergents		3,1E-04		2,2E-06	2,2E-06	4,3E-06	6,5E-06		2,6E-05	3,2E-05
	246600	Other chemical products		2,5E-04	8,6E-06				1,7E-05	8,6E-06	1,7E-05	1,3E-04
	251300	Rubber products		4,0E-03	2,4E-05		3,5E-05	1,3E-04	3,5E-05	8,3E-05	1,4E-04	3,2E-04
Note 6	**Plastic products**											
	252	**Plastic products - average**	7,6E-07	1,4E-03	4,5E-06	1,1E-05	3,4E-05	4,0E-05	1,4E-05	1,8E-05	4,8E-05	2,0E-04
	2521	Sheets, films, tubes, hoses, profiles		8,3E-04	6,0E-06	8,0E-06	2,2E-05	2,6E-05	1,0E-05	6,0E-06	1,8E-05	7,8E-05
	252110	Sheets, films, flat products		1,0E-03	6,1E-06	9,1E-06	3,3E-05	3,3E-05	1,2E-05	6,1E-06	2,4E-05	1,0E-04
	252120	Tubes, piping and hoses		4,6E-04	6,1E-06	6,1E-06		1,2E-05		6,1E-06	6,1E-06	3,0E-05
	252130	Bars and profiles		2,1E-03					4,2E-04			4,2E-04
	2522	Plastic packing goods		1,4E-03	2,3E-06	7,0E-06	3,5E-05	4,5E-05	4,7E-06	7,0E-06	2,8E-05	1,7E-04
	2523	Builders ware of plastic	9,1E-06	1,3E-03		9,1E-06	1,8E-05	7,3E-05	9,1E-06	9,1E-06	3,6E-05	1,3E-04
	252310	Sanitary products		1,3E-03		7,4E-05	7,4E-05			7,4E-05	1,5E-04	7,4E-05
	252390	Building products	1,0E-05	1,3E-03			1,0E-05	8,3E-05	1,0E-05		2,1E-05	1,3E-04
	2524	Other plastic products		2,2E-03	6,9E-06	2,4E-05	5,9E-05	4,5E-05	3,8E-05	5,9E-05	1,3E-04	4,6E-04
	252410	Office and school products		2,1E-03				2,4E-05		2,4E-05	4,1E-05	2,7E-04
	252420	Table service and kitchen products		1,5E-03			9,5E-05					8,6E-04
	252490	Other products of plastic		2,3E-03	1,3E-05	4,5E-05	1,0E-04	6,4E-05	7,0E-05	8,9E-05	2,1E-04	5,8E-04

	DB-93		Fatal accidents	Accidents	Cancer	Psycho-social damages	CNS function disorder	Hearing damages	Airway diseases (non-allergic)	Airway diseases (allergic	Skin diseases	Muscolo-sceletal diseases
			Accidents and reported diseases per tons product									
Intermediates/final products												
	Glass and ceramics											
	2612	Shaping and processing of flat glass		1,5E-03		4,0E-06	1,2E-05	3,6E-05		4,0E-06	4,0E-06	1,3E-04
	2613	Hollow glass (bottles, drinking glass)		1,9E-04	1,1E-06	1,1E-06		1,5E-05	2,2E-06	1,1E-06	4,3E-06	1,7E-05
	2621	Household ceramics		8,2E-03	2,7E-04	1,4E-04		6,9E-04	8,2E-04	1,4E-04	6,9E-04	5,3E-03
	Insulation											
	2614	Glass wool, glass fibres		1,0E-03		6,2E-06	8,7E-05	3,7E-05	1,2E-05	6,2E-06	6,8E-05	1,4E-04
	268220	Rock wool	Confidential information									
	Building products											
	264000	Bricks, tiles in baked clay		3,0E-05	4,1E-07			4,1E-06	8,3E-07		4,1E-07	5,8E-06
	266110	Concrete products	6,7E-07	4,5E-05	6,7E-07	3,3E-07		9,3E-06	2,0E-06		1,3E-06	8,7E-06
	266120	Concrete elements	5,9E-07	1,7E-04	2,0E-07		4,0E-07	6,3E-06	1,6E-06	4,0E-07	6,1E-06	1,1E-05
	266500	Fibre cement products		1,5E-04	4,5E-05			2,5E-05	1,3E-04		5,6E-06	2,5E-05
	Iron, steel and metal products											
	2722	Steel tubes		7,4E-04	3,1E-06		3,1E-06	1,8E-05	3,1E-06		1,7E-05	5,7E-05
	2731	Cold drawing of iron and steel		1,8E-04		5,7E-06		5,7E-06				1,1E-05
	2811	Metal structures	1,8E-06	1,5E-03	8,8E-07	4,4E-06	8,8E-07	6,3E-05	1,3E-05	7,0E-06	1,5E-05	8,5E-05
	2872	Light metal packaging, e.g. tin cans		1,5E-03			7,7E-06	7,3E-05	3,8E-06		5,0E-05	1,5E-04
	2874	Fasteners, springs, screw machine produc		1,6E-03				1,3E-04		2,6E-05	5,1E-05	1,8E-04
	287590	Other finished metal products		2,6E-03	1,7E-05	7,6E-06	1,3E-05	1,5E-04	4,6E-05	1,1E-05	6,3E-05	2,8E-04
	2913	Taps and valves		6,5E-03	1,1E-05	1,6E-05	4,9E-05	4,4E-04	5,4E-05	4,3E-05	6,0E-04	1,4E-03
Note 7	285100	Surface treatment of metal	Cannot be calculated									
	Textiles											
	171	Preparation and spinning		3,8E-03				1,8E-04	2,1E-04	3,5E-05		4,2E-04
	172	Weaving		2,7E-03	4,2E-05			5,1E-04	1,7E-04		2,5E-04	3,4E-04
	177200	Pullovers and cardigans		1,4E-03		5,3E-05		2,6E-04	1,1E-04	1,6E-04	1,1E-04	4,3E-03
	191	Tanning and dressing of leather	5,8E-05	4,7E-03		5,8E-05		5,8E-05	1,2E-04		6,9E-04	6,9E-04
	321010	Printed circuit boards		1,8E-02			1,2E-03	2,9E-04	2,9E-04	2,9E-04	1,8E-03	5,0E-03

DB-93		Fatal accidents	Accidents	Cancer	Psycho-social damages	CNS function disorder	Hearing damages	Airway diseases (non-allergic)	Airway diseases (allergic	Skin diseases	Muscolo-sceletal diseases
		Accidents and reported diseases per tons product									
Final products/assembly											
291220	Fluid pumps and compressors		2,8E-03		4,4E-06	8,9E-06	1,1E-04	3,6E-05	2,2E-05	1,7E-04	3,2E-04
292310	Commercial cooling and refrigeration equi		4,4E-03		8,8E-06	4,4E-05	8,8E-05	7,1E-05	4,4E-05	1,7E-04	4,7E-04
297110	Refrigerators, freezers		2,2E-03	4,2E-06	1,2E-05	1,7E-05	8,7E-05	1,7E-05		4,2E-05	2,8E-04
297120	Stoves, ovens		5,3E-03				9,6E-05			1,4E-04	1,2E-03
297190	Vacuum cleaners		5,1E-03		4,7E-05		4,7E-05	4,7E-05		1,9E-04	6,6E-04
315000	Lighting fitting		3,7E-03		5,6E-05	7,4E-05	1,9E-04	1,1E-04	3,7E-05	1,5E-04	8,5E-04
323010	Radios, televisions		8,3E-04			2,0E-05	2,0E-05	4,0E-05	2,0E-05	6,1E-05	5,7E-04
361110	Chairs	5,6E-06	2,1E-03	1,1E-05	2,8E-05	4,5E-05	1,6E-04	1,7E-05	2,2E-05	6,2E-05	5,8E-04
361200	Office and shop furniture		1,6E-03	1,1E-05	1,7E-05	1,1E-05	5,7E-05	2,9E-05		1,7E-05	1,8E-04
Transport		**Accidents and reported diseases per tons-kilometers**									
Note 8	**Transport by railway**	**6,0E-10**	**1,1E-07**	**6,0E-10**	**1,8E-09**		**3,0E-09**			**6,0E-10**	**1,9E-08**
632110	Stations and goods stations, depots	6,0E-10	1,1E-07	6,0E-10	1,8E-09		3,0E-09			6,0E-10	1,9E-08
		Accidents and reported diseases per tons-kilometers									
	Transport by truck	**3,4E-10**	**3,1E-08**	**9,2E-11**	**4,6E-11**	**1,5E-11**	**9,2E-10**	**2,8E-10**	**7,7E-11**	**7,7E-11**	**3,0E-09**
602410	Haulage contractor	3,2E-10	2,8E-08	7,7E-11	4,6E-11	1,5E-11	6,9E-10	1,7E-10	7,7E-11	6,1E-11	2,7E-09
631100	Transportation of goods	1,5E-11	3,0E-09	1,5E-11			2,3E-10	1,1E-10		1,5E-11	2,8E-10
		Accidents and reported diseases per tons									
Note 9	**Transport by ship**	**5,6E-07**	**6,2E-05**	**9,7E-07**	**2,9E-07**	**7,1E-07**	**1,0E-05**	**1,0E-06**	**1,7E-07**	**1,6E-06**	**5,9E-06**
611010	Carriage of goods		9,1E-07	2,4E-07	1,1E-07	1,1E-07	3,2E-06	2,4E-07	5,3E-08	4,5E-07	1,3E-06
611020	Carriage of passengers	5,3E-08	2,8E-06	1,9E-07	1,6E-07	1,3E-07	1,3E-06	1,1E-07	5,3E-08	3,5E-07	1,5E-06
632210	Commercial harbours		3,2E-06	1,1E-07	2,7E-08	2,7E-08	3,2E-07	1,3E-07	2,7E-08	2,7E-08	2,7E-07
Note 10	Traders and passenger ships	5,1E-07	5,5E-05	4,4E-07		4,4E-07	5,4E-06	5,2E-07	4,0E-08	8,0E-07	2,8E-06

9.1 Explantory notes

Note 1: Calculated for 1995-1997 on the basis of information in “Denmarks oil and gas production 1997”. Energistyrelsen, 1998.

Note 2: This is a total number of accidents and diseases for both raw materials production (oil, gas and coal), and for the production and distribution of electricity. The number of diseases is underestimated because no diseases are reported for coal production.

Note 3: Calculated by using figures for Swedish steel production (average 1994 to 1996). Only data for accidents have been integrated.

Note 4: Calculated by use of information from WMC (1996 or an average of 1996-1997). WWW-address:http://www.wmc.com.au/

Note 5: The basic chemicals are made in the sectors 241300 "Manufacturing of other inorganic chemicals" and 241400 "Manufacturing of other organic chemicals".

Note 6: Notice the difference in level of detail in the DB93/NACE-codes (3-, 4-, 5-digit level). It is recommended that the highest level of detail is used.

Note 7: The goods statistics cannot be used for this sector because of differences in the collected information.

Note 8: Average figures for national and international transport with Danish carriers, because the accidents are reported for both national and international haulage.

Note 9: Notice, that in transport by ship accidents and diseases are reported per ton and not per ton-kilometer. The numbers also includes impacts from passenger transportation as most ships carry goods one way or the other. The amount of goods transported include transportation on Danish as well as foreign ships and the figures are therefore underestimated, because only the impacts on Danish ships are used in the calculations.

Note 10: For 1996 no diseases are reported. The average is therefore calculated for two years.

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Appendix 1: Review of existing methods for WE-LCA

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1 Summary

1.1 Introduction

A review of six methods for life cycle assessment of the working environment (WE-LCA) has been carried out as a part of the Danish LCA-development project. The results of the review were presented at a workshop in June 1998 in Copenhagen together with experiences from Denmark and Sweden regarding the inclusion of working environment in LCA. The present Appendix A outlines the main conclusions from the review and the workshop, the focus being on the identification of the most important problems that must be solved in order to gain a more widespread acceptance of WE-LCA. The Appendix also contains the full reviews of the existing methods.

It should be noticed that the Appendix reflects the situation in the autumn of 1998. Changes following renewed discussions during the second half of the project are not mirrored in the Appendix, only in the technical report.

1.2 Methods for WE-LCA

The review of the available WE-LCA methods shows that three main types can be identified:

1.2.1 Chemical screening methods

Chemical screening methods have the main focus of identifying processes that may have a significant impact on the working environment. The screening methods are based on very few informations, e.g. a hazard assessment of the substances used in the process and an indication of the exposure potential of the process.

The screening methodologies can thus be used in a very early stage of a product development process to assess whether a change in processes may have an unwanted chemical impact on the working environment. The screening may also be used to pinpoint the processes that primarily should be included in an in-depth LCA of a product or a product system, but the proposed methods do not give the possibility of aggregating the impacts over the whole life cycle in a consistent manner.

1.2.2 Sector methods

Sector methods have the main objective of giving an assessment of products or services that are common to many product systems, e.g. electricity production and transportation. A common feature of the sector methods is that they by relatively simple means aggregate a large number of processes into one assessment (of a product unit).

The results from the use of a sector method can be used for a number of purposes, e.g.:

- to assess the relative importance of the working environmental impacts in different phases of the life cycle and thereby identify which activities that should be further examined in a detailed WE-LCA using more refined methods,
- to fill out data gaps in a detailed WE-LCA

The use of sector methods is restricted to an assessment of large and uniform productions and they cannot distinguish between different producers of the product or service system in question. Experience shows that this is a minor problem as the impact from e.g. raw material production is relatively small compared to the subsequent processes in the life cycle. For some products, however, the results from a sector assessment may play an important role, e.g. the use of electricity in household products.

The sector methods are in general associated with a relatively large uncertainty, primarily due to the fact that statistics on e.g. working conditions and work injuries in different countries are based on different traditions and are of varying quality. Furthermore, average data for the whole sector will often be used, which will give a considerable uncertainty if the sector is heterogenous with respect to its output. Aggregation is therefore associated with significant uncertainty but overall, use of sector assessments can be compared to the use of industrial averages when assessing impacts in the natural environment.

1.2.3 Process assessment methods

Process assessment methods have the main objective of giving detailed information on the working environmental impacts in specific processes. The methods allow an aggregation of several processes and are also suited for distinguishing between different producers (or production methods), although the two reviewed methods are significantly different in their level of detail.

The "ideal" WE-LCA should be based on a process assessment method that includes as many parameters as possible in order to give a broad overview of the potential impacts. There are however some constraints in applying a process method, e.g. that the method is resource demanding for products with many components and that some of the information requested for the assessment is considered to be confidential by many companies. It is therefore a prerequisite for the application of the method that all involved companies are willing to provide the necessary data, eventually after a confidentiality agreement has been signed.

In the longer term the constraints in using the process assessment methods will decrease, especially if development of LCA data can be co-ordinated with the "normal" efforts to improve the working environment in companies. A possible solution is to develop the concept of work place assessments (WPA, Danish: APV) so they can be used both for their primary purpose, i.e. improving the structure and results from internal work with the working environment, and in LCA's.

1.3 Possibilities in WE-LCA

The present state-of-art in WE-LCA is that methods are available for

- Identification of potential problem areas, especially in the chemical working environment. The two screening methods that have been examined are almost identical and will probably give the same results.
- Comparison of sectors with a large and uniform output, e.g. production of bulk raw material and electricity. The two examined methods are rather similar in their design and will probably give the same level of detail in the results, although different headings for the impact categories are used.
- Comparison of specific processes and their output. The two examined methods have a different level of sophistication with respect to both the number of impact cetagories (IVF includes e.g. psycho-social impacts) and the level of detail in the assessment. The two methods are also different with respect to normalisation and weighting, one (EDIP) relating all impacts to the average annual impact of a worker, the other using monetary considerations (annual expenditure on work related diseases, sick leave, compensations etc.).

1.4 Important issues in the development of WE-LCA

The primary goal for WE-LCA has been to secure that the working environment do not deteriorate when products with less environmental impacts are developed. The level of sophistication in WE-LCA is at the moment significantly lower than for the natural environment, mostly because neither inventory nor impact assessment and valuation data are present in amounts similar to those for the natural environment.

Two methods, i.e. the EDIP and IVF methods, seek to fully integrate assessment of the working environment with assessment of the natural environment and it is therefore obvious to use these two methods as the basis for further development.

Future developments of WE-LCA methods will strongly depend on the intended applications. As the EDIP method is believed to be the main vehicle for future developments and use of LCA in Denmark, the efforts in improving the LCA method should be closely related to the intentions regarding the general EDIP methodology.

The following general issues are of special concern in the development of more suitable and precise WE-LCA methods:

1.4.1 System boundaries

The review of methods and case studies indicates that there may be a need for different system boundaries in a WE-LCA as compared to a LCA of the natural environment. A main difference is the relative importance of different phases of the life cycle. Production of components and final products seems to be the more important than production of raw materials with respect to the work environment - at least in terms of working time - whereas these process steps are of little significance in the overall assessment of the impacts on the natural environment. Exclusion criteria would therefore give different results when the working environment is included in the LCA. In practice this implies that a detailed data collection and assessment of the working environment will be necessary for some of the processes that would otherwise be excluded from the LCA or perhaps be treated on a relatively superficial level.

1.4.2 Functional unit

WE-LCA's uses a functional unit for comparison of different options in the same way as a normal LCA. When performing a LCA, it should always be kept in mind that there is a risk of suboptimization. An example is that a reduction in production time per product *inter alia* will result in a better working environmental profile per functional unit. However, if the reduced cycle time leads to more products being produced by the same person, this may cause a deterioration of the working conditions for this person, e.g. in the form of an increase in monotonous repetitive work, increased stress, or a decrease in the freedom to act.

1.4.3 Data availability

The general EDIP-methodology is used together with a PC-tool with an extensive database regarding impacts in the natural environment. In order to include the working environment in future assessments, this database should be supplemented with matching data for the working environment. The present database structure gives this possibility, but large efforts are necessary in order to achieve the desired functionality. Development of a new PC-tool that exclusively deals with WE-LCA should therefore also be considered.

1.4.4 Data quality

The quality of the data used in WE-LCA is uncertain, both for the process and the sector methods. With respect to the process methods, a certain degree of subjectivity is inevitable as a large part of the assessment in both the EDIP and the IVF methods is based on individual judgements. Ideally, measurements of exposure to chemicals and noise should be used in the assessment, but such measurements will often be replaced with more simple exposure criteria. Use of this procedure can give reproducible results, provided the person performing the assessment is experienced. It should be noted that measurements are preferred whenever they are available.

The sector methods are almost exclusively based on statistics from companies as well as national and international labour statistics. There are a number of inherent uncertainties in such statistics, e.g.

- The diseases reported in one year may be attributed to exposures that took place several years ago under very different working conditions. One example is exposure to carcinogenic substances, the effect of which will be observed perhaps 20 years later.
- Statistics on the national and international level may be considerably older than statistics on the company level and it may cause some uncertainty if a combination of statistics is used to assess a production chain.
- There may be large variations in statistics from different nations. These variations may reflect the actual differences in the working conditions but they can also reflect differences in national regulations or the propensity to report occupational injuries or accidents.
- Even in countries with detailed occupational statistics the number of reported injuries and accidents in a given sector may vary considerably from one year to another with no obvious explanation. It is therefore suggested that five-year averaged are used.

1.4.5 Choice of methods - sector or process assessment

The sector and process assessment supplements each other in the present EDIP WE-LCA methodology and will possibly do so for a long period. With the currently very limited data availability it is suggested that both sector and process specific information is entered in the database whenever possible and relevant. As the amount of data in the database increases, it may be possible to replace a general sector assessment with a more precise assessment of all the single processes.

1.4.6 Level of detail

The current level of detail in the EDIP method can mostly be used to assess the extent of selected impacts in sectors and processes but does not give a good possibility of distinguishing between the good and the bad working environment. The IVF method gives a more precise picture of both impacts (e.g. in the form of differentiated scoring systems) and working conditions (e.g. by including indicators for the psycho-social working environment) and must *inter alia* be preferred because of this. It should however be kept in mind that large parts of the assessment procedure is based on subjective assessments and do not meet the scientific requirements that are normally applied to other impact categories.

1.4.7 Valuation

The valuation (normalisation and weighting) step in the EDIP sector and process assessment methods is designed to match the assessment of the natural environment, i.e. all elements are related to the average impacts of an average citizen in a relevant geographical area. Likewise, the valuation step in IVF's method is designed to match the output from the EPS-method, i.e. a monetarisation of the impacts. With the very different procedures and outputs from the two methodologies it is difficult to assess the possibilities of directly reusing parts of the IVF method for future developments in the EDIP method.

1.4.8 Allocation

At this point of the project allocation procedures in WE-LCA seems to be a minor problem. The primary reason for this is that the uncertainty in other parts of the assessment is much larger. Another reason is that the present allocation procedures in WE-LCA, primarily using working time, will take care of the most imminent problems and it is anticipated that the general allocation procedure in LCA will be able to handle other questions.

1.5 Workshop remarks and conclusions

About 60 persons, primarily from Scandinavia, attended a workshop where the WE-LCA methods and their future use was the main discussion topic.

The workshop showed that there is a great interest in integrating the working environment in general LCA. The workshop, however, also showed that working environment professional are somewhat sceptic about the available methods. Their main concerns were:

- The methods are not precise
- The methods include a limited number of working environmental parameters
- The methods are rather demanding in terms of time and resources
- Other tools are better suited for improvements in the working environment

This scepticism has previously been voiced with respect to the general concept of LCA, but the criticism has decreased significantly as a result of the development of a standardised framework. Only a fraction of the resources used in development of LCA has been devoted to the working environment, and a Scandinavian/European co-ordination (through a SETAC working group) of the future developments is expected to increase the usefulness and the credibility of the methods.

The workshop also indicated that the chance for success for WE-LCA is connected to the way the work for improving the environmental and working environmental conditions of the company and its products is organised. LCA is often used by product developers and environmental managers (or other responsible persons), but it is difficult to integrate WE-LCA in general LCA as it will often be other parts of the organisation that handles working environmental issues, e.g. the production planner, the safety organisation and the occupational health service centres (BST).

The use of WE-LCA by the Danish Labour Inspectorate is not judged to be realistic at present. The objective for the Labour Inspectorate is to improve the working conditions for individuals and the focus for the work is therefore on processes rather than products. However, the life cycle perspective in assessment of the working environment should be included in official purchasing policy and perhaps in some form of declaration of the working environmental impacts of products. The number of parameters however, has to be broader than currently available in the EDIP WE-LCA methodology.

1.6 Overall conclusions from Phase 1

The following crude conclusions were drawn following the first phase of the project.

