DANISH MINISTRY
OF THE ENVIRONMENT

Environmental
Protection Agency

Update on Impact Categories, Normalisation and Weighting in LCA

- Selected EDIP97-data

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Content

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 2004 and spring 2005. 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.

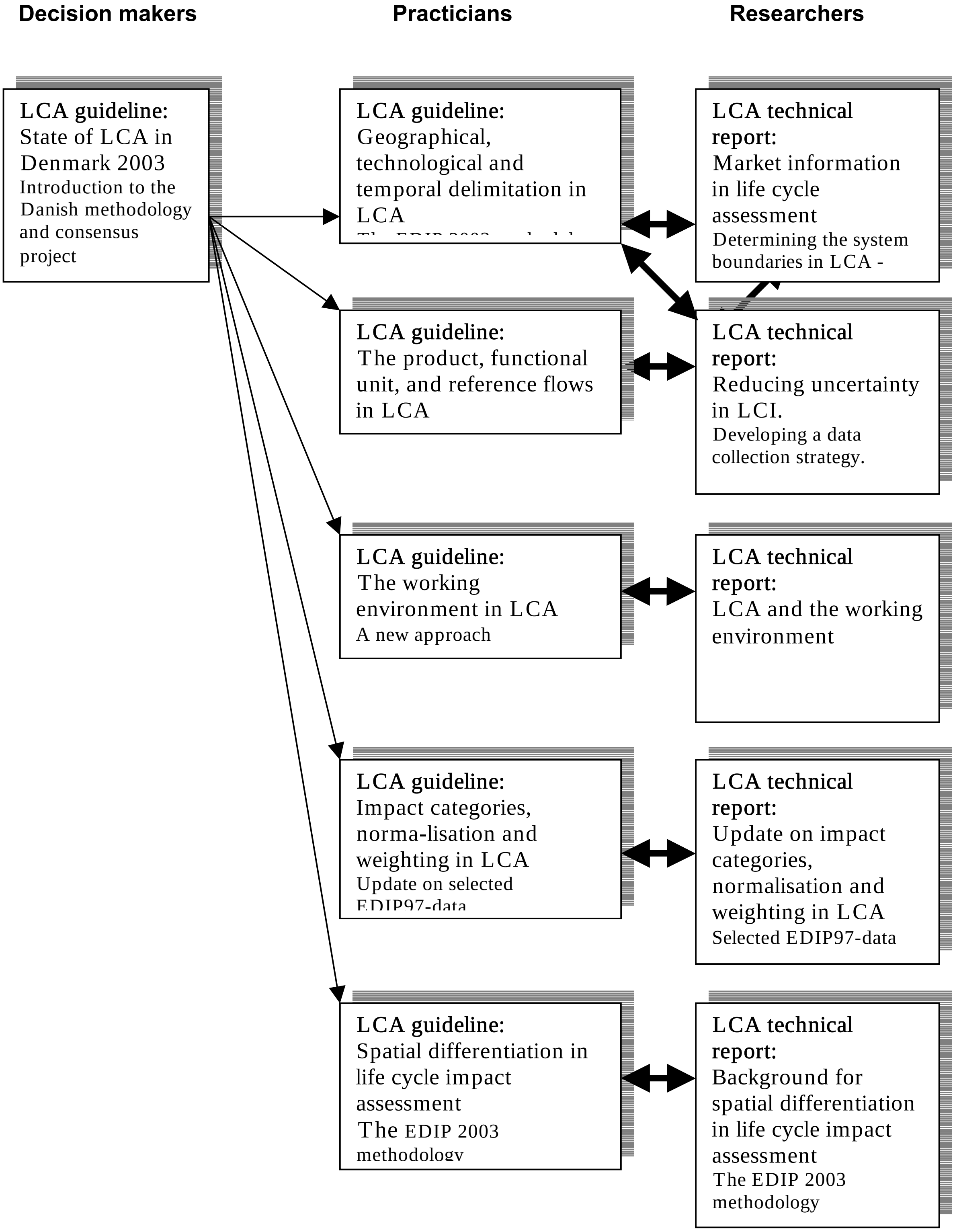
A primary objective of the guidelines has been to provide advice and recommendations on key issues in LCA at a more detailed level than offered by general literature, like the ISO-standards, the EDIP reports, the Nordic LCA project and SETAC publications. The guidelines must be regarded as a supplement 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
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



Authors preface

This technical report is a result of a LCA methodology and consensus-making project focusing on normalisation and weighing. The project has involved a large part of the LCA practitioners and interested parties in Denmark. The technical report documents normalisation references with the reference year 1994 and weighting factors with 2004 as the target year. Along with the technical report a guideline ("LCA Guideline: Impact categories, normalisation and weighting in LCA") has been developed.

The project has been organised as a true consensus-process. First, the project leader in dialogue with the involved consultants and researchers discussed and agreed upon a general data collection process, the idea being to receive consistent data from a wide range of national and international information sources. However, this approach appeared to be less effective than hoped for, and it was therefore decided to proceed in a less uniform way within different impact categories in order to obtain the requested/necessary data and use them in development of normalisation references. The choices made were presented at two workshops, each providing valuable input to the project group as well as securing a consensus among all interested parties.

The following persons have been responsible for the individual chapters:

Chapter 2+3: Heidi K. Stranddorf and Leif Hoffmann, dk-TEKNIK ENERGY & ENVIRONMENT
Chapter 4: Global warming: M.Sc (Chem. Eng) Leif Hoffmann, dk-TEKNIK ENERGY & ENVIRONMENT
Chapter 5: Ozone depletion: M.Sc (Chem. Eng) Leif Hoffmann, dk-TEKNIK ENERGY & ENVIRONMENT
Chapter 6: Photochemical ozone formation: B.Sc (Chem. Eng) Karsten Fuglsang, dk-TEKNIK ENERGY & ENVIRONMENT
Chapter 7: Acidification: M.Sc (Chem. Eng) Leif Hoffmann, dk-TEKNIK ENERGY & ENVIRONMENT
Chapter 8: Nutrient enrichment: Ph.D. (Biology) Jørgen Larsen, Danish Technological Institute
Chapter 9: Ecotoxicity: Ph.D. (Ecotoxicology) Jens Tørsløv, DHI Water and Environment
Chapter 10: Human toxicity: M.Sc (Eng) Frans Møller Christensen, Danish Toxicology Centre & M.Sc (Chem. Eng) Leif Hoffmann, dk-TEKNIK ENERGY & ENVIRONMENT
Chapter 11: Weighting: M.Sc (Eng) Niels Juul Busch, Rambøll

The main part of the data collection and calculations have been performed in the period 1998-2001, with small adjustments and re-calculations being made in 2003. Anders Schmidt, FORCE Technology/dk-TEKNIK ENERGY & ENVIRONMENT was responsible for the final editing of the report in autumn, 2003. A special thank is given to Michael Hauschild, Danish Technical University, for his guidance and reviews of the efforts in the project.