The EDIP method can handle simple and yet relevant questions in the product development process and eventually end up with an overview of relatively a few selected impact categories to be integrated in the overall assessment.

The EDIP database is at present very limited in the content of WE data, and this is prohibitive for a widespread use of WE-LCA. The database can be improved if working environmental data are collected at companies, entered in the database and made public to all users of the PC-tool. If this is not done, it will be very difficult to integrate the working environment in LCA due to resource constraints. Publicly financed studies may provide sector assessments that can be used until more specific process assessments become available.

Further developments in the methodology will probably be associated with an increased degree of subjectivity in the assessment, but will also increase the usability of WE-LCA significantly. Interesting application areas are choice of suppliers/chain management and development of criteria for work environmentally friendly products.

There is a need for co-ordination of the future developments in WE-LCA. This task will be handled by a new working group within SETAC that was established in May 1998. The working group includes members from Denmark, Sweden, Norway, Germany and Holland.

1.7 Important questions

The main questions to be answered in the second phase of the project were identified to be:

What shall WE-LCA be used for in the future? The main purpose of developing WE-LCA methods have been to secure that the working conditions do not deteriorate on the expense of improvements in the natural environment. The currently available methods in EDIP are able to elucidate differences between products on a sector level, e.g. in comparisons between paper and plastic bags, and to some extent also between products and components that can be produced by different processes. The possibilities for discrimination between more complicated products is probably more limited, but must necessarily be possible if WE-LCA is to become a part of the general LCA work.

How large a degree of subjectivity is acceptable? Measurements are very difficult to carry out for the "soft" WE-parameters, and therefore more or less subjective judgements must be applied. Seen from a scientific point of view this should be avoided, but in order to have a more modern approach to the working environment, inclusion of psycho social as well as ergonomic aspects is necessary.

How can the database be extended and improved? The next phases in the project includes an assessment of one or more cases which still are to be determined. Some WE-information will be collected, but it will under all circumstances be far from sufficient to cover WE-LCA in general. To ensure an integration of working environment in LCA a prioritised list of requested data must be established along with an indication of possible data sources. Also, a strategy for dissemination of LCA inventory data is necessary.

1.8 Future developments in WE-LCA

The following actions were identified as relevant in order to facilitate the integration of the working environment in LCA:

Identification of the main future application areas. Input from industry, the Labour Inspectorate and LCA-practitioners is requested at a level of detail that is sufficient for specifications of the requirements for the method to be applied.

Improvement and refinement of methodologies. Development of methods that fulfil the requirements from industry and government. Four main options were seen as available:

- Keeping the EDIP-methodology as it is and focus the efforts on building a database which can be used by LCA-practitioners.

- Refining the screening methodology by including more parameters/effect categories. This option would be helpful for e.g. product developers wanting an indication of potential problems regarding for example accidents, noise and ergonomy, but not having the time and resources necessary to conduct a full WE-LCA.
- Refining the existing EDIP-methodology by increasing the number of impact categories and/or increasing the level of detail in the assessment methods used. This option primarily aims at bringing WE-LCA to a level that is comparable to LCA of the natural environment. The drawback of this option is that it will increase the need for data - a need that most probably cannot be fulfilled by the common LCA-practitioner but will require collaboration with work environment professionals.
- Creating new tools that can handle specific application areas, e.g. guidelines for purchasing products with a minimal impact in the working environment.

Demands to the development and maintenance of a WE-LCA database. Input from industry on confidentiality issues, discussion with health service centres (BST) on the possible use of Work Place Assessments (WPA), discussions with the Danish EPA regarding database maintenance procedures and updates.

1.9 Phase 2 of the project

Based on the finding in the first phase of the project, the discussions at the workshop and the current initiatives from the Danish Labour Inspectorate the following goals for the work in the second phase of the project were set:

- *Establish a broader database*. This will be done by making a WE-LCA on a case that is common to all activities in the methodology project. Working with a case will demand that both the sector and the process method will be used. At present, the case is an office chair for which good inventory data for LCA of the external environment already are available. The case thus gives the possibility of examining many sectors (textile, steel, aluminium, plastics) and processes (metal shaping, blow moulding, textile processing, etc.) and will in the end give a good indication of the possibilities and difficulties in including the working environment in general LCA.
- *Compare different methods.* Swedish and Norwegian WE-LCA practitioners have expressed an interest in collaboration with the Danish methodology project. If possible, parallel testing of both EDIP and other methods will be conducted in the second phase of the project.
- *Examine other application areas.* A number of projects with a life cycle perspective have been initiated by the Danish Labour Inspectorate. The project group will as far as possible use the results from the relevant projects when establishing the guidelines for WE-LCA, one of the expected outcomes of the projects.

1.10 The reviews

The reviews were made by different persons using the same template for all methods. Due to the inherent differences not all aspects could be addressed for all methods. All methods are however summarised using the same evaluation table with a subjective evaluation of diferent parameters. The key to the evaluation table is given in the next paragraphs.

1.10.1 The evaluation table

The following table is used to sum up the evaluation of each method.

Table 1.1. Our evaluation of the methods.

Topic	Our evaluation of the method
Methodical requirements	
Integration with LCA for external environment	
Applicability in LC-phases	
Aggregation possible	
Working environmental aspects	
Coverage of WE'al issues	
Graduation of exposures and effects	
Practicability	
Practical in use	
Software tool	
Transparency	
Can be used by non-experts	
Data issues	
Data reliability	
Amount of data in existing database	
Data accessibility	
Data can be obtained by WPA	

❍ = missing, ✗ = poor, ✗✗ = acceptable, ✗✗✗ = good, ✗✗✗✗ = excellent

The following text explains the considerations in the project group and indicates the basis for the scoring.

1.10.1.1 Integration with LCA for external environment

The impacts for both the working environment and the external environment should be based on the same functional unit, and it should be possible to normalize and weight the impacts by the same method. The WE-LCA should therefore be quantitative.

1.10.1.2 Applicability in LC-phases

The method must be applicable in all life cycle phases, and not just the production phase.

1.10.1.3 Aggregation possible

It is necessary that the working environmental impacts can be aggregated over the entire life cylce.

1.10.1.4 Coverage of WE'al issues

The WE-LCA method is more complete the more issues (working environmental) the method covers.

1.10.1.5 Graduation of exposures and effect

In order to get the most correct evaluation of the working environment, it is necessary to grade both the exposures and the effects.

1.10.1.6 Practical in use

In order to become widespread the method need to be practical in use. Both with regard to time consumption and user-friendliness of the method.

1.10.1.7 Software tool

The practicability of the method also depends on a good and user-friendly software tool being available. Another requirement is the existence of an extensive database, which makes it possible to perform comprehenive WE-LCA's within a reasonable time.

1.10.1.8 Transparency

Both the method and the outputs of the method should be clear and understandable. Furthermore the data's origin should be transparent, which makes the LCA report easier to read and understand.

1.10.1.9 Can be used by non-experts

If non-experts can carry out the WE-LCA, the method may probably end up being more widespread. Experts are in this case defined as persons with both LCA knowledge and working environmental knowledge.

1.10.1.10 Data reliability

It is important that the data used are reliable. The data should be reliable with respect to both uncertainty and objectivity. It can be difficult to obtain objectivity when collecting data because some working environmental parameters are more "soft" than others. The answers depends on the person to collect them, because some working environmental issues can not be measured in absolute numbers.

1.10.1.11 Amount of data in existing database

If a large database exist over working environmental impacts, the WE-LCA will be much easier to perform.

1.10.1.12 Data accessibility

It is a requirement that the necessary data, for carrying out the method, are accessible. Also if a software tool does not exist or if the necessary data are not available in the database.

1.10.1.13 Data can be obtained by WPA

It is an advantage if the data can be obtained form WPA (Work Place Assessment), because that will make the data collection easier in the future.

2 MUP chemical screening method

2.1 The general methodology

The chemical screening method described in this review was the result of the frame programme “Integrated environmental and occupational assessment of new materials”, which was part of the Danish Materials Technology Programme (MUP). The screening method was developed because - within MUP - it was compulsory to assess the impact on the environment and the working environment.

Before the development of this method, another chemical screening method for integrated environmental and working environmental assessments was developed. The method described in this review has been developed in an iterative process, and the complete method has never been used. The method does not strictly follow the general LCA methodology and is therefore difficult to fit into the framework that is made for review of the LCA methods.

2.1.1 Purpose

The purpose of the above-mentioned frame programme was:

- To improve the earlier developed screening method and to ensure that the method was able to identify critical situations in the life cycle of a material or a product
- To use the method on the activities in the Material Technology Centres that participated in MUP
- To develop a flexible method that was usable outside MUP
- To assess the effects of selected materials and activities under MUP and to compare alternative materials.

In addition to this, it was important to ensure that the screening was useful for developers of materials or products.

The leading principles of MUP were therefore to develop a method that - in a relatively quick and inexpensive way - would make it possible to identify the potentially critical situations in a product life cycle. Furthermore the method should be rooted in the international terms and concepts which form the basis of the international standardised methodology.

2.1.2 The overall contents of the methodology

The MUP method was developed for chemical screening of the environmental and working environmental impact of a material or a product.

The product or material life cycle is divided into four phases:

- Production of raw materials
- Production of final products
- Use

- Disposal

To assess the impact from a new material or product seven parameters are included in the method:

1. Consumption of raw materials
2. Consumption of energy and related emissions
3. Waste and recycling
4. Screening for potential health effects
5. Screening for potential environmental impacts
6. Accidents
7. Life time of the materials

The screening of the specific material or product is documented in an environmental file consisting of:

- A short description of the material and the phases of the material life cycle
- An assessment of each of the above-mentioned six parameters (the seventh parameter "Life time" is included in the other parameters) in the four phases of the life cycle. In this part of the environmental file the impacts and potential effects as well as possibilities of improvements are described.
- A summary where the results for the entire life cycle are collected and the critical situations are pointed out.

2.1.3 The general principles of the methodology

MUP's chemical screening method was developed to identify and assess the impact from new materials and products on a very limited data basis. Due to the lack of data and the desire that the method should be quick and inexpensive the method is semi-quantitative.

The chemical screening will often be part of the material development process. An industrial production has seldom been started and there will be no experiences from production, use or disposal of the product. The screening is therefore a snapshot of the environmental and working environmental impact from the material life cycle.

The screening can provide a dialogue between the product developer and the environmental expert as well as it can initiate substitutions of materials and processes or be the basis for a more complete life cycle assessment.

MUP's chemical screening method does not strictly follow the terminology and principles outlined in the ISO 14040-series.

The first step is goal and scope definition. The method does not operate with a functional unit. In the "environmental file" mentioned in section **2.1.2**, the use of the material or product and its life cycle is described and the components and materials related to the product or material are listed. Materials that are not listed will not be included in the screening.

The next step is the inventory analysis and classification where the impacts are outlined in the environmental file. As mentioned, the parameter "Life time of the materials" is included in the other parameters so the description is performed with only six parameters. For each of the six parameters the impacts are described for all four phases of the life cycle. The impact and potential effects are listed and possibilities of minimising the impact are discussed. Finally the most critical situations are outlined for each of the four life cycle phases.

In the summary the most critical situations are identified in a matrix with the four life cycle phases and the six parameters. Possibilities of improvements are listed. If possible (e.g. for the consumption of energy) the potential global and regional effects are quantified for the four life cycle phases.

2.1.3.1 Working environment in MUP

In MUP's chemical screening method the working environment is included in the parameter "Screening for potential health effects". The screening is not just a working environmental screening as it includes the potential health effects when the chemicals are exposed to the local environment, regionally and globally.

In this review only the part including exposure to the working environment will be described.

MUP's chemical screening method includes an "Analysis of accidents", where the impacts and potential effects (on environment, health and material) from fire, explosion and leaks of toxic substances (by air and fluid) are assessed. The method includes acute effects (death, illness) and chronic effect (irreversible eye damages, respiratory damages and cancer). The analysis of accidents is not further discussed in this review, as the risk of accidents is not a pronounced working environmental parameter.

2.1.4 Combined environment and work environment assessment

The "Screening for potential health effects" covers exposures to the working environment as well as local, regional and global exposures. Therefore some of the exposures are evaluated with the same methods and limits that are used in the "Screening for potential environmental impact". An example of this is bio-accumulation and bio-degradation.

2.1.5 Software tool

A paradigm for the environmental files is available on a computer disc.

2.2 Working environmental assessment methodology

2.2.1 Purpose and goal

The purpose of the parameter "screening for potential health effects" was to develop a method that, primarily from literature references, can quickly perform a screening of the health effects related to a new product or material.

The purpose of this parameter is not a detailed toxicity and health assessment but a screening to identify potential hazardous situations that should lead to substitutions, or undergo a further investigation.

2.2.2 Scope of the methodology

2.2.2.1 System boundaries

The material life cycle is covered by the four phases - production of raw materials, production of final products, use, and disposal. There are no major differences between the assessment method for the different impacts and the method does not set any criteria for exclusion of impacts as all impacts may be relevant at this stage of development.

In the "screening for potential health effects" there are no procedures for allocation.

2.2.2.2 Impact categories

In the "screening for potential health effects" only potential effects related to exposure of chemicals are included. Therefore the working environmental method operates only with one impact category, "Chemical Impacts". The effects covered by the method are shown in **Table 2.1**

Table 2.1. Effects included in the "screening for potential health effects" in MUP.

Impact categories	Effects
Chemical impacts	Acute toxicity
	Irritation
	Allergy
	Specific organ effects
	Genotoxic effects
	Cancer
	Neurotoxic effects
	Reproductive effects

According to internationally accepted criteria for labelling and classification the potential health effects of the chemical are divided into three categories and the chemical is assigned an *effect-score*. Guidelines for how the effects should be categorised and scored are outlined in the method description.

As mentioned in the beginning another method was developed before the development of the method described in this review. In the earlier method, physical working environment and ergonomics were included, but it was omitted in the final method.

2.2.2.3 Data requirements

The "screening for potential health effects" includes an exposure screening and a screening for potential health effects. Both are described in more detail in the following sections. The information needed for the "screening for potential health effects" is collected by an environmental specialist and the product developers.

If possible the exposures of the chemicals are measured, but because the screening is part of the product or material development process, it is often necessary to estimate the exposure from process parameters. This means that the assessment will often be theoretical and not based on observations from the working place.

2.2.2.4 Inventory parameters

The data needed for the exposure screening are:

- a list with names (and CAS No.) of the substances and materials that will be used or processed in the product or material life cycle
- working hygienic measurements of the exposures or
- qualitative and quantitative process parameters

When it is possible to measure the level of exposure it will be assigned a score on the basis of threshold limit values (TLV) in the working environment:

Substances detected		=> Low exposure	(score 1)
Generally	<10% of TLV	=> Medium exposure	(score 2)
Frequently	>10% of TLV	=> High exposure	(score 3)

It is often not possible to measure the exposure. In this case the following process parameters are used:

- consumption of materials (kg per day)
- open/closed process
- volatility
- dust/aerosol formation
- skin contact

The process parameters are divided into three categories and the process is assigned an *exposure-score.* Guidelines for how the exposures should be categorised and scored are outlined in the method description.

2.2.2.5 Impact assessment – screening of potential effects

The chemical screening method is not in accordance with the ISO 14042 standard. The method does not operate with the five steps - category definition, classification, normalisation (optional) and weighting (optional). Instead the method operates with an effect screening and a scoring system for the potential effects.

The eight potential effects included in the method are shown in **Table 2.1**. For each substance the potential effect is assigned a score:

Low effect	=>	score 1
Medium effect	=>	score 2
High effect	=>	score 4

The score depends - amongst other things - on the number of potential effects and seriousness of the effects. The characterisation is based on threshold limit values, labelling criteria, classification rules etc. for the potential effects. The method description includes a detailed guideline on how to assign the effect score.

2.2.2.6 Combining the screening of exposure and effects

The exposure screening and the effect screening are combined in a matrix (Table 2.2).

Table 2.2. Matrix for identifying potentially critical situations.

Exposure Effect	Low (1)	Medium (2)	High (4)
Low (1)	1	2	4
Medium (2)	2	4	8
High (4)	4	8	16

The method recommends that for all the situations with the score "8" or "16" a more detailed examination should be carried out, the process should be changed, or the chemical/substance should be substituted.

The method does not include any aggregation of working environmental effects in the life cycle and there is no normalisation or weighting of the effects.

2.3 Cases

MUP's chemical screening method was developed in co-operation with the Materials Technology Centres in Denmark. The five Centres have tested the method in 16 cases divided into five groups:

- Composites based on plastics
- Dry covering processes
- Advanced technique for galvanisation
- Advanced technical ceramics
- Powder metallurgy

For each of the 16 cases an environmental file has been completed. None of the evaluated materials or products have been tested in a life cycle assessment before.

The cases showed that it was difficult to obtain data from the processes outside the Centres, e.g. the production of raw material or disposal. This lack of data will most likely be typical when assessing products or materials under development where a production has not been started.

In the cases where the data were available, the screening was able to identify the critical situations in the product or material life cycle.

The screening method was tested, evaluated, and further developed in an iterative process. This means that the final method has never been used but consists of sub-elements that all have been tested individually.

2.4 Discussion

In this section we discuss the strong and weak sides of MUP's method. The text therefore reflects the opinion of the project group. The purpose of the discussion is partly to evaluate the method and partly to learn form the strong and weak sides of the method, and thereby be able to set guidelines for the "perfect" working environmental LCA.

In the discussion, the strong and weak sides of the method are firstly summarised (Table 2.3), after which the points are elaborated. Secondly, an overview of *our* evaluation of the working environmental LCA is given. Finally, suggestions for improving the method are discussed.

Table 2.3. Strong and weak sides of MUP's chemical screening method.

Strong sides	Weak sides
Interacts well with the other parameters in the screening There is accordance between purpose, data requirements and results Impact assessment criteria are readily available The method promotes dialogue between the developer and the environmental expert The method can be used in all life cycle phases Exposures and effects are graduated Scoring system is simple and easy to use Requires only a limited number of data Most data are easily available	No interaction with other LCA methods Focuses on substances rather than products The method is semi-quantitative Aggregations are not possible Includes only a limited number of impacts Use of the method requires expertise in assessment and classification of chemicals The method does not include a database

2.4.1 Methodical requirements

2.4.1.1 Interaction with other parameters in the method

The "screening for potential health effects" interacts well with the other parameters in the screening method, primarily the "screening for potential environmental impacts" and the "accident analysis". The data requirements and the level of assessment are essentially the same for the three parameters.

In the environmental file the six parameters are handled equally and described with the same framework.

2.4.1.2 Interaction with other LCA methods

The method does not relate to other LCA methods and it will be difficult to compare results with other methods.

The "screening for potential health effects" can be used as a tool of its own or can complement results from a quantitative LCA, where the working environmental aspects are not included.

2.4.1.3 Accordance between purpose, data requirements and results

The purpose of the "screening for potential health effects" was to develop a method that - primarily from literature references - could quickly perform a screening of the health effects related to the life cycle of new products or materials. As the data requirements are limited, the screening can be based on literature without working hygienic measurements and the method can identify the critical situations in the material or product life cycle. There is accordance between the purpose, data requirements, and results of the method.

2.4.1.4 Availability of impact assessment criteria

The method description includes a detailed guideline (based on threshold limit values, labelling criteria etc.) for assessment and characterisation of the potential effects. These threshold limit values and labelling criteria will already be available for many of the substances.

2.4.1.5 *Dialogue between product developer and environmental expert*
As the method assesses the materials or products at a very early stage in the development process, the developer will be very involved in the screening. Furthermore a dialogue between the developer and the environmental expert will be necessary for listing possible improvements of the product or material in the environmental files.

2.4.1.6 *Other methodological issues*
The method focuses on substances rather than products. The screening does not operate with a functional unit and there are no allocation procedures. Therefore it can be difficult to relate the results of the working environmental screening to the material or product.

The method is semi-quantitative but when possible - e.g. for energy consumption - the impact is quantified.

In the "screening for potential health effects" the exposures and effects are graded in three groups (low, medium or high exposure or effect). The scoring system is easy to use but some of the transparency and information get lost. This can make it difficult to compare the result with results from other LCA methods.

With the scoring system it is not possible to make aggregations of the life cycle phases. In the environmental file all phases (production of raw materials, production of final products, use, and disposal) are described in separate sections. The final result of the chemical screening is a matrix with the four phases and the seven impact categories.

2.4.2 Working environmental aspects

The method includes only the chemical working environment and thereby only a limited number of impacts. No other impacts are covered by the assessment. This leads to the risk of preclusion of very significant working environmental impacts such as noise, vibrations, dust, and monotonous repetitive work.

The method can be used in all life cycle phases as long as chemical information and measurements of exposures or process parameters are available.

Both the exposures and the effects are assigned a score and thereby graduated in three levels. When the effect-score and the exposure-score are combined in a matrix it is easy to assess for which situations a more detailed examination should be carried out or the process or chemical should be changed or substituted.

2.4.3 Practicability

2.4.3.1 *Scoring system*
The scoring system operates with simple guidelines showing how to assign a score (low, medium or high) to the exposures and effects. The scoring system and the matrixes are simple to use and give a quick and clear overview of the potential critical situations where a substance should be substituted, a process changed or a more detailed examination should be carried out. Another advantage of the scoring system and the matrixes is that they make it fairly

easy to compare alternative products or materials that have been assessed with the screening method.

2.4.3.2 *Required expertise*

To use the method extensive knowledge of chemical substances and processes is required. This demands some involvement of a person with chemical knowledge and experience with working hygienic measurements or assessment of processes.

2.4.3.3 *No database*

The method does not include a database, which would be a valuable help when assessing the effects of the chemicals.

2.4.4 Data issues

As the "screening for potential health effects" solely covers exposure of chemicals it only requires a limited number of data. If possible the exposure should be measured but more often the exposure will be estimated from process parameters. This means that the critical situations can be identified without a large number of measurements and on the basis of literature references.

As the method to a large extent is based on literature information most of the data will be relatively easy to obtain and only a few measurements will be necessary.

2.4.5 Summary of the assessment

In **Table 2.4** the above discussion is summarised. This table illustrates how the project group evaluates the MUP method. The exact meaning of the topics in the first column is described in section 1.10.

Table 2.4. Fulfilment of the MUP method.