Summary and conclusions

The report addresses a number of elements that all are related to the impact assessment step in the EDIP methodology:

- It gives a short introduction to some of the key elements in EDIP, e.g. the person equivalent, and the normalisation and weighting steps
- It gives a short discussion regarding choice of impact categories in relation to the recommendations in the ISO 14040 standard series, the international consensus regarding the applicability of different methods and the possibilities of performing calculations in the LCV programme that has been made especially in order to make EDIP calculations
- It describes a number of procedures that makes it possible to establish normalisation factors for the EU-15 and the World through extrapolation from relatively limited data sets
- It gives a detailed insight into the data base that has been used in the updating of the existing normalisation and weighting factors and to establish new factors for EU-15 and globally.

Regarding the choice of impact categories the report gives an overview of the categories that have been addressed in central LCA documents and method papers. A number of impact categories and the methods used for their assessment is common to all methods, while methods suggested for assessment of impacts on the local scale like human toxicity, ecotoxicity, noise, land use, etc. show marked differences in their approach. The report does not give a final recommendation whether a specific impact category shall be included in the LCA or whether one or the other approach is better. The recommendation is to include a sufficiently wide range of impact categories to fulfil the goal and scope of the LCA. Omission of impact categories should be a conscious and motivated choice, for which the lack of quantifiability for a given category is not necessarily a valid excuse. There are no requirements in the general LCA concept that all results should be quantified, and qualitative assessments can therefore be used to describe areas and issues that would otherwise be neglected. In some cases it will be relevant to develop and apply new methods in order to assess other impact categories than those traditionally addressed in LCA. This can be very demanding in terms of resources, and the final decision to do so should be determined by the commissioner and the LCA practician.

Another aim of the subproject was to develop new normalisation references for the current 15 member states of the EU (EU-15) and at the Global level – a “World Proxy”. The background for this aim is that in the original EDIP method, normalisation references have only been developed for “Denmark” which can make it difficult to interpret the results of a LCA with a broader geographic scope. With the calculation of additional normalisation references, primarily for the EU-15, the LCA practitioner therefore gets better possibilities to assess the relative importance of different impact categories in an international perspective.

For the EU-15 the new normalisation references for photochemical ozone formation, acidification, nutrient enrichment, human toxicity and ecotoxicity were calculated by using different approaches and information from a broad range of literature sources. For some combinations of impact categories/compounds/activities, e.g. regarding many of the contributions to human toxicity and ecotoxicity, the normalisation references were calculated by extrapolation from selected national inventories as no consistent database was available. The extrapolation was based on the assumption that there is a linear relationship between the economic activity in a given EU-country and its emissions of a given substance or group of substances. Where possible, a cross reference was made with the few available data in order to give an indication of the uncertainty introduced by extrapolation.

The extrapolation approach used for calculation of global normalisation references was to use the relation between the economic activity in a country/region (measured as the Gross Domestic Product, GDP) and the emission of substances contributing to acidification. Both parameters have a well-founded statistical base for many countries and the correlation between them was considered to be adequate for further calculations. Based on the relationship a general extrapolation was developed, simply scaling the European normalisation reference to the global level, the so-called World Proxy.

The report describes the uncertainties associated with the newly developed normalisation references and recommends that the European normalisation references be used in general to calculate the base case scenarios. The recommendations are described in more detail in the Guidelines from the project, but are primarily based on the assumption that most LCA's include impact potentials that are found on a broad geographical scale and therefore should be matched by relevant normalisation factors. A final recommendation, however, is to use Danish normalisations references and the World Proxies in a sensitivity analysis in order to get a better indication of the robustness of the results.

The report gives a detailed insight into the data sources and calculation procedures that have been used in the calculation of each normalisation reference. For each impact category the database is presented in tabular form along with the most important intermediate calculations. This content is probably most interesting for experts in different areas, giving the possibility for other types of calculation, but is of course also a good starting point for future updates.

The last chapter in the report presents new weighting factors for Denmark, EU-15 and the World. This chapter also provides a detailed insight into the basic data, the way the weighting factors have been calculated, and the associated uncertainties. It is emphasized that the Global weighting factors for impact categories on the regional scale can only be calculated with a relatively high uncertainty, and for the impact categories on the local scale it has not been possible to establish reliable weighting factors. In order to make such calculations, information on current emissions as well as reduction targets must be available for each country/region. It was far beyond the scope of the project to collect and manipulate this very large amount of information, and it is therefore recommended to use the weighting factors for EU-15 in the base case calculations. It is, however, mentioned that especially the weighting factors for local impacts tend to be underestimated, compared to those for the regional impacts. The reason for this is that even for the EU-15 is it difficult to establish the full overview of the single member states' reduction targets for emissions of single substances or groups of substances.

It is concluded that the results of the project increases the possibility of making a LCA with a broader perspective than the original EDIP method allows. The broader perspective is, however, achieved at the cost of an increased uncertainty and the recommendations of the report and and the associated Guidelines are therefore focused on the use of sensitivity analysis to the extent relevant to fulfil the goal and scope of the study.

Sammenfatning og konklusioner

Rapporten indeholder en række elementer der alle har relation til vurdering af miljøbelastninger i UMIP-metoden:

- Den giver en kortfattet introduktion til visse nøglebegreber i UMIP såsom personækvivalenter, normalisering og vægtning
- Den indeholder en kortfattet diskussion omkring valg af belastningskategorier, set i relation til anbefalingerne i ISO's standarder om livscyklusvurdering, den internationale konsensus om de enkelte metoders anvendelighed samt mulighederne for at foretage beregninger i et EDB- værktøjet LCV, der er specielt udviklet til at håndtere UMIP-metoden
- Den beskriver en række procedurer, der gør det muligt at udarbejde normaliseringsfaktorer for EU-15 og Verden gennem ekstrapolation fra forholdsvis begrænsede datamængder
- Den giver et detaljeret indblik i det datagrundlag, der er anvendt for at opdatere UMIP's eksisterende vægtningsfaktorer og udarbejde nye vægtningsfaktorer for EU-15 og på globalt plan.

Omkring valg af belastningskategorier giver rapporten en oversigt over de belastningstyper, som er nævnt/behandlet i en række centrale LCA-dokumenter og metodebeskrivelser. Der er naturligvis en del kategorier og metoder, der er fælles for alle metoder, men omkring vurdering af forskellige former for lokale belastninger som human toksicitet, økotoksicitet, brug af arealer, støj m.v. er der foreslået metoder, der har betydelige forskelle. Rapporten tager ikke stilling til, om en bestemt kategori skal medtages i en LCA eller om den ene eller den anden fremgangsmåde er den bedste. Anbefalingen er, at man inkluderer en så bred vifte af belastningstyper, at formålet med LCA'en kan opfyldes. Hvis man udelader visse belastningstyper, skal dette være et bevidst og begrundet valg, hvor manglende kvantificerbarhed ikke uden videre bør accepteres som begrundelse. Der er i det overordnede LCA-koncept ikke krav om kvantificering, og kvalitative vurderinger kan derfor meget vel anvendes til at beskrive vidensmæssige huller. Endelig peger rapporten på, at det i nogle tilfælde kan være relevant at udvikle og anvende metoder til vurdering af andre belastningskategorier end de traditionelle. Her skal man dog være opmærksom på, at dette ofte er tidskrævende/dyrt, men den endelige beslutning om at inkludere en eller flere nye belastningskategorier bør afgøres i samråd mellem opgavestilleren og LCA-praktikeren.

Et andet formål med delprojektet var at udvikle normaliseringsfaktorer for de 15 nuværende EU-lande og – hvor muligt og relevant – også på globalt niveau. I den originale UMIP-metode er der ”kun” udarbejdet normaliseringsreferencer for Danmark, hvilket på nogle områder kan give vanskeligheder med at tolke resultaterne. Ved at udarbejde nye normaliseringsreferencer, først og fremmest for EU-15, får LCA-praktikeren og opgavestilleren bedre muligheder for at vurdere betydningen af de enkelte belastninger i et internationalt perspektiv.

For EU-15 blev de nye normaliseringsreferencer for fotokemisk ozondannelse, forsuring, næringssaltbelastning og human- og økotoksicitet beregnet på forskellige måde ved hjælp af tilgængelige data fra en bred vifte af litteraturkilder. For visse stoffer/aktiviteters bidrag til belastninger som human- og økotoksicitet er der dog ekstrapoleret fra enkeltstående nationale opgørelser, idet der ikke findes et konsistent datagrundlag. Ekstrapolationen er foretaget ud fra den basale antagelse, at der er en lineær sammenhæng mellem et EU-lands økonomiske aktivitet og dets udledninger af et givet stof eller stofgruppe. Hvor muligt, er der i sådanne tilfælde krydsrefereret med de få tilgængelige data for at få en indikation af usikkerheden.

De nye globale normaliseringsreferencer er fremkommet ved at anvende relationen mellem et lands/regions (EU-15) økonomiske aktivitet (målt som bruttonationalproduktet (GDP)) og dets udledninger af stoffer, der bidrager til forsuring. Begge parametre har et relativt velfunderet statistisk grundlag for mange lande og det var muligt at vise en god korrelation mellem dem. Baseret på den viste sammenhæng er der udarbejdet en generel ekstrapolationsmodel, der simpelt skalerer fra den europæiske normaliseringsreference til globalt niveau, en såkaldt Verdensproxy.

Rapporten beskriver de – ofte betydelige – usikkerheder, der er ved de ny normaliseringsreferencer. På trods af usikkerheden anbefaler rapporten dog brug af de europæiske normaliseringsreferencer som udgangspunkt i en vurdering. Anbefalingerne, der er mere detaljeret beskrevet i delprojektets vejledning, begrundes i at de fleste LCA'er inkluderer belastningspotentialer, der finder sted i et bredt udvalg af lande og regioner, og at det derfor er mest relevant at bruge normaliseringsfaktorer, der matcher det geografiske spektrum. Det anbefales dog også at anvende de danske normaliseringsreferencer og Verdensproxyer i en følsomhedsanalyse med henblik på at fastslå, hvor robuste konklusionerne er.

Rapporten giver et detaljeret indblik i de datakilder og procedurer, der er anvendt ved beregning af alle normaliseringsreferencer. For hver enkelt belastningskategori findes talmaterialet i tabelform, inklusive en lang række mellemregninger. Disse kapitler har mest interesse for eksperter, der for eksempel kan bruge tallene til andre typer af beregninger, men de er naturligvis også et godt udgangspunkt for eventuelle opdateringer.

Rapporten afsluttes med et kapitel, hvori der beregnes nye vægtningsfaktorer for Danmark, EU-15 og på globalt plan. Også dette kapitel giver et detaljeret indblik i de grundlæggende data og de usikkerheder, der er forbundet med beregningerne. Globale vægtningsfaktorer for regionale belastningskategorier behæftet med relativ stor usikkerhed, og for de lokale belastningskategorier har det ikke været muligt at beregne en troværdig vægtningsfaktor. Dette kræver i princippet at der findes oplysninger om både de nuværende udledninger og specifikke reduktionsmål for disse for et givet land eller region. En konsistent indsamling og bearbejdning af sådanne informationer ligger langt udenfor rammerne det nærværende projekt, og det anbefales derfor, at man anvender vægtningsfaktorerne for EU-15 som udgangspunkt i sin vurdering, idet disse er beregnet med en acceptabel sikkerhed. Det skal dog bemærkes, at de europæiske vægtningsfaktorer for lokale belastninger med stor sandsynlighed er underestimerede i forhold til faktorerne for regionale belastninger. Årsagen er, at det selv for "nærområdet" EU-15 er vanskeligt at skabe et overblik over de enkelte landes reduktionsmål for udledninger af enkeltstoffer og stofgrupper.