Topic	Evaluation of the MUP method
Methodical requirements	
Integration with LCA for external environment	✗✗
Applicability in LC-phases	✗✗✗✗
Aggregation possible	❍
Working environmental aspects	
Coverage of WE'al issues	✗
Graduation of exposures and effects	✗✗✗
Practicability	
Practical in use	✗✗
Software tool	❍
Transparency	✗✗✗✗
Data issues	
Data reliability	✗
Amount of data in existing database	❍
Data accessibility	✗✗
Data can be obtained by WPA	❍

❍ = missing, ✗ = poor, ✗✗ = acceptable, ✗✗✗ = good, ✗✗✗✗ = excellent

2.5 References

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MUP, 1994b. Schmidt a *et al*. "Livscyklusmodel til vurdering af nye materialer, Baggrund, principper og anvendelse", *English title: "Life Cycle Model for assessment of new materials: Background, principles and use".*

3 The EDIP screening method

3.1 The general methodology

Development of the EDIP method for assessment of the working environment was part of the Environmental Design of Industrial Product programme (the EDIP-programme). The programme was sponsored by the Danish EPA, and the participants were five major Danish industrial companies as well as institutes at the Technical University of Denmark.

3.1.1 Purpose

The purpose of the EDIP project was:

1. To develop methods for environmental assessment of complex industrial products,
2. To develop guidelines for design and construction of environmental friendly industrial products,
3. To develop a database and a computer based tool as support for environmental assessment, and
4. To implement the methods and tools in the companies participating in the project.

3.1.2 The overall content of the methodology

The purpose of the EDIP project was, as mentioned, to perform an environmental assessment of products. For this purpose a quantitative process assessment method for LCA was developed within the project. The assessment parameters used within the EDIP method are shown in **Table 3.1.** . According to the table the method operates with three groups of assessment parameters: environmental effects, resource consumption, and working environmental effects.

Table 3.1. Assessment parameters used in EDIP.

Effects	Environment	Resources	Working environment
Global	Greenhouse effect Stratospheric ozone depletion	Fossil fuels Metals Other minerals Others (animals etc.)	
Regional	Photochemical ozone creation Acidification Eutrophication Ecotoxicity (water, chronic) Human toxicity (water)		
Local	Ecotoxicity (water, acute) Human toxicity (air) Hazardous waste Nuclear waste Incineration ash Bulky waste	Biomass Water Others	Cancer due to chemicals Reproduction damages due to chemicals Allergy due to chemicals CNS-damages due to chemicals Muscle-skeletal damages due to monotonous repetitive work Hearing damage due to noise Body damages due to accidents

Most of the effect potentials are relatively straightforward to handle in the quantitative assessment method. However, the quantitative assessment of the effect potentials “ecotoxicity” and “human toxicity” demands much more work. To avoid too much unnecessary work, screening methods have been developed. These screening methods can help in the decision of identifying the potential contributes to human toxicity or ecotoxicity.

3.1.3 The general principles of the methodology

The EDIP methodology is based on the following steps:

- *Inventory* : the data (e.g. resource consumption, emissions to air and water, waste etc.) from the product system are measured, calculated or estimated
- *Classification*: the inventory data are classified by their potential to cause impacts, e.g. use of non-renewable resources, global warming and ozone depletion
- *Characterisation*: the data are characterised with respect to the impact categories, i.e. equivalence factors are used to determine the impacts from several sources to an impact category.

These steps follow the principles outlined in the ISO 14040-series and are generally accepted as a sound methodology in LCA.

The aggregated impacts are subsequently normalised by relating them to the average annual impacts caused by one person in a relevant geographical area (the World/Denmark). In doing so, the contribution to an impact category is related to the potential impact from the society’s activities as a whole.

Finally, the impacts are weighted using international or Danish political stated reduction targets for different impacts or specific compounds. Hereby it is assessed which of the potential impacts from a product system that are the most important.

These steps of the EDIP methodology differ slightly from the ISO 14040 standard, where only a weighting step is recommended. There is, however, little doubt that the normalisation step used in the EDIP methodology adds significant information, provided that the mechanism and principles are scientifically based and understood by the decision-makers.

3.1.3.1 The working environment in EDIP

EDIP operates with three different methods for assessing the working environment, a screening method, a process assessment method, and a sector assessment method.

The screening method is a chemical screening method and thereby only covers the chemical working environment of an LCA. The chemical screening method can be used early in the product development or together with the process assessment method. In the last-mentioned case the chemical screening will be a preliminary step for the quantitative assessment with the purpose of deciding which processes to include in the process assessment.

The process assessment method can be used in the assessment of the manufacturing process in the company and possibly for those subcontractors who are able and willing to supply the information needed.

The sector assessment method can be used together with the process method, in processes where specific working environmental data not are available (Hauschild, 1996, Broberg & Rasmussen, 1996).

3.1.4 Combined environmental and working environmental assessment

The assessment parameters used in the EDIP method are shown in **Table 3.1.** . The method operates with three groups of assessment parameters (environmental effects, resource consumption, and working environmental effects), which all play an equal role in the methodology.

All three groups of assessment parameters are related to the same functional unit and measured by the same environmental unit - the person equivalent. Because the same basic assessment method is used, it is possible to aggregate over several steps in the life cycle and to compare the results from assessment of the working environment with other impact categories.

The data describing the working environment are collected from different sources depending on the assessment method used. For use of the chemical screening method, information about the chemicals used in the specific processes is needed. The screening scores the processes by relating them to European and national lists of dangerous substances, and lists of substances with special effects.

The process assessment method requires more specific data from the company. Examples are information concerning impacts due to accidents, chemicals, noise, and monotonous repetitive work. Furthermore, it should be stated how much of the company's production time that is used to manufacture the examined product in each of the processes.

When using the sector assessment method similar data should be collected. However, it should be noted that the data in this case represents the average working environmental impacts from the entire sector instead of the specific company and thereby - everything being equal - will lead to higher uncertainty.

3.2 Working environmental assessment methodology

3.2.1 Purpose and goal

The purpose of the working environment project within EDIP was

- to develop a method for including working environmental parameters in LCAs based on the methodical framework described by SETAC and the EDIP programme,
- to use the developed method for assessing the working environmental impacts in the life cycle of five industrial products (reference products),
- to identify the critical working environmental impacts of the reference products and point out the possibilities for improvements of new products in progress,
- to outline the principles for good working environmental construction of industrial products, and
- to describe and evaluate the use of the developed methods and tools in product development within the companies participating in the project (Broberg & Rasmussen, 1996).

The EDIP programme includes the working environment in LCAs for three reasons:

- The working environment should be included in LCAs to avoid working environmental deterioration when production processes are changed. LCAs will often be the basis of production changes or development of new products with lower environmental burdens. These changes determine the choice of production materials and processes, which directly influence the working environment.
- Including assessments of the working environment in LCAs makes it possible to prevent working environmental problems when the LCAs are used in the technological planning.
- The working environment should be included in LCAs because some working environmental problems are of life cycle character, e.g. by chemical substances following the product throughout its entire life cycle (Broberg & Rasmussen, 1996).

The screening method has been developed to serve several purposes. First of all the screening can be used to assess chemical substances on the basis of their inherent properties. This is important because it is often difficult to get detailed information about the chemical burden outside the companies' own production.

Secondly, the screening can be used at an early level in the product development, where the detailed production information is not yet known or when a general comparison between alternative materials and processes is wanted.

Thirdly, the purpose of the screening is to point out the life cycle processes that can burden the chemical working environment and to give an early idea of the working environmental properties of a material or product. The important processes and materials are then later on examined further by the process assessment method. To save time, the qualitative screening method is used to find the important processes quickly for the quantitative assessment.

3.2.2 Scope of the methodology

3.2.2.1 System boundaries

The system boundaries for the screening method with regard to the inclusion of life cycle phases are not mentioned in the description of the method. It is assumed that the screening method in principle can be used in all phases of the life cycle if the necessary data exist. The entire life cycle is therefore in principle covered by the working environmental assessment. However, only work-related processes are examined. Private use of the products is not included as a part of the working environmental assessment as this is not covered by legislation. Furthermore, only chemical working environmental problems are included in the screening as the chemical burden is one of the largest working environmental problems in Denmark (Broberg & Rasmussen, 1996).

Allocation is not used in the screening method because the method is merely used preliminary to find the chemically burdened processes that should be examined further, e.g. by using the process assessment method. Otherwise the impacts are allocated by production time (Broberg & Rasmussen, 1996).

3.2.2.2 Impact categories

The working environmental impacts included in the screening method are only related to chemicals. The screening includes the potential effects of the chemicals by assessing the inherent properties of the chemicals. The actual effect that occur because of an exposure is very difficult to describe because the effect depends on the size of the exposure, the time exposed, the exposure route, the individuality of humans etc. The potential effects are listed in **Table 3.2** below.

Table 3.2. Working environmental effects included in EDIP's screening method

• Acute toxicity
• Irritation, corrosion
• Allergy
• Irreversible damages, damages to organs
• Genotoxicity / mutagenic effects
• Carcinogenic effects
• Reprotoxicity
• Neurotoxicity
• General chemical effects

3.2.2.3 Data requirements

The data needed are found at process and/or company level. Some data can be found in literature; others at the examined companies.

The necessary data for the EDIP screening method can be divided into three groups.

- Group one is the inventory data from the process description, which include a list with names of substances and materials used at the individual life cycle processes (preferably with the attached CAS-numbers).
- Group two is information on the potential effects of these chemicals according to Danish and European legislation.
- Group three is an evaluation of the potential exposure to the listed chemicals.

The chemicals to be listed in group one do not only cover the chemicals in the production but also auxiliary materials, breakdown products, impurities, etc. (Broberg & Rasmussen, 1996).

Data on the effects of the chemicals can be found and are generally available. Data on the potential exposure are more difficult to find, but the screening method only demands data on a very low level ("no exposure", "no knowledge", "exposure exists"), which makes it easier to find the data or come up with educated guesses. The exposure is estimated with the use of knowledge about the process and about the chemicals, e.g. open or closed process, existence of process ventilation, existence of contact with the chemical, and physicochemical parameters (Broberg & Rasmussen, 1996).
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3.2.2.4 Inventory parameters

The necessary inventory parameters are, as listed above, a list of the chemical substances, and the potential effects and exposure of these substances.

Collection of the inventory data for the chemical screening is carried out individually, because the data collection merely is at a screening stage. It can, however, be beneficial to collect data on emission of the chemicals for the external environment at the same time.

The necessary workload for performing the chemical screening is low. When a precise identification of the chemicals have been made, the screening can be carried out by the use of toxicity data based on EU-classification, lists from Danish authorities concerning carcinogenic, reprotoxic, allergenic, and neurotoxic (CRAN) substances, and data about the potential exposure (often common knowledge or educated guesses).

3.2.2.5 Impact assessment

The chemical screening process reviews the exposure and effects of the chemical substances, and thereby evaluates how burdened the chemical working environment is. The purpose of the screening is merely to pinpoint important processes for the inventory and the impact assessment at an intermediate stage in the assessment. For a chemical working environment to be burdened there has to be both an exposure and an effect of some kind. The screening method is therefore based on a matrix consisting of the two parameters "exposure to" and "toxic effects of" the chemicals, see **Table 3.3**.

The chemical substances are given a score on the basis of their toxic properties and effects, and a score based on the risk of exposure to that chemical. If a chemical substance have more than one potential toxic effect the score is determined by the highest score. The score of a substance with both a carcinogenic and irritating effect will, for example, be 8. The final score is found by multiplying the effect score with the exposure score (Broberg & Rasmussen, 1996).

Table 3.3. EDIP's total screening method (simplified). Final score is given in brackets ().

Type of effect / Risk of exposure	Score 0 Well exaimined substances without classification	Score 1 Irritating and hazardous substances	Score 4 Corrosive, toxic, very toxic, allergenic or neurotoxic substances.	Score 8 Carcinogenic, reprotoxic or mutagenic substances.
Score 0 No exposure	No further investigation (0)	No further investigation (0)	No further investigation (0)	No further investigation (0)
Score 1 No knowledge	No further investigation (0)	Further inv. if necessary (1)	Further investigation (4)	Included in the assessment (8)
Score 2 Exposure occurs	No further investigation (0)	Further inv. if necessary (2)	Included in the assessment (8)	Included in the assessment (16)

The final score can be used to compare different alternatives, and if handled with care the screening method can be used to choose between alternatives. Care should be taken because the screening is a very general assessment with a relatively high uncertainty. However, the screening can be used as a guide in development work.

It is suggested that the choice between alternatives can be carried out by selecting the alternatives with no final score of 16, then selecting the alternatives with no score of 8, and so on. Furthermore, the final scores can be added for the entire life cycle. However, this number will only have limited value, because the final score does not represent the true chemical burden of the processes in the life cycle as substances with unknown exposure are given a medium score (Broberg & Rasmussen, 1996).

No aggregation of the results is used within the screening method. Likewise, further assessment or weighting is not carried out as the method merely is regarded as a preliminary screening method.

The chemical screening method does not live up to the ISO 14040 standard in all respects. Primarily, because it only addresses the chemical aspects, and secondly, because the assessment is not based on the actual emissions, but on the inherent properties of the chemicals. Thirdly, the classification, characterisation and the weighting is carried out in one step by using the developed matrix for the screening.

3.3 Cases

No cases have been documented for use of the chemical screening method. The screening method was developed late in the process of developing the process assessment method, because the detailed level of the process assessment method led to the need of a screening method. Therefore the screening method has not been used on any cases.

3.4 Discussion

In this section we discuss the strong and weak sides of the EDIP screening method. The text therefore reflects the opinion of the project group. The purpose of the discussion is partly to evaluate the screening method and partly to be able to learn from these strong and weak sides, and thereby be able to set guidelines for the "perfect" working environmental LCA.

Firstly, the strong and weak sides are summarised in this discussion (**Table 3.4**), whereupon the points are elaborated. Secondly, an overview of our evaluation of the working environmental LCA is given and finally, suggestions for improving the method are discussed.

Table 3.4. Strong and weak points of EDIP's chemical screening method.

Strong points	Weak points
Can in principle be used in all life cycle phases The method can to some extent compare alternatives Serve its purpose of being a screening Do not include the use of personal safety protection equipment The screening encourages reduction of chemicals Easy to use – clear outputs Few data needed Realistic to carry out the method - data are available The necessary data can be obtained by work place assessment	No direct integration with the general LCA-methodology No possibility of correct aggregation Too many processes will be investigated further The screening and the process assessment method do not match each other Covers only chemical impacts No possibility to differentiate between exposure levels No software tool available Difficult to use by non-experts

3.5 Methodical requirements

3.5.1.1 Integration with the general LCA-methodology

EDIP's chemical screening method can in principle be used in all phases of the life cycle. It has no direct integration with the general EDIP LCA-methodology. The screening method is primarily developed as an auxiliary tool for the process assessment method, in order to save time in the data collection phase.

The screening is very similar to the screening method in MUP. The screening for exposure is, however, not as elaborated as in MUP. In MUP the exposure is given a score based on different physicochemical parameters, whereas EDIP gives some guidelines, based on process specific information, for how to determine whether an exposure exists or not.

3.5.1.2 Aggregation over the life cycle

The screening method gives the possibility to aggregate the scores, but it is not possible to make a "correct" aggregation. The working hours, which are used to aggregate the impacts in EDIP's general methodology, are not included in the screening method. The final score can be added for the entire life cycle and give the total score for the specific alternative. As stated in Broberg & Rasmussen (1996), the method should, however, be used with great care as the total score does not represent the true chemical burden of the processes in the life cycle, because substances with unknown exposure are given a medium score. Furthermore, it only makes sense to add up the individual scores if the total number of processes, and the total number of chemicals used through the entire life cycle is the same for all alternatives. The final score should therefore only be used to select the chemicals and their matching processes that should be included in the impact assessment.

3.5.1.3 *Comparison of alternatives*

The screening method can to some extent be used to compare alternatives and to choose between them. The choice can, however, only be made if the difference between the alternatives is clear, (e.g. by choosing the alternatives that have no scores of 16), because of the general level of the screening method. Even though the choice only is possible on this level, it is significant to be able to perform a choice between alternatives (on the basis of one impact area that is!) already at the screening stage.

Even with the low level of data needed, the screening serves its purpose to leave out the processes with no relevance for the extended impact assessment, i.e. processes with either no exposure or processes using substances with no effects on human beings.

3.5.1.4 *Other methodological issues*

If the screening should live up to its other purposes of being able to assess the chemicals and compare alternatives, it seems that the scoring interval is too narrow. Too many processes will end up with either a score of 8 or 16, and thereby be investigated further. Even the processes with no knowledge about the exposure can end up with a score of 8. For the purpose of choosing between alternatives it is therefore necessary to widen the scoring possibilities.

In addition, the chemical screening method recommends that processes with an effect score of 1, and with an exposure score of either 1 or 2 could be examined further. These processes will, however, not be included in EDIP's process assessment method, and therefore there is no need to examine these processes any further. The screening method and the method used for process assessment should match each other in a way so that processes chosen as important by the screening process are a part of the working environmental assessment in the LCA. This imbalance can, however, be improved by expanding the process assessment method.

3.5.2 Working environmental aspects

The screening method covers only the chemical impacts, whereas the process assessment method in EDIP includes the impact categories chemical impacts, noise, monotonous and repetitive work, and accidents. Conversely, the screening covers all effect groups of the chemical working environment whereas the process assessment only includes the chemical CRAN-effects/damages (Cancer, Reproduction damages, Allergy, Neurotoxic effects). This means that a process using toxic or very toxic substances with the possibility of causing irreversible damage on human beings is chosen as a process that should be included in the LCA when applying the screening method. The process will, however, be left out of the impact assessment in the process method because only CRAN-effects are covered by this method.

3.5.2.1 *No differentiation between exposure levels*

The screening method does not give the possibility to differentiate between different exposure levels, because the screening method only distinguishes between an exposure and no exposure to chemicals. A small short-time exposure is not likely to produce the same effects as a long-time exposure of a large dose. However, the relation between the level of exposure and the resulting effects is very complex and can be difficult to handle in a screening method.

The screening method does not consider the use of personal safety protection equipment. This is an advantage when the purpose is to promote more working environmental friendly products and processes. Prevention is preferred over protection. The method thereby ensures that less hazardous substances will be preferred instead of using a solution with more personal protection.

The EDIP method has been used by some companies during the development of the method. One important lesson from this was that the screening also might be helpful in reducing the total amount of chemical products used by the companies (Broberg & Rasmussen, 1996). The screening method was, however, not developed to serve this purpose but this example shows that use of the screening brings the use of chemicals into focus, which then leads to a reduction.

3.5.3 Practicability

3.5.3.1 Easy to use - clear outputs

One strong point of the method is that it is easy to use. The matrix represents some simple guidelines on how to score the processes when the exposure to and the effects of the chemicals are known. Furthermore, the outcome of the screening is clear and comprehensible, because it is one single figure, which easily can be compared with another output.

3.5.3.2 No software tool available

No software tool is available for the screening method.

3.5.3.3 Difficult to use by non-experts

While the effects are straightforward to handle, because the information can be found on European or national lists of substances, the exposure is more difficult to deal with. One weak point is that, even at this low data level, educated guesses are often needed, based on general knowledge about how the different processes are carried out. It is therefore necessary to possess knowledge about different processes, and the circumstances that will lead to an exposure to chemicals. Knowledge about the chemical working environment and chemistry in general is also necessary for carrying out the screening. If no exposure knowledge exists the “no knowledge” score for the exposure will be given, and thereby make the score unreliable.

3.5.4 Data issues

The basic data needed for giving the processes the score are names of the chemicals used and information about the human exposure to the individual chemicals. With the CAS-number potential effects of the chemicals can easily be obtained. The potential exposure to the chemicals is scarcely described which is an advantage, because less data are needed when you only have to choose between the three categories: “no exposure”, “no knowledge”, and “exposure exists”.

It is realistic to carry out the chemical screening because the level of data needed for the screening is comparatively low, and because the data often will be available. It may, however, be necessary to come up with educated guesses for the exposure conditions.

Information about the chemicals and the exposure to the chemicals can be obtained from a work place assessment.

3.5.5 Summary of the assessment

In Table 3.5 the discussion above is summarised. The table illustrates how we evaluate the EDIP screening method. The exact meaning of the topics in the first column is described in section **1.10**.

Table 3.5. Evaluation of EDIP's screening method.

Topic	Evaluation of EDIP's screening method
Methodical requirements	
Integration with LCA for external environment	❍
Applicability in LC-phases	✗ ✗ ✗ ✗
Aggregation possible	✗
Working environmental aspects	
Coverage of WE'al issues	✗
Graduation of exposures and effects	✗ ✗
Practicability	
Practical in use	✗ ✗ ✗
Software tool	❍
Transparency	✗ ✗ ✗ ✗
Can be used by non-experts	✗ ✗
Data issues	
Data reliability	✗
Amount of data in existing database	❍
Data accessibility	✗ ✗ ✗
Data can be obtained by WPA	✗ ✗ ✗

❍ = missing, ✗ = poor, ✗ ✗ = acceptable, ✗ ✗ ✗ = good, ✗ ✗ ✗ ✗ = excellent

3.5.6 Suggestions for improvements

One improvement that could be useful is to develop the screening method in a way so the final scores for each process can be aggregated and give a more correct total score. However, this requires that exposure score 1 for "no knowledge" is removed, because this score produces the "incorrect" total score. But the possibility to tick off "no knowledge" is on the other hand also very useful at the screening level of an LCA. At this stage there will always be data that can not be found, and it is useful to know which processes should be further examined. For this reason it will also be difficult to go into more details about the kind of exposure or the level of exposure, even though this will produce a more correct picture of the actual effects of the processes. But the data on the exposure will be too difficult to find.

Alternatively a more simple aggregation method could be used, which makes it possible to keep the exposure score of "no knowledge". This will not involve a summation of all the scores. Instead the highest score for all the individual chemicals in the entire life cycle will be used as the "total score", similar to the principle mentioned in Broberg & Rasmussen, (1996). This will in many cases not be very useful, because it is likely that exposure to a substance with carcinogenic, reprotoxic or mutagenic effects will appear somewhere in the life cycle of the examined product. If this is the case, the maximum score of 16 will end up as the "total score" for all alternatives. This method can therefore only be used if the exposure score and the effect score are described in much more details and split up in more scores, thereby producing many more levels for the final score. This method may, however, become too comprehensive to serve the purpose of a screening, but it will improve the possibility of choosing between alternatives.

3.6 References

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4 IVL's sector assessment method

4.1 The general methodology

IVL, the Swedish Environmental Research Institute (Institutet för Vatten- och Luftvårdsforskning), has developed a method for assessment of the working environment. The development of IVL's sector assessment method was sponsored by the Swedish Work Environment Fund. The method only covers assessment of the working environment and does not refer to any specific method for assessing the external environment.