Det konkluderes afslutningsvis, at rapportens resultater giver mulighed for en livscyklusvurdering med et bredere perspektiv end den originale UMIP-metode. Det bredere perspektiv kan imidlertid kun opnås på bekostning af en større usikkerhed, og rapportens og den tilhørende vejlednings anbefalinger fokuserer derfor på, at der bør anvendes følsomhedsanalyser i det omfang, det er muligt og relevant for at leve op til LCA'ens målsætninger.

1 Introduction to the project

This report updates and extends the LCA normalisation and weighing data and methods that are presented in EDIP (Environmental Design of Industrial Products) (Wenzel ***et al.*** 1997; Hauchild & Wenzel 1998) further. Normalisation is a methodology used to compare results (e.g. potential greenhouse effect) to well-known figures and weighting aims to weight or rank different impact categories by using different principles i.e. political goals etc. The fundamental principles in normalisation and weighting are described in details in Wenzel ***et al.*** (1997).

This project has had four goals through a consensus process to:

1) Establish a comprehensive list of impact categories and improve the basis for the LCA practitioners choice of impact categories
2) Provide more options for normalisation and weighting of regional and local impact categories
3) Update the existing normalisation reference for a number of impact categories in EDIP
4) Update the weighting factors in EDIP.

1.1 Background

The background for the project is the international standards as well as the theoretical and practical considerations in Wenzel ***et al***. (1997) and Haucshild and Wenzel (1998). The relevant sections from the relevant standards will shortly be introduced below.

1.1.1 The ISO standards of LCA and LCIA

The ISO 14040 standard “Life Cycle Assessment – Principles and frameworks” presents, as a part of an interactive process, the following steps in a Life Cycle Assessment:

- The Goal and Scope Definition

The goal of an LCA study shall unambiguously state the intended application, the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be communicated (for details see ISO 14041 (ISO 1998)).

- Life Cycle Inventory Analysis (LCI)

The phase of the life cycle inventory analysis involves the compilation and quantification of inputs and outputs, for a given product system throughout its life cycle (for details see ISO 14041 (ISO 1998)).

- Life Cycle Impact Assessment (LCIA)

The phase of life cycle impact assessment is aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system (for details see ISO 14042 (ISO 2000a)).

- Life Cycle Interpretation

The phase of Life Cycle interpretation is where the findings of either the inventory analysis or the impact assessment, or both, are combined consistent with the defined goal and scope in order to reach conclusions and recommendations (for details see ISO 14043 (ISO 2000b)).

The goal and scope definition, the inventory and the interpretation is mandatory while impact assessment is optional.

According to ISO 14042 (ISO 2000a), life cycle impact assessment includes several steps from the Inventory to the Interpretation:

- Life cycle inventory assignment of LCI-results ("classification"), where the impact categories are defined and the exchanges from the inventory are assigned to impact categories according to their ability to contribute to different problem areas.
- Calculation of category indicator results ("characterisation"), where the LCI results are calculated and converted to common units and finally aggregated within each impact category. Together, this results in a numerical indicator result, i.e. the LCIA profile for the product system.
- Normalisation or calculating the magnitude of the category indicator results relative to reference values where the different impact potentials and consumption of resources are expressed on a common scale through relating them to a common reference, in order to facilitate comparisons across impact categories.
- Weighting where weights are assigned to the different impact categories and resources reflecting the relative importance they are assigned in the study in accordance with the goal of the study.
- Interpretation where sensitivity analysis and uncertainty analysis assist interpreting the results of the life cycle assessment according to the goal and scope of the study to reach conclusions and recommendations.

In Life Cycle Impact Assessment, the first three steps; assignment of inventory results to impact categories, the characterisation, and the classification are mandatory, while normalisation, grouping and weighting are optional elements.

1.2 The basis of normalisation and weighting in EDIP-methodology

In EDIP as well as in the ISO standards, the overall advantage of normalisation is an increased possibility of interpretation of indicator results compared to each other. Further, it also provides an option of control by unveiling extreme indicator results. Finally, normalisation is a preparatory element in the optional element of weighting.

The goal of normalisation is to set a common reference enabling comparison of different environmental impacts.

It is an integral part of EDIP that the impacts are summarised for the area, which actually contributes to the current condition of the environment as it is experienced. For the global impacts it makes no difference where the environmental exchanges occur. But for regional and local impacts, only the exchanges occurring within the regions or local areas in question contribute to the current and future condition in the environment there. Due to this reasoning the normalisation and the subsequent weighting should ideally be carried out with normalisation references and weighting factors which, for each individual emission, are representative of the region where the emissions occur. However in the EDIP 1997, the data of the global impacts are available while data for regional impacts, generally, are not available. Instead, EDIP use Danish normalisation references as default values.

In contrast to EDIP 97 it has been chosen to regard human toxicity and ecotoxicity as being primarily regional impacts with the same normalisation reference being applied to all EU-15 countries. It is, however, also possible to use the updated Danish normalisation reference, e.g. in an assessment of specific Danish products or product systems, or as an element in the sensitivity analysis. The same possibility also exists for most of the other EU-15 countries.

Due to lack of data no regional normalisation references for other regions e.g. Central Africa and the Middle East have been developed. For acidification, normalisation references are provided for EU-15 as well as for the individual countries within EU-15. The individual normalisation references can be found in the current report.

This project has provided a large number of normalisation references for EU-15 countries but some additional work still remains to be done before the ultimate goal, i.e. normalisation references for all relevant regions in the World, can be reached.

A different approach has been taken in a parallel project within the LCA methodology and consensus project, site-characterisation (Hauschild & Potting, 2003). The present report does not discuss the pros and cons of either method, but provides only an update of the original EDIP97 method with respect to normalisation and weighting.

1.2.1 The person-equivalent

The global impact will always be much greater than the impact from a particular region, irrespective of the type of effect to which the impact contributes. Use of global impacts as the normalisation reference for the global impact categories and regional impacts for the regional and the local impact categories will thus give an imbalance in the normalisation, and it will result in global impacts from the product system coming to appear much less than the other impacts, because they are compared with the activity of the population of the entire world, while the others are compared only with the activity of e.g. the Danish population.

To correct this bias and ensure that the set of normalising references constitutes a common scale for all impact categories, irrespective of whether they are global or regional, the normalisation references are calculated as the background impact over the course of one year per person in the area for which the impact is computed. This gives the normalisation references the unit “impact potential ***per person*** per year” for each individual impact category.

1.2.2 Establishing of normalisation references

Normalisation references are established for Denmark, Europe (EU-15), and worldwide. For the relevant areas surveys of emissions contributing to the different impact categories have been established. The normalisation references are calculated based on EDIP (Wenzel ***et al***. 1997):

$$\text{Normref} = \frac{\sum_i^n m_i * EF_i}{N} \qquad \left[\frac{\text{impact potential}}{\text{capita}}\right]$$

where: ***mi*** is emitted quantity of substance i
EF$_i$ is the equivalence factor for substance i
N is number of capita in the considered area

i.e. for each of the substances contributing to the impact category, the emitted quantity is multiplied with the equivalence factor for the specific substance giving the potential impact caused by the specific substance. The potential impacts by all the contributing substances are summarised and finally divided with the number of capita in the considered area.

The figures used for normalisation in the EDIP methodology are the potential effects caused per capita in a defined geographical area e.g. potential greenhouse effect per capita per year. 1994 has been chosen as reference year. The actual normalisation references are expressed as kg CO_2-eq./capita/year. The potential environmental impact e.g. greenhouse effect is expressed as person equivalents (PE) i.e. relative to the yearly contribution to the greenhouse effect by one person. In principle, the normalisation methodology allows different impact categories to be compared to each other. The present study develops normalisation references for Denmark, Europe (EU-15) and worldwide.

1.2.3 Weighting

The figures used for weighting in the EDIP methodology are the political reduction goals for the individual substances contributing to the relevant impact category. 2004 has been chosen as the reference year. The actual weighting factors are dimensionless. The weighting factors are linked to the above mentioned normalisation references with regard to the geographical area covered. The present study presents weighting factors for Denmark, Europe (EU-15) and worldwide.

1.2.4 Reference year

In EDIP 1996, 1990 was used as reference year for normalisation, while 1990 and 2000 were chosen as reference years for weighting. In this update, 1994 and 2004 have been chosen as new reference years for normalisation references and weighting factors, respectively. The reason for choosing 1994 as reference year has been easy availability of compilations of data for most of the countries included in the EU-15 normalisation reference. In the recent years the availability of emission data has increased significantly e.g. by access to databases via Internet, and the delay caused by central compilation of data can be expected to be reduced in the future. Therefore, future updating can be expected to be faster with reference years closer to the actual year.

1.3 Guide to the reader

The report is divided in three parts. The first part deals with choice of impact categories and of normalisation reference. The second part is focused on update and expansion of selected impact categories, and the third part is dealing with update on weighting factors.

Part I includes chapter 2 and chapter 3.

Chapter 2 is an overview of five international lists regarding different impact categories. Each impact category is discussed and it is concluded whether the impact category is internationally recognised as well as to which extend characterisation models are agreed upon.

Chapter 3 deals with a global approximation (“world proxies”) of normalisation references. This includes the development of a simple extrapolation model based on emissions of acidifying substances. This allows the calculation of world proxies of the regional impact e.g. photochemical ozone formation and acidification as well as local impact i.e. human toxicity.

Part II includes the update and expansion of impact categories. Each chapter describes shortly the impact category and includes a list of substances contributing to the impact. The methodology used for calculation of the normalisation reference and the calculated normalisation references for the whole world, EU-15 and Denmark are presented in each chapter. For each chapter, one or more appendices elaborates the content, e.g. by describing relevant data sources and providing detailed figures for emissions of substances in a number of countries.

Chapter 4 deals with global warming. Global warming is a global impact category.

Chapter 5 deals with stratospheric ozone depletion. Stratospheric ozone depletion is a global impact category.

Chapter 6 deals with photochemical ozone formation, Photochemical ozone formation is considered primarily as a regional impact category. Normalisation references for EU-15 as well as Denmark are presented. Also a world proxy is presented.

Chapter 7 deals with acidification. Acidification is considered as a regional impact category. A normalisation reference for EU-15 is provided as well as normalisation references for the individual countries within EU-15. A world proxy is presented.

Chapter 8 deals with nutrient enrichment (eutrophication). Nutrient enrichment is considered as a local as well as a regional impact category. Normalisation references for Denmark as well as for EU-15 are provided. A world proxy is presented.

Chapter 9 deals with human toxicity. Human toxicity is a local impact category. The chapter offers a normalisation reference for Denmark together with normalisation references for each of the EU-15 countries as well. A world proxy is also presented.

Chapter 10 deals with ecotoxicity. Ecotoxicity is considered to be a local as well as regional impact category. Normalisation references for Denmark and EU are provided in the chapter. Further, normalisation references for each of the individual EU-15 countries is presented along with a world proxy.

Part III includes chapter 11. It presents weighting factors for the seven impact categories

The actual normalisation references and weighting factors are presented in tables in the summary in each chapter. The description of data collection, data handling, data sources, and data quality is intended for future update of the figures. The actual weighting factors are also presented in a summarising table.

1.4 References

Hauschild, M. & Wenzel, H. 1998, ***Environmental Assessment of Products. Volume 2 - Scientific background***. First edition. Chapman & Hall, London.

ISO 1997, ***Environmental management – Life cycle assessment – Principles and Framework***. ISO 14040.

ISO 1998, ***Environmental management – Life cycle assessment – Goal and scope definition and inventory analysis***. ISO 14041.

ISO 2000a, ***Environmental management – Life cycle assessment – Life cycle impact assessment***. ISO 14042.

ISO 2000b, ***Environmental management – Life cycle assessment – Life cycle interpretation***. ISO 14043.

Wenzel, H., Hauschild, M. & Alting, L. 1997, ***Environmental Assessment of Products. Volume 1 - Methodology, Tools and Case Studies in Product Development***. First edition. Chapman & Hall, London.

2 Selection of impact categories

The purpose of this chapter is first of all to give an overview of impact categories that are defined in different LCA methodology frameworks. The overview is formed by going through the impact categories defined in different LCA methodologies. Each impact category is described briefly and it is stated to which extend the impact category is included in the methodologies. Similarities and differences among the methods are highlighted.

The overview of geographical scaling is presented in a table in which it is indicated if the international consensus also includes the characterisation model.

The chapter also includes an overview regarding recommendations of the selection of impact categories. The overview is based on the same internationally recognised framework as just mentioned. The chapter is concluded by some general recommendations of when to apply which impact categories.