As the method is based on statistics, it primarily deals with effects rather than exposures. This makes it difficult to describe the method according to the framework used in this project.

4.1.1 Purpose

The purpose of including the sector assessment method in LCA is to ensure that environmental improvements do not result in deterioration of the working environment (Antonsson, 1995a).

The method was developed with the purpose of integration in the quantitative LCA methods that are developed within the framework of SETAC and in projects financed by the Nordic Council of Ministers (Antonsson, 1995b).

4.1.2 The overall content of the methodology

As IVL's sector assessment method is not connected to any certain method for assessment of the external environment, there is no prescription of such a method.

4.1.3 The general principles of the methodology

The method recommends use of the principles outlined in the ISO 14040-series (Goal and scope definition, Inventory analysis and Impact assessment), but it does not strictly follow the principles.

The working environment method is based on official statistics for different sectors or individual companies. The result is a number of expected accidents and diseases related to the production of e.g. one ton of steel or to a service.

The method is based on five quantitative and two semi-quantitative effect categories. The quantitative effect categories do not include exposure but only effects, whereas the semi-quantitative effect categories includes both exposure and effects:

Quantitative effect categories

- death due to work-related accidents
- workdays lost due to work-related accidents and diseases

- workdays lost due to illness (exceeding normal)
- hearing damage
- allergy, eczema and similar diseases

Semi-quantitative effect categories

- cancer
- prenatal damage

4.1.3.1 Combined environment and work environment assessment

As mentioned, the method can be used in combination with earlier developed quantitative methods for life cycle assessment of the external environment. The method does not recommend any specific method.

4.1.3.2 Software tool

No software tool is available.

4.2 Working environmental assessment methodology

4.2.1 Purpose and goal

First of all, it was a demand for IVL that the method should be quantitative. Secondly - as mentioned – it should be suitable for integration in the quantitative methods that have already been developed to assess the external environment (Antonsson, 1995a).

In addition to this, the method should include all aspects of the working environment and it should be able to cover the variable working environmental aspects in the life cycle of different products and services.

4.2.2 Scope of the methodology

4.2.2.1 System boundaries

In principle all phases in the product life cycle (including transportation, energy consumption?, etc.) can be covered by IVL's sector assessment method. The method can be performed on a sector or at company level.

For the semi-quantitative categories only effects caused by impact from the main production line are included in the assessments. Repairs, office functions etc. are not included.

The work-related effects are allocated to the product by the economic value of the production (e.g. for goods transported by train, allocation is made by the percentage of the total income for the railway, that is related to transportation of goods).

4.2.2.2 Impact categories

The seven effect categories (five quantitative and two semi-quantitative) are shown in section 4.1.3. In principle all impacts that leads to any of the effects in the effect categories are included in the method. In the effect category "workdays lost due to work-related accidents and diseases" several impacts, e.g. chemical, ergonomic, psychosocial and physical are included.

The category “workdays lost due to illness (exceeding normal)” does in principle cover other work-related effects, e.g. psychosocial effects (or effects that are due to factors in the work environment, but which are rarely reported). It is, however, not clearly defined in the method (Antonsson, 1995a), which environmental factors this impact category encompass.

In general the effect categories have been chosen to reflect the most serious working environmental damages. In addition to this the quantitative effect categories have been selected on the basis of

- availability of statistical data
- clear correlation between the exposure to the working environment and the effects
- an aim to reduce the number of categories in order to make the method as simple as possible

The semi-quantitative effect categories have been included due to their consequence and seriousness.

4.2.2.3 Data requirements

Data for assessment of the quantitative effects are collected from official statistics on a sector or company level. It is mentioned in the description that it can be difficult to ensure that the sectors are defined similarly in different data sources. For large companies it is recommended using data on company level instead of sector statistics.

To improve the quality of the data, it is recommended that – whenever possible - the average values from a period of several years (approximately five years) should be used. It is also recommended that standard deviations should be calculated for use in a sensitivity analysis (Antonsson, 1995b).

Table 4.1. Data requirement and sources for IVL's method.

Effect categories	Data requirement and sources	Comments
Quantitative effects		
Death due to work-related accidents	sector statistics or company statistics for large companies	
Workdays lost due to work-related accidents or diseases	sector statistics or company statistics for large companies	Data for different sectors are standardised according to age and sex to compensate for divergences from the public in general
Workdays lost due to illness (exceeding normal)	company statistics for large companies	Data on sick leave (all sick leave, not only work-related) for sectors can not be derived from official statistics in Sweden. The method recommends that statistics from one or several companies in a sector can be used. The data should be normalised according to age, sex, company size etc.
Hearing damage	sector statistics or company statistics for large companies	
Allergy, eczema and similar diseases	sector statistics or company statistics for large companies	
Semi-quantitative effects		
Cancer	qualitative examination of the occurrence of substances and factors which may lead to damage official statistics	Only chemical impacts are evaluated.
Prenatal damage	qualitative examination of the occurrence of substances and impacts which may lead to damage official statistics	Only chemical impacts are evaluated.

Statistical data for the quantitative effect categories are primarily collected from ISA (Occupational Injury Information System) at the Swedish National Board of Occupational Health. All Swedish work-related accidents and diseases resulting in absence from work are reported to ISA. Data on average sick leave are provided from the Swedish Social Insurance Office.

For each sector the yearly production amount is calculated from SCB (Statistiska Centralbyrån - Statistics Sweden). The number of incidents in each effect category is divided by the yearly production amount. If the sector produces more than one product, the effects are allocated by the economic value of the products.

The data are aggregated over the phases in the life cycle.

The result of the life cycle assessment is one figure for each of the effect categories showing the expected work-related accidents/diseases from the product life cycle.

4.2.2.4 Inventory parameters

The method does not deal with exposure in the same way as e.g. EDIP's process assessment method. For the five quantitative effects the method only deals with the accidents and diseases that are registered in the sector and company statistics.

For the two semi-quantitative effects it is evaluated whether the impact threshold limit values are exceeded or not. For a further description, see the next section.

4.2.2.5 *Impact assessment*

The sector assessment method is not strictly in accordance with the five steps in the ISO 14042 standard (category definition, classification, characterisation, normalisation (optional) and weighting (optional)). The IVL method operates with fewer steps.

As mentioned, the method does not operate with exposures but only statistics of effects (except for the semi-quantitative effects). When the effect categories are defined, classification is carried out for cancer and prenatal damage. The classification is simple as e.g. exposure of substances causing cancer is related to the effect category “cancer”.

In the assessment of semi-quantitative effect categories the exposures which may cause cancer and prenatal damage are examined. As mentioned only effects caused by impact from the main production line are included in the assessments.

The semi-quantitative effects are characterised in four categories:

1: Unacceptable effects
2: Unwanted effects
3: Other effects
4: Substances under suspicion but the effects are not documented

Cancer. The characterisation is done in accordance with present legislation (Impact threshold limits, prohibitions etc.). It is recommended that an effect should be characterised as category 1 when 50% of the threshold limit value is exceeded or if proven carcinogenic and prohibited substances are being used. Category 2 is used when there is adequate knowledge that the substances are carcinogenic and when handling of the substances implies exposure. If the exposure is very controlled, category 3 applies. Substances under suspicion of being carcinogenic are characterised as category 4. (IVL, 1995 p. 21-22)

Prenatal damage. When regarding the risk of prenatal damage it is a problem that it is uncertain whether pregnant women are exposed or not. The characterisation is done on the basis of existing legislation (legislation applying to all women but not to men). Category 1 is used when general rules and regulations concerning substances with reproductive impact are not respected. Other substances with reproductive impact are characterised as category 2 or 3 dependent on the exposure. If the relation between the substance and the risk of prenatal damage is uncertain, category 4 is used.

4.2.2.6 *Weighting and normalisation*

Weighting and normalisation is not used in the method. An option proposed by IVL (personal communication) is to introduce normalisation by comparing the statistics per person for four of the effect categories (excluding workdays lost, exceeding normal) with the average numbers for the effect categories. The average numbers could even be subtracted from the actual numbers before counting the contribution from the different sectors to the total life cycle impact on the working environment.

4.3 Cases

4.3.1 Energy production, transportation and steel production

In order to evaluate the method, IVL has performed an assessment of:

- energy production (production of 1 GWh of electric energy and district heating)
- transportation of goods (million ton-kilometres by train, truck or aeroplane)
- steel production (manufacturing of 1 ton of steel).

These activities were chosen because they will occur in most life cycle assessments.

4.3.1.1 Collection of data and data processing

The data are based on statistics for sectors and not all the life cycle phases are included (e.g. the production of raw material is not included in the assessment of energy production). The statistics are based on data from ISA and SCB and have been standardized according to age and sex.

In all cases the category "workdays lost (exceeding normal)" as well as the semi-quantitative effects are not included. The results concerning the quantitative effects are stated as mean values with a standard deviation for the period 1987 to 1991.

No company experiences are described, but as a conclusion of the cases it is stated in the method description that further testing and development will be necessary before the method is ready for regular use in life cycle assessments.

At present IVL is testing the method in a case study, a comparison of different ways to treat grinding swarf from grinding of steel. Another case study is planned which will focus on two alternative fuels that are different with respect to most of the sectors that are part of the life cycle. The testing is documented in Antonsson (1999). The method will be adjusted in the testing, but the basic statistical concept will not be changed.

4.4 Discussion

In this section we discuss the strong and weak sides of IVL's method. The text therefore reflects the opinion of the project group. The purpose of the discussion is partly to evaluate the method and partly to learn form the strong and weak sides of the method, and thereby be able to set guidelines for the "perfect" working environmental LCA.

Firstly the strong and weak sides of the method are summarised in the discussion (Table 4.2) where after the points are elaborated. Secondly, an overview of *our* evaluation of the working environmental LCA is given. Finally, suggestions for improving the method are discussed.

Table 4.2. Strong and weak points of IVL's sector assessment method.

Strong points	Weak points
Can be used as supplement to any LCA method for the external environment The methodology is simple and requires only a limited number of data Aggregation of the phases in the life cycle is simple The method includes both chemical and non-chemical effects The method is easy to use for other parts of the life cycle than the core processes	It is difficult to cover all phases in the product life cycle equally It is difficult to relate the work environmental problems to a phase in the product life cycle or to a specific process It is questionable whether the category "workdays lost due to illness" is relevant in Denmark The actual number of accidents and diseases can be underestimated because the method is based on reported incidents The method is very dependent on the availability and quality of statistical data The lack of statistical data can lead to unreliable results Some of the statistical data are based on a very low number of incidents

4.4.1 Methodical requirements

4.4.1.1 Supplement to any LCA method

The IVL sector assessment method is not related to any specific LCA method for assessment of the external environment. In principle the sector assessment method can be used as a supplement to any LCA method.

4.4.1.2 Requires only a limited number of data

The methodology is simple and as it is based on statistical data on a sector or company level. It does not require measurements or observations at the working place. This makes the method quick and inexpensive to perform.

4.4.1.3 Aggregation is simple

As the result of the method is a number of expected incidents, the aggregation of the life cycle phases is very simple. The method is suitable to compare alternative products and services, but it might be difficult to identify the critical situations in the life cycle phases.

4.4.1.4 Difficult to cover all phases in the life cycle equally well

As the statistical data can vary a lot for the different phases it will be very difficult to cover the entire life cycle with data of high quality. Especially the production of raw materials can be difficult to cover because the materials often are produced far from northern Europe where the working environmental registration is completely different.

It is difficult to relate the result of the sector assessment to a specific product or process, as the statistical data covers a large number of different companies and processes. In the cases the work-related effects are allocated to the product by the economic value of the production.

4.4.2 Working environmental aspects

The method recommends company statistics from large companies on "workdays lost due to illness" (exceeding normal). It is, however, not stated how large the companies should be. Furthermore, it is not quite clear which working environmental factors are included in this impact category. Due to the uncertainty of what exactly is included, and the lack of this form of statistical data in Denmark, it is questionable whether the category is usable in Denmark, or in other countries.

4.4.2.1 Number of accidents and diseases can be underestimated

The method is based on statistics of reported accidents and occupational diseases. A weakness of this procedure is that the actual number of work-related accidents can be underestimated, because not every actual work-related accident will be reported.

4.4.2.2 Includes both chemical and non-chemical effects

An advantage of the method is that both chemical and non-chemical effects are included. The method calculates the number of accidents, hearing damages, and several chemical effects. It is, however, opaque which working environmental factors are responsible for a higher rate of workdays lost - exceeding normal.

4.4.3 Practicability

4.4.3.1 Lack of data

If the method is completed with unreliable data or the data are not measured or calculated in the same way - e.g. data from different countries - the result of the assessment can be unreliable. Use of unreliable data is, however, not a weakness of the IVL method in itself, but a weakness of this type of LCA method in general.

4.4.4 Data issues

4.4.4.1 Low number of reported incidents in some sectors

The statistical data on hearing losses and allergies, eczemas and similar diseases will consist of very low numbers from companies or trades. The limited number of statistic data will make the results unreliable. However, IVL tries to handle this uncertainty by calculating the mean value and standard deviation over a five years period.

The method is only based on statistical data and it is very dependent on the access to data of a satisfactory quality. The method is based on statistics from Sweden and it is questioned whether all data and statistics described in the method will be available outside Sweden.

4.4.5 Summary of the assessment

In Table 4.3 the above discussion is summarised. The table illustrates how the project group evaluates the IVL method. The exact meaning of the topics in the first column is described in section 1.10.

Table 4.3. Evaluation of the IVL method.

Topic	Evaluation of the IVL method
Methodical requirements	
Integration with LCA for external environment	❍
Applicability in LC-phases	✗ ✗
Aggregation possible	✗ ✗ ✗ ✗
Working environmental aspects	
Coverage of WE'al issues	✗ ✗ ✗
Graduation of exposures and effects	✗ ✗
Practicability	
Practical in use	✗ ✗ ✗
Software tool	❍
Transparency	✗ ✗
Can be used by non-experts	✗ ✗
Data issues	
Data reliability	✗
Amount of data in existing database	❍
Data accessibility	✗
Data can be obtained by WPA	❍

❍ = missing, ✗ = poor, ✗ ✗ = acceptable, ✗ ✗ ✗ = good, ✗ ✗ ✗ ✗ = excellent

4.4.6 Suggestions for improvements

On basis of IVL's ongoing testing, the method will be further developed. To ensure success of the method outside Sweden, it is very important to consider how the method is best suited for the varying statistics from different countries.

At the moment, no software tool is available. The method is, however, based on statistical data, which can make it easier to create a database.

4.5 References

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5 EDIP's sector assessment

5.1 The general methodology

Development of the EDIP method for assessment of the working environment was part of the Environmental Design of Industrial Product programme (the EDIP-programme). The programme was sponsored by the Danish EPA and the participants were five major Danish industrial companies as well as institutes at the Technical University of Denmark.

5.1.1 Purpose

The purpose of the EDIP project was:

- to develop methods for environmental assessment of complex industrial products,
- to develop guidelines for design and construction of environmental friendly industrial products,
- to develop a database and a computer based tool as support for environmental assessment, and
- to implement the methods and tools in the companies participating in the project.

5.1.2 The overall content of the methodology

The purpose of the EDIP project was, as mentioned, to perform an environmental assessment of products. For this purpose a quantitative process assessment method for LCA was developed within the project. The assessment parameters used within the EDIP method are shown in **Table 5.1**. According to the table the method operates with three groups of assessment parameters: environmental effects, resource consumption, and working environmental effects.

Table 5.1. Assessment parameters used in EDIP.

Effects	Environment	Resources	Working environment
Global	Greenhouse effect Stratospheric ozone depletion	Fossil fuels Metals Other minerals Others (animals etc.)	
Regional	Photochemical ozone creation Acidification Eutrophication Ecotoxicity (water, chronic) Human toxicity (water)		
Local	Ecotoxicity (water, acute) Human toxicity (air) Hazardous waste Nuclear waste Incineration ash Bulky waste	Biomass Water Others	Cancer due to chemicals Reproduction damages due to chemicals Allergy due to chemicals Damages to the nervous system due to chemicals Muscle-skeletal damages due to monotonous repetitive work Hearing damage due to noise Body damages due to accidents

Most of the effect potentials are relatively straightforward to handle in the quantitative assessment method. However, the quantitative assessment of the effect potentials "ecotoxicity" and "human toxicity" demands much more work. To avoid too much unnecessary work, screening methods have been developed. These screening methods can help in the decision of identifying the potential contributes to human toxicity or ecotoxicity (Wenzel, 1996).

5.1.3 The general principles of the methodology

The EDIP methodology is based on the following steps:

- the data (e.g. resource consumption, emissions to air and water, waste etc.) from the product system are measured, calculated or estimated
- these data are classified by their potential to cause impacts, e.g. use of non-renewable resources, global warming and ozone depletion
- the data are characterised with respect to the impact categories, i.e. equivalence factors are used to determine the impacts from several sources to an impact category.

These steps follow the principles outlined in the ISO 14040-series and are generally accepted as a sound methodology in LCA.

5.1.3.1 Normalisation

The aggregated impacts are subsequently normalized by relating them to the average annual impacts caused by one person in a relevant geographical area (the World/Denmark). In doing so, the contribution to an impact category is related to the potential impact from the society's activities as a whole.

5.1.3.2 Weighting

Finally, the impacts are weighted using international or Danish political stated reduction targets for different impacts or specific compounds. Hereby it is assessed which of the potential impacts from a product system are most important.

These steps of the EDIP methodology differ slightly from the ISO 14040 standard, where only a weighting step is recommended. There is, however, little doubt that the normalisation step used in the EDIP methodology adds significant information, provided that the mechanism and principles are scientifically based and understood by the decision-makers.

5.1.3.3 Working environment

EDIP operates with three different methods for assessing the working environment, a screening method, a process assessment method and a sector assessment method.

The screening method is a chemical screening method and thereby only covers the chemical working environment of an LCA. The chemical screening method can be used early in the product development or together with the process assessment method. In the last-mentioned case the chemical screening will be a preliminary step for the quantitative assessment with the purpose of deciding which processes to include in the process assessment.

The process assessment method can be used in the assessment of the manufacturing process in the company and possibly for those subcontractors who are able and willing to supply the information needed.

The sector assessment method can be used together with the process method, in processes where specific working environmental data are not available. (Hauschild, 1996, Broberg & Rasmussen, 1996).

5.1.4 Combined environmental and working environmental assessment

The assessment parameters used in the EDIP method are shown in **Table 5.1**. The method operates with three groups of assessment parameters (environmental effects, resource consumption, and working environmental effects), which all play an equal role in the methodology.

All three groups of assessment parameters are related to the same functional unit and measured by the same environmental unit - the person equivalent. Because the same basic assessment method is used, it is possible to aggregate over several steps in the life cycle and to compare the results from assessment of the working environment with other impact categories.

The data describing the working environment are collected from different sources depending on the assessment method used. For use of the chemical screening method, information about the chemicals used in the specific processes is needed. The screening scores the processes by relating them to European and national lists of dangerous substances and lists of substances with special effects.

The process assessment method requires more specific data from the company. Examples are information concerning impacts due to accidents, chemicals, noise, and monotonous repetitive work. Furthermore, it should be stated how much of the company's production time is used to manufacture the examined product in each of the processes.

When using the sector assessment method similar data should be collected. However, it should be noted that the data in this case represents the average working environmental impacts from the entire sector instead of the specific company and thereby - everything being equal - will lead to higher uncertainty.

5.2 Working environmental assessment methodology

5.2.1 Purpose and goal

The purpose of the working environment project within EDIP was

- to develop a method for including working environmental parameters in LCAs based on the methodical framework described by SETAC and the EDIP programme,
- to use the developed method for assessing the working environmental impacts in the life cycle of five industrial products (reference products),
- to identify the critical working environmental impacts of the reference products and point out the possibilities for improvements of new products in progress,
- to outline the principles for good working environmental construction of industrial products, and
- to describe and evaluate the use of the developed methods and tools in product development within the companies participating in the project (Broberg & Rasmussen, 1996).

The EDIP programme includes the working environment in LCAs for three reasons:

- the working environment should be included in LCAs to avoid working environmental deterioration when production processes are changed. LCAs will often be the basis of production changes or development of new products with lower environmental burdens. These changes determine the choice of production materials and processes, which directly influence the working environment.
- including assessments of the working environment in LCAs makes it possible to prevent working environmental problems when the LCAs are used in the technological planning.
- the working environment should be included in LCAs because some working environmental problems are of life cycle character, e.g. by chemical substances following the product throughout its entire life cycle.

The purpose of the sector assessment method is to assess the working environment in processes not directly connected to the primary production process, where EDIP's process assessment is used. In other words, the sector assessment method is used for the processes where it is not possible to achieve very process specific information. In these cases the sector assessment method can give an overview of the number of work-related injuries and accidents for the individual stages of a products life cycle (Broberg & Rasmussen, 1996). The sector assessment method can thus be seen as a supplement to the process assessment method.

5.2.2 Scope of the methodology

5.2.2.1 System boundaries

Like all other parts of the EDIP methodology the sector assessment methodology can be applied to all processes in the life cycle. As pointed out above, the sector methodology, in contrast to the process assessment method, is best suited for the processes that are not directly connected to the company commissioning the LCA, simply because it is less data intensive and requires less collaboration from external suppliers.

The only formal limitation is that the processes assessed in the sector assessment method must be the processes in which a professional work situation is taking place. As described in an example, transportation is not included as no usable working environmental data could be found (Broberg & Rasmussen, 1996).

The sector assessment method differs to some extent from the assessment method for the external environment by always being performed on a general level. The sector assessment method is based on working environmental data from the examined sector, and does therefore represent the average working environmental impacts within that sector for a certain period of time. Basically, the sector assessment methodology can be compared to the inventories published by e.g. APME on plastic materials. In the assessment steps, the sector assessment method operates with the same kind of normalisation and weighting as for the assessment of the external environment.

The work-related injuries and accidents evaluated within the sector assessment method, are allocated to the product by using the number of working hours needed for the production - the production time. As the information is very general, one cannot be certain whether the data apply to the specific production process or the specific product.

5.2.2.2 Impact categories

The impact categories included in EDIP's sector assessment method are shown in **Table 5.2**. The impact categories included are, in principle, the seven ones listed in **Table 5.1**. The impact categories listed in **Table 5.2** are, however, impact categories that can be assumed to come under the larger categories listed in **Table 5.1**.

Table 5.2. Overview of working environmental impact categories included in EDIP's sector assessment method.