2.1 Comprehensive list of impact categories

During the recent years different national and international working groups have worked with development of characterisation methods to assign input and output data to different impact categories. The research groups have to a large extent used the work of others as a point of reference, and some persons have participated in the work of two or more groups. The methods have been improved/modified continuously e.g. by adaptation to restricted geographical areas or national conditions. As point of reference for the description and discussion of impact categories the present paper will use lists made by five different groups:

- The “Leiden list” (SETAC-Europe 1992)
- The “Nordic list” (Lindfors ***et al***. 1995)
- The SETAC “default list” (Udo de Haes 1996)
- The “EDIP list” (Wenzel ***et al***. 1996)
- The ISO 14047 list (preliminary) (ISO 1999)

The ISO 14047 list is a draft (ISO 1999). It only includes few impact categories. The purpose of ISO 14047 is primarily to illustrate how to work with the ISO 14040 - 14043 standards and it does not deal with which impact categorise that has to be included in LCA.

The lists of impact categories are compiled in Table 2-1.

Table 2-1
Compilation of different lists of impact categories.

List → Impact category ↓	The “Leiden list ” SETAC-Europe (1992)	The “Nordic list” Lindfors *et al.* (1995)	SETAC, “default list” Udo de Haes (1996)	The “EDIP list” (Wenzel *et al.* 1997)	ISO, preliminary list (ISO 1999)
Global warming	Global warming CO_2-eq.	Global warming CO_2-eq.	Global warming CO_2-eq.	Global warming CO_2-eq.	Global warming/ climate change
Depletion of stratospheric ozone	Depletion of stratospheric ozone CFC-11-eq.	Depletion of stratospheric ozone CFC-11-eq.	Depletion of stratospheric ozone CFC-11-eq.	Stratospheric ozone depletion CFC-11-eq.	Stratospheric ozone depletion
Photo-oxidant formation	Photo-oxidant formation C_2H_4-eq.	Photo-oxidant formation C_2H_4-eq.	Photo-oxidant formation C_2H_4-eq.	Photochemical oxidant formation C_2H_4-eq.	Photochemical oxidant formation (smog)
Acidification	Acidification SO_2-eq.	Acidification SO_2-eq.	Acidification SO_2-eq.	Acidification SO_2-eq.	Acidification
Nutrient enrichment - Eutrophication	Eutrophication - PO_4^{3-}eq. - COD (chemical oxygen demand) discharge	Eutrophication - N-emissions to air For aquatic systems: - Aggregation of P to water - Aggregation of N to water - Aggregation of N to water plus N to air - Aggregation of N and P to water and air	Eutrophication BOD (biological oxygen demand) discharge - PO_4^{3-}eq. is suggested	Nutrient enrichment - NO_3^--equivalents - N-equivalents - P-equivalents	Nutrient enrichment
Effects of waste heat on water			included		
Ecotoxicity	Ecotoxicity - aquatic - terrestrial	Ecotoxicological impacts - acute - chronic - wastewater	Ecotoxicological impacts	Ecotoxicity - water, acute - water, chronic - soil - wastewater-plants	Ecotoxicity
Human toxicity	Human toxicity - air, water, soil	Human health, toxicological and non-toxicological	Human toxicological impact	Human toxicity - air, water, soil	Human toxicity
Occupational health and safety	Occupational safety - qualitatively	Human health impacts in work environment		Work environment - carcinogenicity - teratogenicity - allergy - neurotoxicity - hearing impairments - repetitive work - accidents	
Odour	Critical volume approach is suggested	Included in “Habitat alteration...”	Odour		
Noise	Worst case scenario is	Included in “Habitat	Noise		

List → Impact category ↓	The “Leiden list ” SETAC-Europe (1992)	The “Nordic list” Lindfors *et al.* (1995)	SETAC, “default list” Udo de Haes (1996)	The “EDIP list” (Wenzel *et al.* 1997)	ISO, preliminary list (ISO 1999)
	suggested	alteration...”			
Radiation			Radiation		
Waste	Final solid waste (hazardous) Final solid waste (non-hazardous)		Final solid waste	Waste - volume waste - hazardous waste - slags and ashes - radioactive waste	Waste
Resource consumption *- water* *- land use*	Energy and material - renewable and non-renewable Space requirement	Energy and material - scarcity Water Land, including wetland	Depletion of abiotic resources Depletion of biotic resources	Resource consumption - renewable - non-renewable	
Habitat alterations and impacts on biological diversity		Habitat alterations and impacts on biological diversity			

2.2 Impact categories

The considered impact categories will be described briefly below with the impact categories included in the “EDIP”-method for the time being as point of reference (Wenzel ***et al.***, 1997). The description is qualitative and it includes an overview of the inventory input or output data that contribute to the specific impact categories. In the description, emphasis is placed on the geographical scaling as well as impact categories that are included.

Interrelationships between emissions, environmental impacts and their various impacts and their consequences differ from one emitted substance to another. To illustrate to examples; emission of CO_2 and CH_4, is described below.

The potential impact of the emission of CO_2 is global warming which is considered as a global effect. No matter where CO_2 is emitted the potential impact will be the same; global warming. The consequences of global warming can, among others, be; loss of human lives, loss of crops and loss habitats. The potential impact of CH_4 could be global warming as well as photochemical ozone formation. The effects of photochemical ozone formation could be local when smog is formed and it can be regional, when CH_4 is transported, and ozone is formed.

In LCA geographical scaling is divided in

- global effects,
- regional effects,
- local effect,
- working environmental effects.

Global effects and working environmental effects are relatively well defined by name, while regional and local are not very well defined terms. “Local” could be defined as impacts caused by human activity within a radius of 25 km. “Regional” could be defined as impacts cased by human activity outside a radius of 25 km but not effecting globally.

2.2.1 Global warming

Global warming - or the “greenhouse effect” - is the effect of increasing temperature in the lower atmosphere. The lower atmosphere is normally heated by incoming radiation from the outer atmosphere (from the sun). A part of the radiation is normally reflected by the soil surface but the content of carbon dioxide (CO_2) and other “greenhouse” gasses (e.g. methane (CH_4), nitrogen dioxide (NO_2), chlorofluorocarbons etc.) in the atmosphere absorb the IR-radiation. This results in the ***greenhouse effect*** e.g. an increase of temperature in the lower atmosphere to a level above normal. The possible consequences of the greenhouse effect include an increase of the temperature level leading to melting of the polar ice caps, resulting in elevated sea levels. The increasing temperature level may also result in regional climate change. Wherever greenhouse gasses are emitted they contribute to the same effect and thus the impact category is considered to be global.

All five lists include global warming as an impact category. The understanding of global warming in the lists is the same and they are generally referring to the same substances like CO_2, CH_4 and halocarbons as contributors to the impact. N_2O is included in the youngest of the lists. Further, there is also an international agreement about the characterisation model.

The impact category is described in more detail in chapter 4 in part II of this report.

2.2.2 Stratospheric ozone depletion

Decomposition of the stratospheric ozone layer is causing increased incoming UV-radiation that leads to impacts on humans, natural organisms and ecosystems. On humans the impacts can be increased incidence of i.e. skin cancer, cataracts and decreased immune defence. The primary impact on natural organisms and ecosystems is probably a decreased production of plankton in the South Pole region, and this may affect the food chain dramatically. The stratospheric ozone layer occurs at an altitude from 10 - 40 km, with maximum concentration from 15 - 25 km. The maximal generation of stratospheric ozone (O_3) occurs in the top of the stratosphere at the altitude of 40 km as a result of a reaction of molecular oxygen (O_2) and atomic oxygen (O). The reaction depends on the UV-radiation used in the decomposition of oxygen and the availability of other molecules used in the absorption of excess energy from the decomposition process. No matter where the contributing substances are emitted they contribute to the same effect, and the impact category is therefore considered to be global.

All five lists include stratospheric ozone depletion as an impact category. Further, they include the same type of substances as contributors. These are halocarbons (CFCs, HCFCs, halons, etc.). There is also international agreement about the characterisation model. The impact category is described more detailed in chapter 5 in part II of the report.

2.2.3 Photochemical oxidant formation

Photochemical ozone formation is caused by degradation of volatile organic compounds (VOC) in the presence of light and nitrogen oxide (NO_x) (“smog” as a local impact and “tropospheric ozone” as a regional impact). The biological effects of photochemical ozone can be attributed to biochemical effects of reactive ozone compounds. Exposure of plants to ozone may result in damage of the leaf surface, leading to damage of the photosynthetic function, discolouring of the leaves, dieback of leaves and finally the whole plant. Exposure of humans to ozone may result in eye irritation, respiratory problems, and chronic damage of the respiratory system.

UK AEA (United Kingdom Atomic Energy Authority) Environment and Energy Modelling and Assessment Group has been leading in the development of a “Photochemical Trajectory Model” describing the photochemical oxidant formation in the atmosphere. The model involves the following factors:

- degradation route for specific substance including information on intermediates and reactions involved in the degradation
- background level of VOCs
- background level of NO_x
- residence time of specific substance in air

Depending on the actual location for the emission of the considered VOCs scenarios can be set up and a POCP-value can be calculated for the actual case.

All five lists include formation of ozone as an impact category to be considered. Substances mentioned in the lists as contributing to the impact are: Alkanes, halogenated hydrocarbons, alcohols, aldehydes, ketones, esters, olefins, acetylenes, aromatics and other organic compounds. There is international consensus regarding the characterisation model used. The impact category is further described in chapter 6.

2.2.4 Acidification

Acidification is caused by release of protons in the terrestrial or aquatic ecosystems. In the terrestrial ecosystem the effects are seen in softwood forests (e.g. spruce) as inefficient growth and as a final consequence dieback of the forest. These effects are mainly seen in Scandinavia and in the middle and eastern parts of Europe. In the aquatic ecosystem the effects are seen as (clear), acid lakes without any wildlife. These effects are mainly seen in Scandinavia. Buildings, constructions, sculptures and other objects worthy of preservation are also damaged by e.g. acid rain. The substances contributing to acidification can be transported across boundaries via air. Acidification is rarely or not at all seen in North America. The impact category is considered to regional.

All five lists include acidification as an impact category. SO_2 and its potential for acid formation is suggested in all lists as the reference substance. Sulfur oxides, nitrogen oxides, inorganic acids (hydrochloric acid, nitric acid, sulfuric acid, phosphoric acid, hydrofluoric acid, hydrogen sulfide), and ammonia are mentioned as substances contributing to acidification. Inclusion of the impact category as well as the characterisation model is generally agreed upon internationally. The impact category is further described in chapter 7.

2.2.5 Nutrient enrichment

Nutrient enrichment (eutrophication) can be defined as: enrichment of aquatic ecosystems with nutrients leading to increased production of plankton, algae and higher aquatic plants leading to a deterioration of the water quality and a reduction in the value of the utilisation of the aquatic ecosystem.

The primary effect of surplus nitrogen and phosphorus in aquatic ecosystems is growth of algae. The secondary effect is decomposition of dead organic material (e.g. algae) and anthropogenic organic substances. The decomposition of organic material is an oxygen consuming process leading to decreasing oxygen saturation and - sometimes - anaerobic conditions. The anaerobic conditions in the sediment at the bottom of lakes or other inland waters may furthermore result in production of hydrogen sulfide (H_2S) which may lead to "bottom up" incidents and liberation of toxic hydrogen sulfide to the surrounding water.

The effects of nutrient enrichment of terrestrial ecosystem are seen on changes in function and diversity of species in nutrient poor ecosystems as heaths, dune heaths, raised bogs etc. and they are caused by atmospheric deposition of nitrogen compounds. Nutrient enrichment can be considered as a regional as well as local effect.

Nutrient enrichment is mentioned in all five lists. Nitrogen and phosphorous compounds are mentioned as the main origin of nutrient enrichment. However, nutrient enrichment is subject for strong development in connection with LCA. Thus, there are plentiful suggestions on how to measure the potential for nutrient enrichment. The development has moved from measurement of COD, BOD and PO_4^{3-} towards NO_3^-. The impact category is further described in chapter 8.

2.2.6 Effects of waste heat on water

Only one of the lists suggests effects of waste heat on water as a potential impact category. However, discharge of heat defiantly has effect at the local environment. The single suggestion can not be considered as a basis for international consensus. In all cases, the energy consumption will be part of an LCA but the possibility for better growth conditions will generally not be included. The exception is cases where the growth condition of the close surroundings might be included in the goal and scope of an LCA.

2.2.7 Human toxicity

Human toxicity is a large group of different impacts on humans. Human toxicity includes in principle all substances that are toxic to humans. It is included in all lists. The handling differs from one list to another. In different ways they include threshold values. While it can be concluded that there is some sort of international agreement about inclusion of human toxicity it is obvious that the perfect method is still to be developed. Thus it is also still a challenge to develop one - or perhaps more characterisation models. The impact category is further described in chapter 9.