Work Environment Parameters	Effect-categories	Included: Yes	Included: No	Remarks
Accidents	Sprains	✓		Accidents are included as a general term in the assessment
	Injuries/lesions	✓		
	Cuts	✓		
	Fractures	✓		
	Burns	✓		
	Death	✓		
Biological	Infections		✓	Allergy is only included in the assessment as "airway and skin diseases"
	Organic dust toxic syndrome		✓	
	Allergy		✓	
Chemical	<u>Acute toxicity</u>:			* Accidents are included as a general term in the assessment
	Irritation (skin, mucous membranes)		✓	
	Chemical burns	✓*		
	Odour		✓	
	Death	✓*		
	<u>Chronic toxicity</u>:			
	Cancer	✓		
	Allergy	✓		
	Reproductive effects	✓		
	Neurotoxic effects	✓		
	Genotoxic effects		✓	
	Specific organ effects		✓	
Physical	Hearing loss/nuisance	✓		* Accidents are included as a general term in the assessment
	White fingers	✓*		
	Burns/frostbite	✓*		
	Cancer	✓		
	Allergy	✓		
	Muscle-skeletal effects	✓		
Physiological/Ergonomic	Cardiovascular effects		✓	* Effects caused by monotonous and repetitive work
	Muscle-skeletal effects	✓*		
	Repetitive strain injuries	✓*		
Psycho-social	General discomfort		✓	
	Stress		✓	
	Mental effects		✓	
	Depression		✓	
	(Cancer)		✓	

The impact categories are limited to the working environmental assessment parameters chosen for the EDIP methodology (see **Table 5.1**): Cancer, reproduction damages, allergy, damages to the nervous system, muscle-skeletal damages, hearing damages, and body damages (due to accidents).

The seven impact categories are chosen because they include the work-related injuries that most often are reported. This information is gathered from a working environmental survey of the Danish sectors ("portraits of the Danish sectors") carried out by the Danish Labour Inspectorate (Arbejdstilsynet, 1995).

Impact categories not included in the assessment are injuries such as circulatory diseases, psycho-social diseases, airway and skin diseases not causing allergy, and some other diseases not coming under the above categories. These diseases are relatively seldom reported within the Danish sectors, and therefore they are not included in the assessment (Broberg & Rasmussen, 1996).

By using only the reported work-related injuries, the impact categories are hereby also limited to the types of effects normally reported as work-related injuries (e.g. it is not a tradition that psycho-social injuries are reported as work-related injuries).

5.2.2.3 Data requirements

The system boundaries sets the limits for which raw materials and other materials should be included in the assessment. For processes included the needed data on working environment can be found in statistical sources describing the work-related injuries within the specific sectors. Some process descriptive data on sector level are also necessary, e.g. production time and production volume. These data can, however, also be found in statistical sources. No interviews or measurements of any kind are necessary, if the sector statistical data exist in literature.

The data should be as recent as possible, preferably given as an average over several years. It should, however, be ensured that no changes in the production method, which could influence the working environment, have taken place within the period the data relates to.

It can be a problem to derive the exact number of working hours used for the production of the specific item. The reason is, that it is often not clear if the number of employees covers full-time employment or part-time work, if the employees have been employed all year, and if the average working hours per employee includes vacation and absence because of illness. The production time will therefore always be somewhat uncertain (Broberg & Rasmussen, 1996).

5.2.2.4 Inventory parameters

The parameters used in the inventory, for each phase of the life cycle, are listed in Table 5.3 below.

Table 5.3. Inventory data of EDIP's sector assessment method

• Number of work-related injuries per year within the sector (for the work-related injuries listed in **Table 5.2**) • Yield (total production) per year within the sector • Number of persons employed within the sector (both employers and employees who participates in the production (part time/full time)) • Total number of working hours per year used for the production (as either working hours per year or per week with a deduction of illness and vacation of the period)

The work-related injuries are listed as an average per year, which makes it possible to compare this information with the annual production size. This will give the number of work-related injuries per ton raw material or per ton product (or per functional unit), which can be added together for each step of the life cycle (Broberg & Rasmussen, 1996). Therefore the necessary data is only the number of work-related injuries and the yearly production. The number of persons employed in the sector is merely used to calculate the number of working hours used to produce the investigated product (the functional unit). The production time per product / functional unit can be used to estimate where the highest or lowest working environmental loads are (Hauschild, 1996).

The working environmental data and the data for the external environment are collected separately. The working environmental data is collected from the Danish Labour Inspectorate, whereas the data for the external environment is collected from other sources.

The number of working hours used to manufacture the specific item can possibly be found at the same source or perhaps from other statistical sources. The total workload for the data collection is therefore not necessarily very high. The data exist for the Danish branches, and can easily be obtained. The major problem is the age of the data, and the uncertainty of calculating the total number of working hours used for the manufacture of the specific item.

5.2.2.5 Impact assessment

EDIP's sector assessment method is not in accordance with the four steps of the impact assessment (category definition, classification, characterisation and weighting) in the ISO 14042 standard. The four steps are not followed individually, but are combined to fewer steps. When the categories are defined the characterisation is at the same time carried out, because it is discussed which working environmental burdens that will give which effects. When the data is classified to the impact categories, the normalisation and weighting are also carried out, because the inventory data is at a form corresponding to the normalised and weighted data used in the process assessment method.

The impact categories used within the sector assessment method are listed Table 5.3. These impact categories are, as mentioned, found by selecting the most frequent reported work-related injuries from the total list of reported work-related injuries (Arbejdstilsynet, 1995).

The categories are defined in accordance with the data source, which means that the number of injuries automatically is classified under the matching impact category. For example all cancer incidents are classified under the impact category "cancer" and all hearing damages are classified under the impact category "noise". The characterisation is also automatically performed because only one kind of impact belongs to the impact category. E.g. the impact category "allergy" is described wide enough to automatically include all kinds of allergies.

The impact categories are defined as having the number of injuries as the category endpoint, which, when divided with the production yield per year, automatically gives the weighted working environmental burdens - the reported work-related injuries per product.

The reported work-related injuries per product is the unit used when comparing alternatives. It may, however, be useful to illustrate the production time used at each process. If the production time is high this might be an indication of a high working environmental burden also. Whereas the production time (cycle time) is the basis of the process assessment method, the production time is not used as an indicator of the working environmental burden in the sector assessment method. A backwards calculation is performed by the use of the normalisation and weighting factors from the process assessment method, just to have a data foundation comparable to the one of the process assessment method. The backwards calculation gives the man hours per product where a working environmentally impact exists, which is the measured or estimated inventory data of the process assessment method (Hauschild, 1996).

5.2.2.6 Software tool
A software tool has been developed for the EDIP methodology. There is, however, only very little information on the working environment included in the beta-version of the programme and it must be concluded that assessment of the working environment has not been made operational at this level.

5.3 Cases

One detailed example of how to use the sector assessment method is described. The example is production of electricity in Denmark (Broberg & Rasmussen, 1996). The result of this example is an integrated part of the five examples that are used to illustrate the use of the EDIP method for assessment of the working environment.

5.3.1 Production of electricity

In this example, the total working environmental load for the production of one million kWh is found. The extraction of coal, oil, and gas, as well as the production of the electricity are included in the study. Transportation is not included as no usable working environmental data could be found. The working environmental impact categories listed Table 5.3 are used.

The working environmental data are found in literature from statistical sources, from the International Labour Organisation etc., and by contacting sector associations.

5.3.1.1 Collection of data
In this case where coal used for producing electricity in Denmark is extracted in several countries, the greatest problem is the uniformity of the data. An example is that England only has data for larger accidents (smaller accidents are not reported or listed), whereas Columbia only lists the accidents that involve lost production time. Another problem is that data for the former USSR does not exist. Alternatively, data from Ukraine has been used. Even when it comes to the Danish statistics on work-related injuries for the production of electricity, lack of data is a problem. Many injury categories are listed but explanations are missing for about 4% of the reported injuries.

Lack of information about the number of working hours per year has also been a problem. Here educated guesses are used to estimate the working time per year with vacation and illness excluded.

The case also shows that it can be a problem to find data from the same period of time for all productions in the examined countries. The lack of data is another source of uncertainty. The substitute data used is however comparable to the data needed.

5.3.1.2 Data processing
Because of the lack of data, educated guesses have been necessary in some cases. Besides this problem, the data processing is very straightforward because relatively simple calculations have to be performed.

In this case the work-related injuries are found per one million kWh for the production of electricity in Denmark, and per ton oil, coal, and natural gas for the production of these raw materials. These figures are then simply added together to give the total work-related injuries for the production of one million kWh. The conversion factor used from tonnes raw material to million kWh is the consumption and composition of oil, coal, and natural gas used to produce one million kWh in 1990.

5.3.1.3 Company experiences

In the described case it has been possible to evaluate which of the working processes that contributes to the highest number of work-related injuries. The example can also be used to calculate the working environmental improvement when changing from using today's (1990) electricity production to e.g. electricity based solely on natural gas.

The conclusion of the example is that the method is very suitable for creating an overview of the number of work-related injuries and accidents in the examined phases of a product's life cycle, if the necessary data can be obtained. The method can thus form the basis of further and more in-depth investigations or form the basis for working environmental improvements.

Generally, it can be said, that EDIP's sector assessment method is not able to distinguish between the working environmental loads of different products if all the processes involved in the life cycles takes place in the same sectors. The only difference between the alternatives will in this case be a difference relating to a shorter or longer production time. The production time is, however, also calculated as an average within the sector, and it can therefore be difficult to distinguish between products. The average production time per product is calculated by multiplying the "total work force per year" with the "total working hours per year", and dividing by the "products produced per year".

The differences between the working environmental loads are larger when different sectors are involved, and the method is suitable for distinguishing between different sectors on the average level.

In the sector assessment method it is clearly the production time that is most significant for the total working environmental load, because the production time is distributed to the working environmental impacts. A process with a short production time becomes insignificant compared to the entire life cycle.

5.4 Discussion

In this section we discuss the strong and weak sides of EDIP's sector assessment method. The text therefore reflects the opinion of the project group. The purpose of the discussion is partly to evaluate the sector assessment method and partly to be able to learn from these strong and weak sides, and thereby be able to set guidelines for the "perfect" working environmental LCA.

In this discussion, the strong and weak sides are firstly summarised (Table 5.4), where after the points are elaborated. Secondly, an overview of *our* evaluation of the working environmental LCA is given. Finally, suggestions for improving the method are discussed.

Table 5.4 . Strong and weak points of EDIP's sector assesment method

Strong points	Weak points
Integration with LCA for the external environment is possible Aggregation possible - can be used to compare alternatives Can be used in all phases of the life cycle Can indicate where the highest working environmental burdens exist Various working environmental aspects included Clear outputs Easy to use - can be completed with reasonable efforts Can be used by non-experts Data are generally available	Exposures and effects are not graded No software tool exists Do not represent today's level of technology Assessment based on only reported injuries Assessment based on average working conditions Assumed that all workers are exposed to the same working conditions Data difficult to obtain by work place assessment

5.4.1 Methodical requirements

5.4.1.1 Integration with assessment of the external environment

EDIP's sector assessment method is supplementary to EDIP's process assessment method. The sector assessment method is used where no process specific information can be found. As a whole (i.e. both the sector and the process assessment methods), the assessment of the working environment in EDIP is closely connected to EDIP's assessment method for the external environment. Both parts of the methodology are related to the same functional unit, and the results are expressed in the same unit, the person equivalent. It is thus possible to compare the impacts for the external environment and the working environment with each other.

5.4.1.2 Aggregation and comparison is possible

In the sector assessment method the production size on sector level is directly connected to the number of reported injuries within the sector. Comparison with the production size makes it possible to aggregate the impacts over the entire life cycle for all the working environmental parameters (if the statistical data exists for all life cycle phases). The sector assessment method therefore gives a basis for comparing and choosing between alternatives.

EDIP's sector assessment method can be used in all phases of the life cycle, provided that the necessary data can be obtained.

As the sector assessment method is simple and quick to use, the method, alternatively, could be used as kind of a "thorough screening" to indicate in which process of the entire life cycle the highest working environmental burdens exist. For these identified processes, with a high working environmental impact, a more thorough assessment can be carried out via the process assessment method.

5.4.2 Working environmental aspects

By using the statistics of work-related injuries a number of working environmental aspects are included in the study. It is positive that not only chemical aspects are included. The assessment also includes accidents, hearing damages and some ergonomic aspects. However, not all working environmental aspects are included in the assessment method. One reason is that it is decided within the EDIP project simply to include the most frequent injuries. Another reason is that sufficient statistics do not exist for all aspects. This is connected with the fact that it is not tradition to report some work-related injuries, e.g. the psychological injuries, simply because the exposure - effect relationship is not well examined.

EDIP's sector assessment method operates with the term impact threshold. Only impacts exceeding the set impact thresholds are assumed to result in an effect. The exposures and effects are therefore not graded other than "no exposure" or "an exposure resulting in an effect".

5.4.3 Practicability

Using the work-related injuries as the endpoint of the category gives a clear output from the inventory. It is easy to relate to the number of injuries that is likely to occur.

One strong point of EDIP's sector assessment method is that it is easy to use. Only a few data is needed to carry out the assessment, and this data can easily be obtained when statistics of the working environment within the sectors exist. When the data exist only simple calculations have to be carried out to perform the working environmental assessment. This means that the inventory can be completed with reasonable efforts.

5.4.3.1 No software tool

No software tool is available for EDIP's sector assessment method.

5.4.3.2 Can be used by non-experts

It is possible for non-experts to use EDIP's sector assessment method . Few statistical data are needed and only simple calculations have to be carried out.

5.4.4 Data issues

5.4.4.1 Data are generally available

The data exists for the Danish sectors. However, the statistical data for some life cycle phases may be more difficult to find compared to others, e.g. the use phase. Data for other countries may be even more difficult to find, especially for the same period of time.

One weak point of the sector assessment method is that the results do not represent the "true" impacts, but the injuries which are likely to happen when working in the examined sector. The method uses statistics of injuries for the working environment within the different sectors. This will normally give a good overview of the injuries likely to happen, if the statistics are up to date. But the problem is that the statistics usually are a couple of years old, and they do therefore not necessarily represent the level of technology that the LCA is trying to evaluate. Another problem is that some effects, e.g. cancer, take a long time to show in the statistics, which means that the statistics for some impact categories actually represents the working conditions of 10 or 20 years ago.

Furthermore, the statistics used are based on only the reported injuries. In reality the work-related injuries are much higher than the reported injuries. This means that the results of the LCA will underestimate the real impacts of the working environment.

The result of the LCA will not be entirely correct as the assessment method is based on average impact data. The impact data does not represent the actually examined processes within the LCA but an average of the working conditions in all the processes included in the specific sector. The uncertainty of the results will be high if the sector is very heterogeneous with respect to the working environment.

The uncertainty of the results is also increased because average sector statistics are used to calculate the production time. It is difficult to calculate the precise number of working hours used to produce the specific product, when the data consists of the total number of people employed within the sector and the total number of products produced. The production time can only be a very rough estimate.

Because the average impacts of the sector are used, it is automatically assumed that the workers are exposed to the same working environmental burden no matter where or how the products are manufactured. The working environmental impacts are therefore not based on the actual exposure of the workers.

5.4.4.2 Data difficult to obtain by work place assessment

It is difficult to obtain the necessary data from work place assessment because it is the average sector data, which is used for the assessment. However, if all companies use their work place assessment to report working environmental data to the statistical offices, the resulting data material will be more reliable and more correct compared to the data material that exists today. This is, however, not likely to happen in the near future.

5.4.5 Summary of the assessment

In Table 5.5 the above discussion is summarised. The table illustrates how we evaluate EDIP's sector assessment method. The exact meaning of the topics in the first column is described in section 1.10.

Table 5.5. Evaluation of the EDIP sector assessment method

Topic	Evaluation of EDIP's sector assessment
Methodical requirements	
Integration with LCA for external environment	✗ ✗ ✗ ✗
Applicability in LC-phases	✗ ✗
Aggregation possible	✗ ✗ ✗
Working environmental aspects	
Coverage of WE'al issues	✗ ✗ ✗
Graduation of exposures and effects	✗ ✗
Practicability	
Practical in use	✗ ✗ ✗
Software tool	❍
Transparency	✗ ✗ ✗
Can be used by non-experts	✗ ✗
Data issues	
Data reliability	✗
Amount of data in existing database	❍
Data accessibility	✗ ✗ ✗
Data can be obtained by WPA	✗

❍ = missing, ✗ = poor, ✗ ✗ = acceptable, ✗ ✗ ✗ = good, ✗ ✗ ✗ ✗ = excellent

5.4.6 Suggestions for improvements

It is difficult to point to specific areas where the sector assessment method can be improved. The developers recognise and describe the inherent weaknesses of the method and the user of the methodology is therefore able to take these into consideration.

The sector assessment method can be seen as an easy and suitable way to establish a crude overview of the potential impacts in the working environment of different sectors. An example of the impacts in electricity production demonstrates that it is possible to use the methodology with a relatively high level of detail.

The calculated cycle time is an important element in the methodology, and by providing this information the method can be used to pinpoint the processes where a more detailed assessment with the process methodology will provide the most interesting information.

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6 IVF's process assessment method

During the years 1994 to 1997 IVF developed the first version of the "WEST" method (Work Environment Screening Tool). The WEST method was developed to be a separate tool for working environmental LCA. However, during the development similarities between the WEST method and the EPS system was found. It was possible to convert the working environmental evaluation to economical figures (ELUs - "Environmental Load Units"). This made it possible to compare the working environmental evaluation of WEST with the environmental evaluation of the EPS-system.

During the development of the WEST method attempts were made to expand the EPS system to include working environmental aspects also. This was carried out by making use of the results from the WEST evaluation method and their relation to the unit effects in the EPS system. In order to fit in the working environment, the system was expanded with additional unit effects.

As IVF is combining their working environmental method with the EPS system, the EPS system is considered to be the general methodology of the combined working enviromental and environmental LCA. The EPS system is hence elaborated in the following text.

6.1 The general methodology

EPS is short for Environmental Priority Strategies in product development, and is an LCA-tool for designers.

The EPS method was developed in the Swedish Product Ecology Project. The first version was published in 1991, but has since been refined with a more detailed valuation strategy. A very detailed description of the EPS-method can be found in (Ryding et al, 1995), but it is possible that further changes have been implemented since this publication.

6.1.1 Purpose

The main objective of the EPS method is to indicate which of two alternative solutions has the least impact on the environment. In practice, the method and computer tool is aimed at functioning as a compass for product developers, showing the right direction but not necessarily the ultimate endpoint.

The unit effects considered in the methodology are chosen in such a way that they are familiar to ordinary people. This makes it possible to have some degree of consensus and to measure value means and standard deviations. The developers acknowledge that the valuations in the study are subjective, but argue that the choice of safe guard subjects for which there is a common experience enhances the possibility of common acceptance of the valuations, as there is a "shared subjectivity".

6.1.2 The overall content of the methodology

The EPS system assesses like other LCAs the impacts from human activities, e.g. consumption of natural resources and emissions. The assessment takes place in three steps:

Determination of relevant safe guard subjects. In Ryding *et al.* (1995), the following subjects are mentioned as the core elements in the method:

- Biological diversity
- Human health
- Production capacity of ecosystems
- Resources
- Aesthetic values

6.1.3 Assessment of unit effects in terms of "willingness to pay"

Determination of the value of the human activity (resource consum ption, emission) in the form of an Environmental Load Index. This index is calculated by multiplying the "willingness to pay" with five factors assessing:

- The change of impact on the safe guard subject
- The extent of the problem:
- Geographical extent
- The intensity
- The time horizon and the reversibility
- The relative contribution to the problem, for example per kg emission

In the end, the impact on the five safe guard subjects can be added, resulting in a single figure for the impact from an activity - the Environmental Load Unit (ELU). Subsequently, figures (ELUs) from several activities in the life cycle of a product can be added, giving just one figure for the overall impacts.

6.1.3.1 ELU data base

An extensive data base with ELUs for a large number of activities has been published (Ryding *et al*., 1995). According to the author, the database should be used with great caution due to differences and variations in ecological preconditions, individual processes and production facilities. Seen from the Danish and international point of view it can be added that the method is developed to meet a mixture of Swedish and international conditions with respect to the safe guard subjects and the willingness to pay. The method is therefore not suitable for use outside Sweden unless national ELUs for the activities are developed.

6.1.4 The general principles of the methodology

The backbone of the EPS method is an assessment of the costs associated with the impact on nature of human activities (one ELU is equal to one ECU in terms of willingness to pay in OECD countries). This approach is significantly different from other LCA methods where the contribution to environmental impacts are calculated for several impact categories and subsequently normalised and weighted against e.g. political or environmental targets. The method for determination of the value for each safe guard subject is as follows:

Table 6.1. The safe guard subjects and their estimation methods.

Safe guard subject	Method for estimation of value
Biodiversity	Society’s cost for protecting biodiversity
Human health	Society’s cost for reducing excess deaths caused by various risks, and people’s willingness to pay to avoid diseases, suffering and irritation
Production capacity of ecosystems	OECD market prices
Resources	Impact on other safe guard subjects when restoring the resource
Aesthetic values	People’s willingness to pay

The choice of unit effects and safe guard subjects may be regarded as the classification step in the ISO 14040 terminology, while the characterisation and valuation step are integrated in the three steps described in the overall content of the methodology.

Principally, the method thus contains the three steps in the ISO-standard. In the calculation procedures, however, only the final result in the form of ELUs per unit is used. This makes the results very easy to use for product development purposes, but the transparency is rather limited.

6.1.5 Combined environment & work environment assessment

The original EPS method does not include work environmental aspects despite the fact that human health is one of the safe guard subjects assessed by the method.

The development of the WEST method is a remedy for this drawback, giving product developers the possibility of including both impacts on nature (incl. human health) as well as work environmental impacts in the life cycle considerations, when the two methods are combined.

The basic idea is that all impacts on nature and human health *a priori* are equally important, irrespective of their cause (general exposure of the nature/population or specific exposure of few people in the work environment). The present state of the EPS methodology does however not give the possibility of including the work environment as a sixth safe guard subject, and this diminishes the functionality of the combined method, at least from the product developers point of view. As is, the combined methodology gives the possibility of estimating the relative importance of the impacts on the five safe guard subjects and the work environment throughout the whole life cycle, but it is not explained how the final choices should be made between two alternatives.

The assessments of both the external environment and the working environment are based on economical principles. It is, however, two different economical principles that make the basis for the assessments, since the WEST method was not developed with the sole purpose to be combined with the EPS system. For the external environment the principle used is the consumers’ willingness to pay for re-establishing the environment to the normal situation. For the working environment the figures used are the actual or assumed costs for a number of work-related parameters. The cost includes expenses for the company because of sick leave, compensation payments, expenses for the society, the willingness to pay for interaction with other people or working in an aesthetic environment, etc.

The costs are “translated” into (negative) points, where one point is equal to the costs and suffering for the society, company and individual caused by an average accident per one million working hours. The cost of one point has been estimated to 0.3 SEK or 0.03 ECU, and there is thus a common denominator for both the external and the work environment.

6.1.5.1 PC-tool

A computer-tool has been developed in which both external and work environmental assessment can be performed (EPS v. 2.01w). The tool is not yet available, but is likely to be released in the future, when a better version is ready (at least one more year before release).

For the working environmental assessment a special PC-tool has been developed. The PC-tool is programmed within Excel 5.0. The tool consists of templates for the inventory data and for the data processing. The working environmental data (and data uncertainty) for each process can be entered, and as a result the working environmental profile is calculated and visualised. The resulting total uncertainty of the profile is also calculated. A database with the inventory and the working environmental profile of 50 different Swedish production processes is also available. The problem with the PC-tool is, however, that it only runs under the Swedish Excel version. (Bengtsson & Berglund, 1997, p.60-64)

6.2 Working environmental assessment methodology

6.2.1 Purpose and goal

The IVF method was developed in the project “Working environment in life cycle assessment”, which was completed by Electrolux, Volvo, IVF (The Swedish Institute of production engineering resarch), CIT (Chalmers Industriteknik), and IVL (Swedish Environmental Research Institute) 1994 to 1995. The project was financed by “Arbetslivfonden” and the participating companies. The WEST method was further developed in the projects “Working environmental analysis as part of LCA methods for the external environment” and “Development of a method for working environmental factors” from 1994 to 1997. These projects were financed by “Rådet for arbetslivsforskning”.

The purpose was to develop a functional method for integrating the working environment in LCAs. No documented quantitative method for assessing the working environment in LCAs existed at the time where the project started (August 1994), whereas the EPS method for the external environment already had been used by the Swedish industry for a few years. The goal was therefore to develop this working environmental assessment method and test the method by performing several cases (Bengtsson et al, 1995), (Bengtsson et al, 1996), (Bengtsson & Berglund, 1997).

The primary reason to include the working environment in the total assessment was that the working environment have a considerable impact on human health, and the purpose of the LCA is exactly to assess how products affect the external environment and the well-being of the human race in all aspects in a long-term perspective. Secondly, including the working environment in LCAs can help to avoid sub-optimisation. A choice of materials, processes, product design, etc., with the thought of reducing the impact on the external environment can in some cases have the opposite effect on the working environment and human health (Bengtsson et al, 1996).

6.2.2 Scope of the methodology

6.2.2.1 System boundaries

Like all other LCA-methods, the present IVF method aims at including all processes in the life cycle. As no inventory data existed at the start of the project, a number of processes with a relatively short production time have been excluded from the case studies. When a data base with inventory is gradually built up, the possibility of including more and more processes will be possible without great use of resources.

The system boundaries can be chosen individually for a given case, depending on the time and resources. The general criteria for inclusion or exclusion of a given process is the production time necessary for the production of one unit. Processes with a short cycle time will in general have a smaller impact, but prior knowledge of potential problems in the work environment may cause the process to be included anyway. If there is no knowledge about the cycle time, product cost may be used as an indicator to estimate the production time.

In the case studies, a number of processes have been excluded because their contribution to the final result was assumed to be negligible or - maybe - because there were not enough resources to perform the assessments. For example are all processes involving less than one man-minute, and building of production facilities and office work excluded from all cases. These omissions can have a significant impact on the results, but this subject is not elaborated further.

The assessment does not include the impact on the consumers in the product's use phase as the method is based on work-related injuries from industrial production processes. The impacts from production of energy (electricity, gasoline) used in the lifetime of the products, are neither included.

No geographical boundaries are set, but it is obvious that assessment of processes taking place in distant geographical regions will be very demanding in terms of resources and time.

The basic data collection strategy is to collect data from the actual processes in the life cycle, i.e. site specific data are used. Therefore, the assessment will concern the actual technology and the time scale is the present production. No information is given on when it will be relevant to perform an update of the data collection, but implementation of new technology or building of new production facilities are assumed to be important indicators.

IVF points out that different factors can have a different importance for the external environment and the working environment with regard to the system boundaries. It may therefore be necessary to expand the system boundaries to account for all important processes for both the external and the working environment. (Bengtsson et al, 1995)

6.2.2.2 Impact categories

The impact categories included in IVFs process assessment method are shown in **Table 6.2** below.

Table 6.2. Impact categories included in IVFs process assessment method.

Risk of accidents	General physical environment
Physical work load	Work atmosphere
Noise	Work taks content
Chemical health hazards	Freedom to act
Vibrations	

The working environmental effects covered by these impact categories can be seen in **Table 6.3**.

Table 6.3. Overview of working environmental effect categories included in IVFs process assessment method

Work Environment Parameters	**Effect-categories**	**Included**		**Remarks**
		Yes	**No**	
Accidents	Sprains Injuries/lesions Cuts Fractures Burns Death	✓ ✓ ✓ ✓ ✓ ✓		Accidents are divided into groups of different situations: risks from moving parts, risk of tripping or slipping, risk of collisions etc.
Biological	Infections Organic dust toxic syndrome Allergy		✓ ? ?[a]	Included under the category "general physical environment".
Chemical	Acute toxicity: Irritation (skin, mucous membranes) Chemical burns Odour Death Chronic toxicity: Cancer Allergy Reproductive effects Neurotoxic effects Genotoxic effects Specific organ effects	 ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓		Included are chemicals that will lead to the described effects. Chemical accidents, including death are listed under accidents.
Physical	Hearing loss/nuisance White fingers Burns/frostbite Cancer Allergy Muscle-skeletal effects	✓ ✓ ✓* ✓	 ?[a] ?[a] 	* Included under accidents.
Physiological/ Ergonomic	Cardiovascular effects Muscle-skeletal effects Repetitive strain injuries	✓ ✓ ✓		Included under the category "physical work load"
Psycho-social	General discomfort Stress Mental effects Depression (Cancer)	✓ ✓ ✓ ✓ 	 ?[a]	Included under the categories "social work environment", "work content", and "freedom to act".

[a] The inclusion of the effects depends on how the statistics on the reported work-related injuries are interpreted. For example can all allergy cases be counted as related to only the chemical working environment or to the biological, chemical and physical working environment. This information is not given. Hence the questionmark.

6.2.2.3 Data requirements

The IVF assessment method is based on data from company level. Very specific data is necessary. Not only is it essential to visit the different companies included in the study, but the method used also demands an experience in the field of working environment to be able to perform the assessment at the companies. Forms, consisting of points to assess for nine individual parameters, have been developed to help with the collection of data. For each point on the lists an assessment have to be made, and a score have to be given. In many cases the evaluation is based on subjective judgements. In other cases, e.g. for the chemical health hazards, measurements may have to be performed. Interviews with workers are carried out to supplement the blank forms.

The data requirements are elaborated in the following section.

6.2.2.4 Inventory parameters

The process assessment method reviews the physical, chemical, psychological, and general working environment. This is done by assessing the work place for each process with respect to the impact categories listed in Table 6.4.

Table 6.4. Impact categories included in IVFs process assessment method.

Impact category	Sub-assessment parameters
Risk of accidents	a) Moving objects, b) Excessive strain, c) Handling of objects, d) Vehicles, collisions, e) Falls and jumps, f) Slips, missteps, g) Burns, frost damages, poisening, corrosions, h) Electricity, fire, explosions, i) Persons or animals causing damages, j) Other factors
Physical work load	a) Work posture, b) Weight / force, c) Frequency, d) Systematic work rotations, e) Long natural breaks, f) Physical activity (positive)
Noise	a) Exposure, b) Impulse sounds, c) Disturbing impact
Chemical health hazards	a) Unhealthy emissions (exposure / threshold limit value) b) Other exposures (contact with allergens, carcinogens, etc.)
Vibrations	a) Vibration dose (vibration level, exposure time) b) Vibrations of the entire body?
General physical environment	a) Daylight, b) Illumination, c) Climate, d) Cleanliness and tidiness e) Personal protective equipment (inconveniences), f) Room for work, g) Room for staff activities (changing, breaks) h) Other factors (exercise room, summer cottage, etc.)
Work atmosphere	a) Physical closeness (contact) with fellow workers, b) Possibility for small talk, c) Group work, d) Breaks together with colleagues e) Contact with other departments or customers
Work task content	a) Cycle time of work, b) Necessary time of training, c) Necessary education, d) Possibilities for personal developments, e) Motivation factors, f) Support for personal ideas
Freedom to act	a) Possibility to build up time for later breaks, b) Planning of own work, c) What determines the work speed?, d) For how long can the workplace be left without a need for a relief? e) Responsibility / powers, f) Flexible working hours, g) Negative stress / time pressure, h) Company organisation

A form has been developed for the assessment of each of these nine working environmental areas (Bengtsson & Berglund, 1997, app.2). Each form contains a number of specific items to be assessed. The specific items are listed in Table 6.4.

Guidelines and ranges for the scoring of each item is given. The score can either be positive or negative depending on the actual situation compared to a reference situation. The reference situation is “not having the examined job”, i.e. what is the difference between having the job in the examined process, and not having the job. (Bengtsson et al, 1995, p.7). Both conditions for unwanted impacts (e.g. exposure to hazardous chemicals) and for the “good working environment” (e.g. group work, daylight, leisure time facilities) are included in the assessment.

The final score is found by adding the scores for the individual answers and multiplying with (or adding) a possible adjustment factor. E.g, for the physical work load, the score is multiplied with an adjustment factor that depends on the workers age and sex, and for the chemical health hazard an adjustment factor is added depending on the effects of the chemicals (carcinogenic, mutagenic, reprotoxic, allergenic, irritation, skin penetration, etc.). (Bengtsson & Berglund, 1997, app.2).

Most of the processes will end up with a negative score that implies that a shorter production time will improve the working environment (Bengtsson et al, 1995).

For each process of the life cycle the scores from the nine areas are found with the use of the blank forms. The scores for each process and for each working environmental parameter are then listed in a table. This table creates an overview of the most working environmental burdened processes. The scores are then added and multiplied with the production time for the particular process. It is thus obvious that the production time often becomes the most important parameter in the assessment. This may to a certain degree justify the exclusion of processes with a short production time, provided that there is no prior knowledge about serious impacts from the process in question (Bengtsson et al, 1995), (Person & Zackrisson, 1995).

Answering the questions in the nine forms is to a large extent a subjective matter. It is therefore suggested that two persons performs the assessments individually and that the average score is used. For each parameter the uncertainty of the score is given as well (Bengtsson et al, 1995, app.1).

6.2.2.5 Impact assessment

Basically, the four steps (inventory, classification, characterisation and valuation) in the LCA are integrated and performed at the same time, i.e. when examining the process.

The main explanation for this is that both the EPS-system and the present assessment of the working environment is performed “top-down”, using societal and individual values as the starting point and then developing a system that can handle an assessment of these values in a structured and operational way.

6.3 Cases

Three cases were carried out in connection with the project “Working environment in LCA” together with Electrolux and Volvo. One case about refrigerators from Electrolux, one about the front end of a Volvo 850, and one about the wishbone of a Volvo. The first two cases are described in details below.

6.3.1 The front end of a Volvo 850

The front end of a Volvo 850 has been manufactured in two different materials. The former production material was SMC (70% polyester / 30% fibreglass). The material used today is GMT (60% polypropylene / 40% fibreglass). These two front ends, produced at two different production sites, are compared. (Berglund et al, 1996b).

6.3.1.1 Data collection

Only direct related work is included in the LCA. Public servant work, construction, work for building the production machinery, and distribution of fuel and electricity production is not included even though it may have a large influence on the final result. Certain services like inspections of the cars, reparation of the cars (replacement of the front end), etc., are not included either, even though the replacement process have a relatively high importance, because it will change the functional unit. Only transportation with truck is included in the LCA (Berglund et al, 1996a), (Berglund et al, 1996b).

Only about 30% of the total production time have been assessed for both alternatives. 29 man minutes out of about a 100 for GMT, and 37 out of about 120 for SMT. Some of the production time not evaluated is production of buildings, machines, etc.

The goal was to include processes that involve more than one man-minutes per functional unit. But in practice processes were excluded during the entire project because it was difficult to find data about the production time at many subcontractors.

The data were collected by visiting the companies. Visits by one person, lasting about half a day were necessary. For each process the blank forms were filled in, and interviews were carried out. Measurements were not necessarily performed. Literature data were only used in the cases where specific data were not available. For example was all transportation with truck assessed by literature data from the branch, phone interviews and a visit to one truck company (Berglund et al, 1996a), (Berglund et al, 1996b).

6.3.1.2 Data processing

After the collection of the inventory data, it was necessary to discuss the scoring of the processes with colleagues for about half a day, because the scoring in some areas is a very subjective matter.

6.3.1.3 Company experiences

The assessment shows that a large part of the direct work in the production of front ends is carried out at only a few work places - mainly production of components and assembling of the cars.

The example shows that it is possible to see a clear difference in the working environmental impacts between the two front ends, despite the uncertainty of the scores. The main difference in the scoring can be attributed to different organisation of the work at the two companies, while only small differences can be attributed to technological changes, e.g. choice of materials and production methods.

The most important factor for the final result of the working environmental assessment is the production (cycle) time, simply because the production time is multiplied with the score of the individual processes to give the number of expected average accidents per million functional units. An implication of this is that the production time is also used as the deciding factor when processes are excluded from the LCA.

6.3.2 Refrigerators from Electrolux

An LCA of four different refrigerators produced at Electrolux was performed. Two base models using different refrigerants were examined, and for each base model a new and an old design were examined. The new models were designed with the aim of being easy to assemble (Person et al, 1995).

6.3.2.1 Data collection

The objective was to include all processes involving more than one man minute per functional unit. This resulted in an assessment of the production of most of the components, whereas the production of bulk raw materials, the production of electricity and the extraction of energy raw materials were excluded. Only direct related work was included in the LCA. Public servant work and work for building the production machinery was not included.

278 out of 340 man minutes was examined at 20 companies. The last 60 minutes was spread at over 40 companies. Half of the cycle time not examined is due to the production of electricity. The remaining time is due to production of the freezing system, plastic raw materials, isolation chemicals, recovery of freon, etc. (Person et al, 1995), (Bengtsson et al, 1995).

6.3.2.2 Data processing

This example shows the same experience as the Volvo example, namely that data collection takes time and is quite extensive. A day-long visit to the companies involved in the assessment was required for collecting the necessary data. Another experience was that it can be difficult to get information from all the subcontractors. Some were unwilling to give information about their production processes, but all gave information about the composition of the components (Person et al, 1995).

In the final assessment, the average score for all examined processes were used as the score for the processes not examined in the LCA. In this way the working environmental impact for the entire life cycle could be estimated (Person et al, 1995).

6.3.2.3 Company experiences

A difference was expected between the old and the new models, because of changes in production-friendliness and assembling-friendliness for the new models. The difference was expected to improve especially the physical work load, but the assessment shows that the initial score for the physical work load, measured per working hour, is almost the same for all models. However, a shorter assembly time causes the score per functional unit to decrease in the new models. The uncertainty of the data is however larger than the differences between the refrigerators, and no clear conclusion can be drawn.

This means that the resulting difference per functional unit is caused by a difference in production time for the assembling process. The assembling-friendliness for the new model probably do exist, but is only manifested in a shorter production time - not in the working environmental factors. More products will instead be assembled in the same period of time and it is questionable whether a real improvement in the working conditions will be observed.

6.4 Discussion

In this section we discuss the strong and weak sides of the IVF method. The text therefore reflects the opinion of the project group. The purpose of the discussion is partly to evaluate the IVF method and partly to be able to learn from these strong and weak sides, and thereby be able to set guidelines for the "perfect" working environmental LCA.

In this discussion, the strong and weak sides are firstly summarised (**Table 6.5**), whereafter the points are elaborated. Secondly, an overview of *our* evaluation of the working environmental LCA is given. Finally, suggestions for improving the method are discussed. We may therefore be focusing more on the weak sides than the strong sides.

Table 6.5. Strong and weak sides of IVFs process assessment method.

Strong points	Weak points
Results can be integrated with LCA for the external environment	Not possible to compare results with LCAs using other methods
Cycle time used to exclude insignificant processes	Method only correct to use on Swedish processes (demands some efforts to use it in other countries)
Can in theory be used in all phases of the life cycle	No interaction with the EDIP-methodology
Aggregation possible - choise between alternatives can be made	Oriented towards working environmental problems in production - not in use
Many working environmental aspects included - "complete" work place survey	Using the production time as aggregation factor can be problematic
Graduation of different exposures and effects	Difficult to see differences between products from the same production (uncertainty of data too high)
Personal safety protective equipment counts as something negative	
Can complete the assessment with reasonable efforts	Exposure assessment based on subjective descriptions
Quick data processing	Method based on subjective descriptions (e.g. psychological working environment)
Software tool with database does exist	
Clear scores	Method needs development on certain items
Data are reliable	Time consuming method (visits to companies necessary)
Score represents the actual average injuries	
Working environmental database does exist	Expert knowledge is necessary
Data can be obtained by work place assessment	Data not always accessible

6.4.1 Methodical requirements

6.4.1.1 Integration with LCA for external environment

It is possible to use IVFs working environmental assessment method in combination with the EPS system for the external environment. Both assessment methods are based on financial circumstances. They are therefore both based on the same functional unit, and the results are expressed in the same (economical) unit, even though two different economical principles are used as the basis for the assessment. This means that the working environmental results can be compared to the assessment of the external environment.

The working environmental assessment method can, however, only be used together with environmental assessment methods based on financial circumstances.

Furthermore, it is only correct to use IVFs method for Swedish production processes, because the normalisation, which is incorporated in the method, refers to Swedish working conditions. The working environmental assessment will therefore be incorrect, if the method is used on non-Swedish processes.

It will take some effort to change the normalisation data to other countries, because the suggested scores have to match the average working conditions for the particular country, i.e. they must correspond to the average number of accidents and damages for the nine working environmental parameters in order to give the correct working environmental picture.

IVF has also tested their method outside of Sweden. In connection with the cases, some subcontracting work was carried out outside of Sweden. IVF finds that the method can be used in other countries with similar working conditions and a similar view of the suffering connected to working environmental accidents and damages. According to IVF, the method can therefore to some degree be used in Western Europe also, when the assessment includes only a limited number of processes outside of Sweden.

6.4.1.2 Interaction with the EDIP-methodology

As IVF operates with the economical aspects of the work-related injuries there is no interaction with the EDIP-methodology, where the person equivalent is operationalised. The normalisation procedures can therefore not directly be transferred from one method to the other. The requested exposure data are naturally related to the subsequent normalisation and are accordingly also very different in the two methods.

Both methods do however use the cycle time as an important assessment parameter and as an indicator of which processes that can be excluded from the study without significant losses of information.

6.4.1.3 Life cycle coverage

In theory, it seems like the method can be used in all phases of the life cycle. The method includes a range of parameters, which also can be used to assess e.g. the use phase of products where working environmental aspects also are important. The method may for example be able to assess the physical work load in the use phase of a computer mouse, because it within the method is possible to assess static work and work postures, which are the major problems of mouse work.

It is, however, a problem that the method is developed to be oriented towards working environmental problems specific for the production phase. As the method has not been used to assess working environmental problems in a product’s use phase, the method may need to be adjusted before applying it for the use phase also. Furthermore, it does not make sense to assess the psychological working environment in the use phase of e.g. a computer mouse, because the psychological working environment do not depend on the mouse. Moreover, the use is typically not related to one specific company.

This problem is, however, not caused by the IVF method itself, but by the fact that making a “correct” working environmental assessment with the use of a working environmental LCA is problematic in some ways. It is difficult to assess the working environment with a focus on the product.

6.4.1.4 Possibilities for aggregation

The scores used are normalised in a way that makes it possible to aggregate the scores for all nine working environmental parameters, and for the entire life cycle, into one single score. It is therefore possible to use the process assessment method for comparing and choosing between different alternatives. The results thus fulfil the aim of being a compass for product developers.

The refrigerator example shows that using the production time can be problematic. Introduction of a new assembly-friendly refrigerator do not improve the total working environment, but only decreases the assembling time. The working environmental burden is the same per working hour, but now it is just possible to assemble more refrigerators in the same time, giving a lower total score per functional unit.

Another example is comparison of a product that is ergonomically friendly to repair, and a similar product that is not. No great difference between the total working environmental burdens will be seen for the two products. The working environment of the repairman will, however, be greatly influenced. Interpretation of the results should therefore be carried out with great care, and always with an eye to the working environmental burden per hour, and not just the burden per product.

This is, however, a problem for all LCAs using the production time as the aggregation factor, because focusing on the product can produce some “wrong” working environmental conclusions.

6.4.2 Working environmental aspects

6.4.2.1 Many working environmental aspects included

One strong point of IVFs process assessment method is that many working environmental aspects are included in the assessment (accidents, physical, chemical, and psycological). The LCA is hereby more complete compared to other methods where only chemical aspects and accidents are included. By using IVFs method the assessment of the working environment is coming close to a “complete” work place survey.

The IVF examples illustrate that it is not only in the more “ordinary” working environmental areas that a difference between the alternatives can be seen. The method is also able to illustrate differences in more untraditional areas like work organisation. In the Volvo front end example the method clearly shows that a modern work organisation would improve the psychological working environment for the employees. The physical working environment can also be improved by modernisation of buildings, because part of the negative score, when using the method, is caused by background noise, lack of day light, etc. (Berglund et al, 1996a).

6.4.2.2 Graduation of the different exposures and effects

IVF operates with an assessment based on the actual exposure situation at the specific company, and compare these with the expenses of the average effects at work places in Sweden. This means that the different exposures are graduated, which result in a graduation of the resulting effects also. For example is the score given higher for a noise level of 90 dB compared to a noise level of 80 dB.

Despite the graduation of the exposures and effects, the refrigerator example shows that it is difficult to see the differences between closely related products that are manufactured at the same company. However, in the scores some minor differences can be seen, possibly as a reflection of the few actual differences, e.g. that the change of design moves some of the working environmental burden to another process in another country. The uncertainty of the data is, however, so large that it is impossible to draw any conclusions.

6.4.2.3 Protective equipment

The use of personal safety protective equipment counts as something negative or do not count at all. The reason for this is that all use of protection devices is troublesome, heavy, warm, etc., and should therefore count as something negative. For the parameter "chemical health hazard" a use of personal safety protection equipment is not included in the assessment, thereby implying that a use of the equipment will not improve the working environment. It is better to prevent than to protect. Instead the use of personal safety protection equipment is included in the parameter "general physical environment", where the use of protective equipment gives a negative score. A negative score is giving for hearing protection devices, helmets, face shields, respiratory protective devices, protective clothing and protective gloves.

In contrast, the use of hearing protection devices also counts as something positive (reduces the negative score) for the parameter "noise". The reduction of the negative score depends on how much of the exposure time the protection devices are used.

6.4.2.4 Exposure assessment based on subjective descriptions

In some cases the assessment of the exposures is subjective, because the method is not based on only quantifiable parameters. Especially the psychological working environment is based on more descriptive parameters. It is for example difficult to quantify the stress factor ranging from "no stress" to "highly stressful work". For accidents subjective answers likewise have to be given. The questions to be answered are if the risks of the listed accidents are insignificant, minimal, very low, low, relatively low, somewhat increased, increased, rather high, high, very high or extremely high.

IVF states that more than one person have to assess the working environment, and suggests that two persons do the scoring individually (Bengtsson et al, 1995, app.1). However, in practice it turns out that one person collects the data, and that the scoring is discussed among the examiners. The scoring will, thus, always be subjective to some extent. Some of the scores will therefore have a much higher uncertainty than others, which is also shown in the cases, even though the uncertainty of each score is assessed and noted.

Not only are the evaluations based on subjective judgements, but the actual method itself is also developed on the basis of subjective judgements, which creates another built-in uncertainty. The scoring system for the psychological working environment is developed subjectively as no large statistical data volume form the basis of the scoring. IVF has therefore themselves laid down the principles for the scoring. E.g. no possibilities at all for personal development gives the score of 0, and very good possibilities for personal development give the score of 30. Another example is a work situation with no stress gives the score of 0, and a highly stressful work, where lunch is often postponed, gives the score of -20. Furthermore, the connection between the scores given for the psychological working environment and the economy is not clear. The aspect is not described in the reports.

6.4.2.5 Needs for further development

The method needs further development on certain items, because of this subjectivity of the method. Furthermore, the method needs to be expanded on certain working environmental parameters. For example does the parameter "work atmosphere" only refer to the positive aspects of contacts with other people. The negative aspect, which exists for e.g. nurses, is not included in the method. Neither is the term bullying.

IVF is aware that the method is not precise enough to show the small differences within the same production site. Further development may therefore also be necessary with regard to this aspect. IVF explains that the roughness of the method is due to the fact that maximum one day is used per visit, and that the basis of the assessment, the evaluation of the points, has its flaws (subjectivity). IVF are especially sceptical of the assessment of the psychological working environment.

6.4.3 Practicability

IVF points out that it is possible to complete the process assessment method with reasonable efforts, if only the relevant processes are included in the assessment. IVF suggests to use the production time for each process as a parameter for which processes to include in the investigation. The processes representing the longest production time are more relevant to include in the inventory.

6.4.3.1 Time consumption

The collection of the inventory data is rather time-consuming, because all (relevant) production processes have to be evaluated, which demands a one-day visit at the companies. One should therefore be aware that the initial use of the method is expensive in terms of time consumption. Additional time should be added if the process are located far away geographically. It may be possible to send the blank forms to the involved companies and have them answer the questions, but good results depends on the willingness and ability of the companies to perform a valid self-assessment. Alternatively, the forms can be send in advance to the companies to save visiting time.

When the data have been collected, it is relatively easy to complete the process assessment, because filling in the blank questionnaire forms automatically results in a score that can be aggregated over the entire life cycle. This also means that the data processing is quick.

6.4.3.2 Software tool with database exists

A working environmental database for the IVF method do exist. The database does now contain data from about 50 processes. It is therefore possible to carry out some LCAs with the use of the software tool.

The output of the assessment, represented by the positive or negative score, is clear and understandable. The working environmental impacts are given directly in average damages per million working hours, which makes it easy to relate to the scores.

6.4.3.3 *Expert knowledge is necessary*

It is necessary to possess good knowledge about working environment in general in order to carry out the assessment.

6.4.4 Data issues

The data used are obtained from exactly the processes that are included in the LCA. This makes the data and the results trustworthy.

6.4.4.1 *Score represents actual average injuries*

IVFs process assessment method is constructed in a way so that the normalisation already is carried out by using the questionnaires created for each of the nine working environmental parameters. This gives the advantage that the score directly represents the actual "average" accidents and damages that the working environmental burden will result in. The normalisation does therefore not demand extra effort.

When new data has to be obtained, they may not always be accessible. It depends on the willingness of the companies to participate. If the companies are willing to provide the necessary data, it may save some data collection time to send the blank forms to the involved companies and have them answer the questions.

6.4.4.2 *Data can be obtained by work place assessment*

IVF has constructed some questionnaire forms, which, when filled in, gives the necessary data for the assessment. IVF call the questionnaire forms for "work place assessments". These questionnaire forms are constructed in a way that may be the "future look" of work place assessment forms. It is therefore possible that the data, in the future, can be obtained by work place assessment.

6.4.5 Summary of the assessment

In **Table 6.6** the above discussion is summarised. This table illustrate how we evaluate the IVF method. The exact meaning of the topics in the first column is described in section **1.10**.

Table 6.6. Evaluation of the IVF method.

Topic	Evaluation of the IVF method
Methodical requirements	
Integration with LCA for external environment	✗ ✗ ✗
Applicability in LC-phases	✗ ✗ ✗
Aggregation possible	✗ ✗ ✗ ✗
Working environmental aspects	
Coverage of WE'al issues	✗ ✗ ✗ ✗
Graduation of exposures and effects	✗ ✗ ✗
Practicability	
Practical in use	✗ ✗
Software tool	✗ ✗ ✗
Transparency	✗ ✗
Can be used by non-experts	✗
Data issues	
Data reliability	✗ ✗ ✗
Amount of data in existing database	✗ ✗ ✗
Data accessibility	✗ ✗
Data can be obtained by WPA	✗ ✗

❍ = missing, ✗ = poor, ✗ ✗ = acceptable, ✗ ✗ ✗ = good, ✗ ✗ ✗ ✗ = excellent

6.4.6 Suggestions for improvements

It is positive that IVFs method includes so many working environmental aspects. The evaluation carried out at the companies can be compared with complete work place surveys. The assessment gives a totality picture and an overall impression of the working environment instead of just focusing on chemical aspects or accidents.

The actual scoring system could possibly be improved. In its present form, it is not very clear why the suggested scoring intervals are chosen for the specific situations. IVF points out that the method need to be developed further in order to improve the evaluation of the different working environmental factors (Bengtsson et al, 1995).

It seems feasible to combine the IVF method with the EDIP method, using the IVF questionnaires to perform the initial steps in the LCA (inventory, classification, characterisation), and the EDIP normalisation and valuation principles (the person equivalent). A combination will require relatively large efforts as questionnaires and scoring systems will have to be adapted to meet specific Danish and/or international working conditions and normalisation values. This will probably prove to be most difficult for the factors describing the psycho-social working environment, simply because the basis for the normalisation and valuation is very difficult to estimate. Efforts will also have to be devoted to the development of questionnaires that relate to other types of work, so that the use phase of products can be assessed to the same extent as the production phase.

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7 EDIP's process assessment method

7.1 The general methodology

Development of the EDIP method for assessment of the working environment was part of the Environmental Design of Industrial Product programme (the EDIP-programme). The programme was sponsored by the Danish EPA and the participators were five major Danish industrial companies as well as institutes at the Technical University of Denmark.

7.1.1 Purpose

The purpose of the EDIP project was (Wenzel, 1996)

- To develop methods for environmental assessment of complex industrial products,
- To develop guidelines for design and construction of environmentally friendly industrial products,
- To develop a database and a computer based tool as support for environmental assessment, and
- To implement the methods and tools in the companies participating in the project.

7.1.2 The overall contents of the methodology

The purpose of the EDIP project was, as mentioned, to perform an environmental assessment of products. For this purpose a quantitative process assessment method for LCA was developed within the project. The assessment parameters used within the EDIP method are shown in **Table 7.1**. According to the table the method operates with three groups of assessment parameters: environmental effects, resource consumption, and working environmental effects.

Table 7.1. Assessment parameters used in EDIP.

Effects	Environment	Resources	Working environment
Global	Greenhouse effect Stratospheric ozone depletion	Fossil fuels Metals Other minerals Others (animals etc.)	
Regional	Photochemical ozone creation Acidification Eutrophication Ecotoxicity (water, chronic) Human toxicity (water)		
Local	Ecotoxicity (water, acute) Human toxicity (air) Hazardous waste Nuclear waste Incineration ash Bulky waste	Biomass Water Others	Cancer due to chemicals Reproduction damage due to chemicals Allergy due to chemicals Damage to the nervous system due to chemicals Muscle-skeletal damage due to monotonous repetitive work Hearing damage due to noise Body damage due to accidents

Most of the effect potentials are relatively straightforward to handle in the quantitative assessment method. However, the quantitative assessment of the effect potentials "ecotoxicity" and "human toxicity" demands much more work. To avoid too much unnecessary work, screening methods have been developed. These screening methods can help in the decision of identifying the potential contributes to human toxicity or ecotoxicity. (Hauschild, 1996)

7.1.3 The general principles of the methodology

The EDIP methodology is based on the following steps:

- the data (e.g. resource consumption, emissions to air and water, waste etc.) from the product system are measured, calculated or estimated
- these data are classified by their potential to cause impacts, e.g. use of non-renewable resources, global warming and ozone depletion
- the data are characterised with respect to the impact categories, i.e. equivalence factors are used to determine the impacts from several sources to an impact category.

These steps follow the principles outlined in ISO 14040-series and are generally accepted as a sound methodology in LCA.

The aggregated impacts are subsequently normalised by relating them to the average annual impacts caused by one person in a relevant geographical area (the world/Denmark). In doing so, the contribution to an impact category is related to the potential impact from society's activities as a whole.

Finally, the impacts are weighted by use of international or Danish politically stated reduction targets for different impacts or specific compounds. Hereby it is assessed which of the potential impacts from a product system are most important.

These steps of the EDIP methodology differ slightly from the ISO 14040 standard, where only a weighting step is recommended. There is, however, little doubt that the normalisation step used in the EDIP methodology adds significant information, provided that the mechanism and principles are scientifically based and understood by the decision-makers.

7.1.3.1 Working environment

EDIP operates with three different methods for assessing the working environment, a screening method, a process assessment method, and a sector assessment method.

The screening method is a chemical screening method and thereby only covers the chemical working environment of an LCA. The chemical screening method can be used early in the product development or together with the process assessment method. In the last-mentioned case the chemical screening will be a preliminary step for the quantitative assessment with the purpose of deciding which processes to be included in the process assessment.

The process assessment method can be used in the assessment of the manufacturing process in the company and possibly for those subcontractors who are able and willing to supply the information needed.

The sector assessment method can be used together with the process method, in processes where specific working environmental data not are available (Hauschild, 1996), (Broberg & Rasmussen, 1996).

7.1.4 Combined environment and work environment assessment

The assessment parameters used in the EDIP method are shown in **Table 7.1**. The method operates with three groups of assessment parameters (environmental effects, resource consumption, and working environmental effects), which all play an equal role in the methodology.

All three groups of assessment parameters are related to the same functional unit and measured by the same environmental unit - the person equivalent. Since the same basic assessment method is used, it is possible to aggregate over several steps in the life cycle and to compare the results from assessment of the working environment with other impact categories.

The data describing the working environment are collected from different sources depending on the assessment method used. For use of the chemical screening method, information about the chemicals used in the specific processes is needed. The screening gives the processes a score by relating them to European and national lists of dangerous substances and lists of substances with special effects.

The process assessment method requires more specific data from the company such as information concerning impacts due to accidents, chemicals, noise and monotonous repetitive work. Furthermore, it should be stated how much of the company's production time is used to manufacture the examined product in each of the processes.

When the sector assessment method is used, similar data should be collected. However, it should be noted that the data in this case represent the average working environmental impacts from the entire sector instead of the specific company and thereby will lead to higher uncertainty.

7.1.4.1 Software tool

The method describes that a software tool has been developed within the EDIP-programme. The software tool shows on which lists of effects (from the Danish Labour Inspectorate) a chemical or substance is registered and which classification EU requires. According to the method the program has not been updated. (Hauschild, 1996)

In the general EDIP software tool, room has been made for working environmental information, but the scattered information found there is far from sufficient to be a relevant help to perform a working environmental assessment. The software tool needs much development to be useful in the assessment of the working environment.

7.2 Working environmental assessment methodology

7.2.1 Purpose and goal

The purpose of the working environment project within EDIP was

- to develop a method for including working environmental parameters in LCAs based on the methodical framework described by SETAC and the EDIP programme,
- to use the developed method for assessing the working environmental impacts in the life cycle of five industrial products (reference products),
- to identify the critical working environmental impacts of the reference products and point out the possibilities of improvements of new products in progress,
- to outline the principles for good working environmental construction of industrial products, and
- to describe and evaluate the use of the developed methods and tools in product development within the companies participating in the project. (Broberg & Rasmussen, 1996)

The EDIP programme includes the working environment in LCAs for three reasons:

- the working environment should be included in LCAs to avoid working environmental deterioration when production processes are changed. LCAs will often be the basis of production changes or development of new products with lower environmental burdens. These changes determine the choice of production materials and processes, which directly influence the working environment.
- including assessments of the working environment in LCAs makes it possible to prevent working environmental problems when the LCAs are used in the technological planning.
- the working environment should be included in LCAs because some working environmental problems are of life cycle character, e.g. by chemical substances following the product throughout its entire life cycle.

The purpose of the process assessment method is to assess the working environment in the manufacturing processes within the company as well as the processes at the suppliers that are able and willing to supply the information needed. The method can be used in all phases of the product life cycle and it is suitable for assessing the whole product or just to compare single parts of selected products (Hauschild, 1996).

7.2.2 Scope of the methodology

7.2.2.1 System boundaries

As mentioned, all phases in the product life cycle can be covered by EDIP's process assessment method. The only exception is private use of the products. In this phase of the life cycle only impacts from activities indirectly related to private use of the products (e.g. production of electricity for use of the product) can be included in the method. This choice reflects the general structure of the Danish regulation. (Broberg & Rasmussen, 1996)

Allocation of the impacts from the working environment is normally done by the production time. The method prescribes that if there is no knowledge of the production time for the individual product, allocation of the impacts for the working environment can be done similarly to the allocation of the external environment. If, for instance, the energy flow is allocated by weight, the production time can also be allocated by weight. (Broberg & Rasmussen, 1996 and Hauschild, 1996)

7.2.2.2 Impact categories

Four impact categories and a total of seven effects are being assessed in EDIP's process assessment method, see Table 7.2. These impacts reflect the most common working environmental problems in Denmark. The impacts are selected from the Danish Working Environment Service's overview of industries with serious working environmental problems. (Broberg & Rasmussen, 1996).

Table 7.2. Impact categories in the process assessment method.

Impact categories	Effects
Chemical impacts	Cancer Reproductive effects Allergy Nervous system damage
Noise impacts	Hearing damage
Impacts of monotonous repetitive work	Muscles-skeletal damage
Risk of accidents	Bodily damage

The seven effects are selected from seriousness, knowledge of the interaction between exposure and potential effects together with data availability.

A more detailed specification of the impacts and effects related to the working environment is listed in Table 7.3.

The impacts have been selected from the Danish Labour Inspectorates' overview of working environmental problems in different industrial sectors in Denmark. The chosen impacts can be supplemented with other impacts in a further development of the methodology.

Table 7.3. Overview of impacts and effects related to the working environment

Working Environmental Impacts	Effects	Included		Remarks
		Yes	No	
Accidents	Sprains	X[1]		1) All accidents resulting in bodily harm causing more than one day of absence from work are included.
	Injuries/lesions	X[1]		
	Cuts	X[1]		
	Fractures	X[1]		
	Burns	X[1]		
	Death	X[1]		
Biological	Infections		X	
	Organic dust toxic syndrome		X	
	Allergy		X	
Chemical	Acute toxicity:			1) All accidents resulting in bodily harm causing more than one day of absence from work are included.
	Irritation (skin, mucous	X[1]		
	membranes)	X[1]		
	Chemical burns	X[1]		
	Odour	X[1]		
	Death			
	Chronic toxicity:			
	Cancer	X		
	Allergy	X		
	Reproductive effects	X		
	Neurotoxic effects	X		
	Genotoxic effects		X	
	Specific organ effects		X	
Physical	Hearing loss/nuisance	X		
	White fingers		X	
	Burns/frostbite		X	
	Cancer		X	
	Allergy		X	
	Muscle-skeletal effects		X	
Physiological/ ergonomic	Cardiovascular effects		X	
	Muscle-skeletal effects		X	
	Repetitive stain injuries	X		
Psycho-social	General discomfort		X	
	Stress		X	
	Mental effects		X	
	Depression		X	

7.2.2.3 Data requirements

The authors of the method state that the process assessment method is best suited for assessment of internal production processes and for assessment of processes in supplier-companies from which it is possible to obtain knowledge of the exposures from the processes. If it is not possible to obtain knowledge of the processes in these companies, the authors of the method recommend that the assessment of these impacts is made by use of sector assessment or chemical screening. (Broberg & Rasmussen, 1996 and Hauschild, 1996).

Data requirements and sources as well as practitioners (exceeding "EDIP experts") are shown in **Table 7.4**. The table is divided into the same impact categories as shown in Table 7.2.

Table 7.4. Impact categories, data requirements and practitioners.

Impact categories	Data requirements and sources	Practitioners
Chemical impacts	Working hygienic measurements Time of exposure Knowledge of substances (for instance CAS No.) Lists of chemicals and effects from the authorities Literature	Person with chemical know-ledge Person with working hygienic experiences
Noise	Measurements of noise level Time of impacts	Working environmental expert
Monotonous repetitive work	Assessments of impacts Time of impacts	Working environmental expert
Risk of accidents	Calculations from the accident statistics of the company or industry Production time	Working environmental expert Statistician

If possible, the exposure to the chemicals is assessed by use of working hygienic measurements. If measurements are not available the exposures are assessed on the basis of process parameters (open/closed process, ventilation/exhaustion, volatility, dust/aerosol formation, temperature etc.). The potential effects of the chemicals are stated on the basis of the Danish and European legislation. (Broberg & Rasmussen, 1996)

For accidents, calculations of the average risk of accidents by means of statistics and the production time are assumed to express how many accidents may be expected in the actual phase of the life cycle of the product. Since some occupational injuries are never reported these figures are probably underestimated. For larger companies, data and statistics specific for the company are preferred, but if these are not available, statistics for Denmark can be used.

7.2.2.4 Inventory parameters

The process assessment method includes the impact parameters shown in Table 7.5.

Not all the impact parameters shown in Table 7.5 are specified in the method, but are derived from the method description by the authors of this review.

Table 7.5. Overview of working environmental impact parameters included in the process assessment method.

Working Environmental Impacts	Impact parameters	Included		Remarks
		Yes	No	
Accidents	Machines Handtools Other technical equipment Handling structures Vehicles (int/external transport) Fire Explosions Leaks	X[1] X[1] X[1] X[1] X[1] X[1] X[1] X[1]		[1)] All accidents resulting in bodily harm causing more than one day of absence from work are included.
Biological	Microorganisms/Biological agents Vira Fungi Dust inhalation		X X X X	
Chemical	Substances and materials Vapours (inhal., skin) Gases (inhal.) Aerosols (inhal.) Dust (inhal., skin) Liquids (splashes to skin) Solids (skin)	X X X X X X X		
Physical	Noise Vibration (arm, hole body) Thermal environments (temp., humidity, air- exchange) Ionising radiation Non-ionising radiation Electromagnetic fields Illumination	X	 X X X X X X	
Physiological/ ergonomic	Heavy work/lifting Repetitive work Work postures	 X	X X	
Psycho-social	Working hours (day/night shift) Time pressure Monotonous work Control, demand and self- determination/contributory influence Work in solitude Workplace design Irritation		X X X X X X X X	

The method states that the list of applied substances and materials for assessing chemical impacts will often be identical to the list of substances and materials for assessing the external environment. For noise, monotonous repetitive work and accidents, the data collection will be independent of the data collection for assessment of the external environment.

The fact that not all levels of exposure result in an effect is used to set impact thresholds within the four impact categories, see Table 7.6.

Table 7.6. Impact thresholds

Impact categories	Impact thresholds
Chemical impacts	Exposure measurements exceeding 10% of the threshold limit value calculated as sum of fractions[1] of all substances in the process or Direct skin contact or if Inconveniences are observed which may be caused by the chemical substance
Noise	Noise impact over 80 dB(A) measured as an average measurement or if Normal speech cannot easily be heard at a distance of 1 metre
Monotonous repetitive work	Working cycle is repeated more than 2 times per minute (lasting at least half an hour) or Uncomfortable or frozen working postures
Risk of accidents	Accidents that result in bodily harm causing more than one day of absence from work

The impacts are only included in the assessment if the impacts exceed the impact threshold. The time that the impact threshold is exceeded can subsequently be added to the exposure time for another process. The fact that the method only assesses whether or not the impact threshold value is exceeded (and not e.g. whether the noise level is 82 or 85 dB(A)) means that the level of exposure is not graded. A grading of the exposures would demand far more detailed data. (Broberg & Rasmussen, 1996)

The synergistic effects of chemical substances are not included in the process assessment method. When assessing the exposures the method assumes that no personal protective equipment (e.g. gloves) is being used. With this boundary it is assumed that the legislation is respected and prevention of working environmental problems instead of use of protective equipment is encouraged. (Broberg & Rasmussen, 1996)

7.2.2.5 Impact assessment

The process assessment method is not strictly in accordance with the ISO 14042 standard. The standard operates with five steps - category definition, classification, characterisation, normalisation (optional) and weighting (optional). EDIP's process assessment method operates with fewer steps.

In the EDIP process assessment method category definition and classification are carried out in one step, because of the fact that all effects are only related to one impact category (e.g. all incidents of allergy are classified under the impact category “allergy”). This is possible because the impact categories (Table 7.2) are very widely described in the method.

In the characterisation it is assumed that all exposures have the same effects if the impact thresholds (Table 7.6) are exceeded. This means that the method does not distinguish between the consequences of exposure to e.g. two different chemicals that are both carcinogenic.

The process assessment method also includes a normalisation step for each of the impacts where the impact has exceeded the impact threshold limit. The

[1] Sum of fractions $= \frac{C_1}{TLV_1} + \frac{C_2}{TLV_2} + \ldots + \frac{C_N}{TLV_n}$

normalisation gives an idea of how relatively common the impact is and whether it is abnormally large. The reference value for the normalisation is time of impact per employee per year in Denmark. When the registered impact time is divided by the normalisation reference value, the impact is expressed as a unit person-equivalent. The unit person-equivalent corresponds to the impact that an average employee in Denmark is exposed to per year. (Broberg & Rasmussen, 1996)

The last step in the method is weighting where the number of potential work-related injuries for each effect is calculated. A weighting factor is calculated as the number of reported work-related injuries divided by the number of employees in Denmark. When the normalised data are multiplied by the weighting factor the number of expected reported work-related injuries per product is obtained. (Broberg & Rasmussen, 1996)

In the weighting step there is a risk that not all work-related injuries are reported which will lead to an underestimate of the number of expected reported work-related injuries per product.

When including the last two steps - normalisation and weighting - a number of uncertainties are introduces but at the same time these calculations add important information to the assessment. The normalisation and weighting steps are useful when comparing the potential effects from alternative products but the use is more doubtful when comparing different impact categories. In the description of the method it is emphasised that it will often be possible to make the working environmental assessment at an earlier stage and thereby preclude normalisation and weighting. (Broberg & Rasmussen, 1996)

7.3 Cases

One part of the EDIP project was a practical test of the developed methods. This was done by use of the method on different products. Each company participating in the project was asked to select a product for this purpose. In the following a short description of each case is given.

7.3.1 The refrigerator LER200 from Gram a|s

The examined product is a refrigerator LER200 (Low Energy Refrigerator). LER200 has the lowest energy consumption of the Gram refrigerators, and is among the refrigerators with the lowest energy consumption on the market. The functional unit is a volume of 200 litres cooled for 13 years to five degrees, with the temperature of the surroundings set at 25 degrees.

7.3.1.1 Collection of data

LER200 is made of several different raw materials from all over the world. Except for steel production, however, extraction of raw materials is not included in the working environmental assessment. The data used in the assessment of steel production are not from the specific supplier used by Gram, but are extrapolated data from another steel making plant.

Energy production is included by use of the sector assessment method. Both the process of extracting the materials for energy production and the energy production itself are included in the assessment. The data have been obtained from the countries supplying the Danish power plants with coal, oil and natural gas, and information from the power sector is used to account for the power production.

All production processes at Gram are included in the assessment, accounting for over 80% of the entire production phase. The rest of the production is situated at different suppliers, but it was not possible to obtain any working environmental data on these processes. Information on the working environment is apparently a more sensitive subject than information on the external environment, and other ways of collecting data must be established.

In the use phase, transportation of the finished refrigerator is included by use of the sector assessment method. An average of Danish transport of goods is used. Otherwise, only data concerning the production and use of energy are included. An average of the Danish power plants is used. No working environmental data could be found for the disposal phase.

7.3.1.2 Data processing

The working environmental profile shows that the total working environmental impact is lower than the environmental impact. LER200 has a long lifetime, and the only working environmental impact in the use phase is caused by the use of electricity. On the other hand the electricity consumption in the use phase is responsible for almost half of the total working environmental impact during the life cycle. Even though LER200 has one of the lowest consumptions of energy on the market, the use of electricity still plays an important part in the total working environmental profile.

The production phase is the most important phase with respect to the working environmental impacts. In the total picture, both transportation and steel production (steel represents more than 50% of LER200’s weight) are insignificant processes.

The case study shows that it is possible to cover a large part of the products’ life cycle. 75% of the life cycle is covered by a combination of the process and sector assessment methods. It may be difficult to find data for raw material acquisition and processing if these process steps take place in other countries. Despite the lacking data it was still possible to identify improvement opportunities on both the structural level and on the component level.

7.3.1.3 Company experience

A main experience at Gram A/S is that it is essential to use working environmental professionals in the data collection and that the data collection is anchored to one person in the company. Data collection from the suppliers to Gram A/S has proved to be very difficult. The product developers at the company have learned something about the working environment, and most of the results have been channelled to the safety organisation for future use. The company does not plan to formally integrate the working environment in product development. Instead, the company will involve the production technicians, who are main actors in working environmental issues, earlier in the process.

7.3.2 The JetpaQ pump from Grundfos a|s

The examined product is a JetpaQ pump used for water supply in private households. The JetpaQ pump was at an early stage of the product development when the EDIP case started, and it was therefor possible to include some of the results of the life cycle assessment in the product development.

The functional unit is supply of five cubic metres of water per hour with a pressure of 1.5 bar or a corresponding smaller amount of water with a higher pressure up to five bar for 4,870 hours.

7.3.2.1 Collection of data

The JetpaQ pump consists of stainless steel, plastics and tinplate which are delivered from all over Europe. For the production of raw materials average data from the EDIP database have been used. The only working environmental data available was for production of steel made from recycled materials. The JetpaQ pump was made from new materials but the production processes are assumed to be similar for new stainless steel and steel made from recycled materials. As steel covers 40% of the total consumption of materials in the pump, 40% of the production of materials is assessed.

The part of the production that is expected to take place at Grundfos - which is the major part - is included in the assessment. For noise impacts and impacts of monotonous repetitive work the total production time is considered as impact time. Furthermore the working environmental impacts from production of electricity are included in the assessment.

For use of the JetpaQ pump, the production of electricity at power stations as well as transportation by van are included in the working environmental assessment. No working environmental data for the disposal phase are included in the assessment.

7.3.2.2 Data processing

The largest impacts in the product life cycle are in the production phase and in the use phase. In the production phase the impacts are caused by energy production as well as the production at Grundfos and the impacts are monotonous repetitive work and noise. In the use phase the largest impact is noise due to production of electricity.

7.3.2.3 Company experience

The case shows that it requires much work to collect and assess the data. Since the product development was at a very early stage, it was difficult to predict where the components would be produced. Grundfos found that it was difficult to collect data from the suppliers. Grundfos sent a letter to a supplier, but there was no reply from the supplier.

The BST was essential in collecting the data and Grundfos expects that BST will play an important role in data collecting in the future. Furthermore the case showed that it was necessary to involve an expert in environment and working environment to handle the method.

The case also showed that it was difficult to identify possibilities of working environmental improvements in the life cycle of the specific product. The project leader expects that the working environmental improvements in the future will be on a company level and identified with help from the BST. It was also a conclusion that it was too complicated to use the work place assessments (APV) to collect the working environmental data.

7.3.3 The electrohydraulic activating unit (PVEH) from Danfoss a/s

The examined product is an electro-hydraulic activating unit PVEH (Proportional Valve Electric High performance) which is used in cranes and contractors' machinery. The product was selected for the assessment because of its complexity and because the company was developing a new generation of the unit. The functional unit is regulation of one hydraulic proportional valve in a hydraulic installation for five years.

7.3.3.1 Collection of data

In total about 80% of the working environment in the product life cycle is covered by the assessment. The production of electricity is included in all the phases and the transport of components and products is included in the assessment.

PVEH is made of materials and components from all over the world. For the production of raw materials only the production of steel is assessed. The product consists of 30% steel.

For the production phase, the production at Danfoss and the production of printed circuit boards at a supplier are included. The working time per component is calculated and all the processes are assessed. Noise and air pollution is measured at the working place and all processes have been evaluated for chemical impacts. Monotonous repetitive work has been assessed by BST and the risk of accidents has been extracted from the company's own statistics.

Extraction of crude oil for use of the activating unit is included in the working environmental assessment. The disposal phase is not included due to lack of data.

7.3.3.2 Data processing

The largest working environmental impacts are in the production phase which includes the production at Danfoss, the production at the supplier of printed circuit boards and the production of electricity to produce the unit.

As a part of the case study the working environmental consequences of a theoretic product change have been evaluated. The simulation showed that a change in the printed circuit board would minimise the working environmental effects by 12-100%.

7.3.3.3 Company experience

The BST at Danfoss has been involved in the data collection - especially concerning chemical products - and BST concludes that the method is directed towards experts.

The case shows that it is difficult to use the production time as a measurement for the working environmental impacts.

The life cycle assessment method and results of the working environmental assessment are not used in the product development process and the case study has not resulted in any changes of the working environment at Danfoss. Furthermore the case showed that it would not be possible to collect data for the EDIP method together with the data for the working place assessment (APV) (Broberg & Rasmussen, 1996).

7.3.4 The high-pressure cleaner Hobby 70 from KEW Industry

The examined product is a portable high-pressure cleaner “Hobby 70”, which is a new product from KEW Industry. The functional unit used is cleaning of a surface for 125 hours over a five year-period for seven different types of cleaning. For every type of cleaning the use of electricity, water and chemicals is described.

Hobby 70 is made of more than 100 different parts. The main part of the components are produced in Denmark. Italy and the Netherlands are the most essential suppliers of materials. Less than 1% of the total weight of Hobby 70 is produced outside of Europe.

7.3.4.1 Collection of data

It was not possible to gather any information about the materials production, because no subcontractors gave this information. The processes production of raw materials and materials production are therefore not included in the assessment.

The production at KEW is mainly assembly work, but also some welding and grinding. The actual modelling of the product is carried out at subcontractors with processes like die casting, pressure die casting and chipping. No surface treatment is carried out. It was not possible to gather any information about the working environmental conditions at the subcontractors. Therefore only processes at KEW are included in the working environmental assessment for the production phase. By use of the sector assessment method, the working environmental impacts caused by the use of electricity are also included. An average of production of electricity from Danish power plants is used.

In the use phase water, electricity and detergents are needed. The use of detergents is included in the working environmental assessment, and by use of the sector assessment method, the working environmental impacts because of the use of electricity are also included.

Waste disposal and transportation is not included in the working environmental assessment because of lack of data.

7.3.4.2 Data processing

The assessment shows that the working environmental contribution is considerably smaller compared with the environmental contribution. However, only working environmental impacts connected to the use phase, electricity production and the production processes at KEW are included in the working environmental assessment.

The largest working environmental problem connected to Hobby 70 is accidents. Muscle-skeletal damage and hearing damage, which are mainly caused by the production at KEW, are also of high importance. 20% of the expected hearing damage is, however, caused by the production of electricity.

7.3.4.3 Company experience

None reported.

7.3.5 Beovision LX 5500 television from Bang & Olufsen

The Beovision LX 5500 television is a complex product. It consists of several different components made of different materials. Some production processes are carried out at Bang & Olufsen, and some at Danish subcontractors. However, a considerable part of the production processes is carried out at foreign subcontractors in mainly France and Germany.

It was not possible to gather information about the working environment from the foreign subcontractors. As the foreign subcontractors represent a considerable part of the life cycle of the television it was decided to leave out the working environmental assessment entirely of the LCA. This example therefore shows the importance of the geographical location of the companies, when it comes to collecting working environmental data for the LCA.

7.4 Discussion

In this section we discuss the strong and weak sides of the EDIP method. The text therefore reflects the opinion of the project group. The purpose of the discussion is partly to evaluate the method and partly to learn from the strong and weak sides of the method, and thereby be able to set guidelines for the "perfect" working environmental LCA.

In the discussion, the strong and weak sides of the method are firstly summarised (**Table 7.7**), after which the points are elaborated. Secondly, an overview of *our* evaluation of the working environmental LCA is given. Finally, suggestions for improving the method are discussed.

In a part of the discussion, EDIP's process assessment method is compared with another process assessment method called "IVF's process assessment method". The two process assessment methods are similar in some ways, but very different in others. IVF's process assessment method is described in details in the chapter 6.

Table 7.7. Strong and weak points of EDIP's process assessment method.

Strong sides	Weak sides
Can be integrated with external environment assessment	No distinct interaction with IVF's process assessment method
In the description of the method it is mentioned that normalisation and weighting introduce uncertainties	The method tends to weight the impacts during the production phase higher than during the other phases of the life cycle
Can distinguish between different products (if the necessary data are available)	The weighting method may cause an unbalance in the assessment
Simulations of theoretical product changes are possible	Difficult to ascertain focus points of working environment in a specific product
The method includes both chemical and non-chemical effects	Impacts are not graded
Can point in directions where it may be interesting to search for alternatives.	Not reliable only to use the production time as a measure for the impact
Possible to involve BST in data collection.	The method excludes significant impacts (e.g. dust and vibrations)
Uses data directly from the local work place	Long term effects of chemical impacts may be overlooked
	Usefulness depends on the purpose of the assessment
	Difficult to use the method without involving experts
	Available software tool is complicated
	Data collection regarding chemicals is entrusted to an expert
	Requires many data. Difficult to obtain data from suppliers
	Difficult to involve the safety organisation in the data collection.

Some of the strong and weak points seem to be contrary. This only reflects the different experience from use of the method in the cases with different products and companies.

7.4.1 Methodical requirements

7.4.1.1 Integration with external environment assessment

The working environmental method can easily be integrated with the method for external environment assessment. The overall methodology is the same. This is regarded to be one of the major strong points. The working environmental method was developed to be integrated with the external environmental method. If working environmental LCA is going to be used on the same level as assessment of the external environment, the two parts should be integrated and based on the same units (person equivalent).

7.4.1.2 Normalisation and weighting

The method recommends that the assessment - if possible - should be made before normalisation and weighting. This shows that the authors of the method are aware that uncertainties are introduced when the normalisation and weighting steps are used. Especially when two different effects are compared, normalisation and weighting may underestimate the potential working environmental effects.

7.4.1.3 Comparison of products

The use of comparable data units makes it possible to distinguish between different products for the assessed effects. The availability of data on the same level of detail is however a necessity.

The method can be used for simulations of product changes. The available software tool can (anything being equal) be useful at this point.

7.4.1.4   Interaction with IVF's process assessment method

EDIP's method is in some ways similar to the IVF process assessment method. For instance IVF also uses the working time as an indicator of which processes can be excluded from the assessment without loss of significant information.

In both methods the normalisation is done according to the actual work-related injuries. As EDIP operates with the unit person equivalent and IVF operates with the economic aspect of the work-related injuries, the normalisation procedures cannot directly be transferred from one method to another.

To assess whether an impact leads to an effect or not EDIP uses impact thresholds. This means that there is no grading of the impacts. IVF uses a scoring system where the score can be negative or positive depending on the actual situation compared to the situation of "not having the examined job". For instance, a noise level of 95 dB(A) will give a higher score than 85 dB(A). The scoring system that operates with the actual exposure situation could be helpful in EDIP to provide a more graded and accurate picture of the impacts.

7.4.1.5   Importance of life cycle phases

The purpose of using a life cycle assessment in a product development course is to consider all the phases in the product life cycle. From the cases described, it looks like the method tends to weight the working environmental impacts during the production phase significantly higher than during the other phases. For instance during production of materials and during application, a large dilution of the impacts takes place because the impacts are measured per product (or per functional unit). This is a result of the method's use of allocating the impacts on the basis of the production time. If this dilution means that significant working environmental impacts are overlooked during one or more of the phases, fatal errors may be made during the product development. An example: A copy machine is developed so it has very little need for changing of spare parts, but it is accepted that some repairs will be ergonomically stressing to make. The method will dilute this impact because few repairs are carried out per measuring unit (the functional unit). The fact that the copier servicer performs this task daily and that his working environment in this way will be more stressed is ignored.

The method weights the impacts in proportion to the number of reported occupational damage. The reporting frequency of different types of occupational damage in Denmark is determined from whether the damage is acknowledged and listed on the occupational disease list.

This means that a very substantial number of actually occurring damage is not registered and as a consequence is not included in the weighting. To illustrate this may be mentioned various injuries to muscles and joints (for instance back injuries and PC mouse injuries), substances suspected of producing cancer and reproduction injuries.

From the cases it is an experience that it can be difficult to ascertain focus points for working environmental improvements in a specific product. It seems more obvious to improve the working environment at the company level in general.

There is no grading of the impacts in the method. Very large and significant differences in the working environmental impacts are not weighted. For instance, there is an enormous difference between the noise impacts at 80 dB(A) and 95 dB(A). When it is considered that the noise limit has only recently been lowered from 90 dB(A) to 85 dB(A), almost all life cycle assessments will register a relatively high noise impact for some time to come.

The use of the production time as a measure for the impact will in many cases give an unwanted dilution effect. See also above: "The method tends to weight the impact during the production phase higher…".

7.4.2 Working environmental aspects

A strong point of the method is that it includes other working environmental impacts than the chemical and that it assesses other effects than the toxic.

A weak point of the method is that it by its inherent limitations precludes some very significant working environmental impacts and effects. If the method is used in a product developing course, an assessment should be made in advance of whether the method will be reasonably covering for the product in question. The method gives no guidelines as how to make such an assessment. In a number of production processes an unbalanced impression may result from the selection of working environmental parameters and effects, as for instance, impacts such as vibrations. In all processes where hand-held tools are used, the vibration impact in the form of hand/arm vibrations will be significant - often a larger impact than noise.

Another example is dust (particles). In all processes involving material finishing (cutting, chopping, sharpening, boring, welding, etc.), in processes using or handling powdered materials, in processes where high-pressure coating takes place and in a number of other processes, a major dust impact on the working environment exists. Some of the harmful effects of the dust will be covered by the chemical screening but the physical impact on the organism will not be included in the assessment. This means that the risk of respiratory damage and the resulting consequences for cardiovascular diseases will not be assessed.

Finally, it seems a drastic limitation of the ergonomic impacts that the analysis is limited to monotonous repetitive work. Firstly, monotonous repetitive work is generally only seen in the production phase. In this way it will only be during one of the life cycle phases that the ergonomic impact is included. If the method had chosen to use, for instance, the definition for heavy lifting, ergonomics had been included in all the life cycle phases. Secondly, the extent of lifting work and working postures has a very major influence on the working environmental impacts in general (the occurrence of back and knee injuries, etc.).

A weak point of the method is that essential long term effects by a chemical impact of the working environment may be overlooked when the impacts are assessed.

For the chemical impacts the method has determined a limit of 10% of the threshold limit value, calculated as a sum of fractions. The Danish threshold limit values (TLV) have not been fixed on an unambiguously equal basis. Historically, only the acute effects of the substances form the basis of determining the value. For a number of substances the values have later been significantly lowered due to the substances' long time effects. One example is Styrene, where the threshold limit value some years ago was lowered by a factor 100 after an incident at Sønderborg Skibsværft.

7.4.3 Practicability

The cases have shown that the method can be used in pointing out directions for improvements. This is a strong point in the general production development schedule in a company.

Usefulness and practicability of LCA methods depend primarily on the purpose of the assessment and on the users' background and experience. Table 7.8 contains an evaluation of the practicability of the EDIP's process assessment method for different applications.

Table 7.8. Practicability of EDIP's process assessment method.

Application	Level of broadness of system boundaries	Level of certainty	User background/ experience	Assessment time for single modification of product, man-hours	Practica-bility Applica-bility
Assessment on community level	Broad	Low	LCA - expert	>500	Low
Wholesale products in company with LCA expertise	Medium	Medium	Employee in environmental department	50	Acceptable
Special/specific products in company with LCA expertise	Medium	Medium	Employee in environmental department	50	Acceptable
Wholesale products in company with limited LCA expertise	Limited	Low	Natural science education	100	Not useful
Special/specific products in company with limited LCA expertise	Limited	Low	Natural science education	100	Not useful
Screening of improvement possibilities in company with limited LCA expertise	Small	Acceptable	Natural science education	50	Not useful

The table is divided into six applications that reflect the different levels where the method is expected to be used. The usefulness and practicability of the method are estimated based on the method description and the experience from the cases.

As shown in the table the method is best suited for use in companies with LCA expertise and an environmental department. For (smaller) companies without LCA expertise and very specific products the method is too complicated.

The method is technically complicated and demands a scientific background, especially general knowledge about LCA.

7.4.3.1 Complicated software tool

The software tool is to complicated to use for designers and constructors. This is a general problem as the tool needs a good and easily understandable surface. However, it is also a specific problem regarding the working environmental assessment that the tool only contains very few useful data.

7.4.4 Data issues

The BST system is well integrated into the working environment activities in many companies. The possibility of using data from BSTs will be a help in obtaining the necessary data.

A strong point of the method is that it includes other data than the available statistics. Especially, it offers the possibility of including data from observations and measurements on the work places.

In the cases this point is regarded as the most difficult for the general user. As the method is now (together with the available software tool), it is difficult to carry out a complete process assessment without the assistance from an LCA expert with a background in chemistry.

Working environmental conditions at the suppliers are regarded to be an important part of any assessment. At present it is, however, in general difficult to obtain the necessary detailed data. Future focus on working environmental data in companies (e.g. by law regulations and work place assessments) could possibly improve this situation.

The problem of involving the safety organisation in the data collection is related to the complexity of the method. In general employees in a safety organisation do not have the necessary LCA knowledge to perform this work.

7.4.5 Summary of the assessment

In **Table 7.9** the above discussion is summarised. The table illustrates how the project group evaluate EDIP's process assessment method. The exact meaning of the topics in the first column are described in section 1.10.

Table 7.9. Fulfilment of general LCA requirements.

Topic	EDIP's process assessment method
Methodical requirements	
Integration with LCA for external environment	✗ ✗ ✗ ✗
Applicability in LC-phases	✗ ✗
Aggregation possible	✗ ✗ ✗
Working environmental aspects	
Coverage of WE'al issues	✗ ✗
Graduation of exposures and effects	✗
Practicability	
Practical in use	✗ ✗
Software tool	✗
Transparency	✗ ✗
Can be used by non-experts	✗
Data issues	
Data reliability	✗ ✗ ✗
Amount of data in existing database	✗
Data accessibility	✗ ✗ ✗
Data can be obtained by WPA	✗

❍ = missing, ✗ = poor, ✗ ✗ = acceptable, ✗ ✗ ✗ = good, ✗ ✗ ✗ ✗ = excellent

7.4.6 Suggestions for improvements

The use of "hazard concept" instead of impact threshold limits when choosing system boundaries and selecting impacts parameters should be considered.

A grading of the impacts should be considered. For instance, after the same principles as when results of working hygienic measurements are assessed over a total work week or as the scoring system in IVF's process assessment method.

To improve the collection of relevant data it should be analysed how the working place assessments can be used in the data collection.

Normalisation and weighting add uncertainty to the method. It should be considered either to preclude weighting and normalisation or alternatively to consider whether more accurate data material could be made available.

It should be considered to make the method more open towards working environmental impacts and effects and then choose system boundaries and select impact parameters later in the assessment.

7.5 References

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