2.2.8 Ecotoxicity

Ecotoxicity includes in principle all substances that are toxic to the environment. Often ecotoxicity is divided in two parts: One for terrestrial and one for aquatic environment. The aquatic often has a subcategory concerning wastewater and sludge thereof. Ecotoxicity is in all cases divided in acute and long-term effects. Depending on the environment, e.g. riverine, sea or terrestrial, the impacts can be regional as well as local.

All five lists include ecotoxicity. The Leiden list suggests a method using maximum acceptable concentration values as the starting point. The Nordic list suggests - by referring to the complexity of the subject - that different approaches are used and that all substances that have an effect on the environment are included in LCA studies. As a minimum requirement the Nordic list suggests that all substances are reported. The SETAC list includes ecotoxicity. In the list it is suggested that both possible effects and doses are included. The SETAC list refers to the EDIP as a good - for the time being - approach of handling of ecotoxicity. The EDIP includes ecotoxicity as an integrated part of the tool. The EDIP is both fate and non-fate based. In principle, all substances with an ecotoxicological potential should be included in the tool. For the time being it is mostly developed with respect to heavy metals and a number of organic substances. Tributyltin oxide, used as an ingredient in antifouling paint, is treated separately.

As for human toxicity, the characterisation models for ecotoxicity is not developed yet. Many institutions work in this area. The impact category is discussed in more details in chapter 10.

2.2.9 Working environment

Working environment or occupational health and safety are in principle impacts on humans (occupants) while being at job. Impacts can be physical and psychological. It may be impacts due to long term exposure or it may - as well - be impacts due to an accident.

Working environment is mentioned in three of the five lists. The Leiden list proposes to include number of victims by accidents. However, the definition of accidents and victims are not elaborated. The Nordic list defines the working environment more broadly and includes both chemically bound impacts and accidents. The Nordic list suggests inclusion of both a qualitative and a quantitative method. The original EDIP method is a mixture of specific assessment of processes and a general assessment on the sector level. In the suggestion for a revised method (Schmidt ***et al***. 2001), only a sector assessment is included. By using the developed database it is possible to create an overview of the working environmental impacts in a relatively quick way, but the method is not recommended for detailed working environmental assessment of specific problems.

2.2.10 Waste

Waste can be defined as co-products without value for the producer. Depending on the nature of the waste - and the local/regional possibilities - the waste can be handled in different ways, e.g. by incineration or landfilling.

The handling of waste differs from one LCA-methodology to the other. Several waste categories have been suggested in the Leiden list, the SETAC default list and EDIP, e.g. solid waste, volume waste, hazardous and non-hazardous waste, slags and ashes and nuclear waste. The Nordic list does not include waste directly, but argues that waste handling is a part of the technical system of the LCA, requiring inputs (e.g. land) and producing output, and therefore the contribution to other impact categories from the waste management processes should be included. A method for this is currently under development in a Danish project.

Until a suitable method for treating the long-term impacts from waste management has been developed, it is suggested to characterise the waste according to the general methodology used.

2.2.11 Land use

One type of impact that relates to waste management as well as other activities is land use. The impact category is not fully operational in LCA-methodology so far, but the main suggestion is that land use is treated by including both the amount of land used for a given activity and the decrease in aesthetic value that is caused by the activity. It is also possible to include land as just one form of abiotic resources, potentially taking the quality of the land into account. Biodiversity can also be an assessment parameter.

Both the Nordic list and the Leiden list include land use as impact categories.

Heijungs (1997) gives an overview of the methods that have been proposed but concludes that none of the proposals are fully satisfying. It is therefore recommended in the present project that land use - if included in a LCA - is treated in a qualitative way.

2.2.12 Resource consumption

The main concern relating to the impact category “Resource consumption” is that use of a given resource leads to a reduced availability of the same resource for future generations.

Resource consumption can be looked upon from different angles. The most common way is to divide resources into a number of sub-categories in order to give a balanced view of the potential impacts, but the approach differs to some extent in the lists. The Leiden list and the Nordic list divides resources into material and energy resources, while the SETAC default list divide resources into biotic and abiotic resources. The Nordic list and the Leiden list also include land as a separate resource. Further, the Nordic list includes water. A common feature of all methodologies developed so far is that they use a scarcity index for the assessment, taking into account the supply adequacy of a given resource.

The methodologies focus on the use of abiotic resources. Biotic (renewable) resources does not receive the same attention, but the problem of a non-sustainable use of e.g. wood from rain forests is acknowledged.

2.2.13 Habitat alterations and impacts on biological diversity

Habitat alterations and impacts on biological diversity is in the Nordic list used to describe a variety of potential impacts. In Lindfors ***et al***. (1995), the heading also covers non-chemical outputs like noise, smell, light, etc with a potential impact that should be considered. Finally, the heading also includes effects of oil spills, introduction of genetically modified organisms and emissions of waste heat to water. However, only a limited number of characterisation methods are assumed to be available.

2.3 Methodological inclusion of impact categories

Based on the five lists above the impact categories have been identified and categorised in groups relating to their geographical scaling and the degree of international consensus that is reached. This is illustrated in **Table 2-2**.

Table 2-2
Characterisation of impact categories.

Impact categories	Geografic scale[1]				International consensus	
	G	R	L	W	Classsification	Characterisation
Global warming	x				yes	yes
Stratospheric ozone depletion	x				yes	yes
Photochemical oxidant formation		x	x		yes	(yes)
Acidification		x	x		yes	(yes)
Nutrient enrichment		x	x		yes	(yes)
Effects of waste heat water			x		no	no
Ecotoxicity		x	x		(yes)	no
Human toxicity		x	x		(yes)	no
Working environment				x	yes	no
Odour			x		yes	no
Noise			x		yes	no
Radiation					yes	no
Resource consumption	x	x	x		yes	(yes)
Land use			x		no	no
Waste			x		(yes)	no
Effects on eco-systems					no	no

G: global, R: regional, L: local, W: work environment.

1. Nielsen PH and Laursen J has recently June 2000 submitted with a substantial input regarding classification and characterisation of noise, integration of external noise nuisance from road and rail transportation in life cycle assessment.

Choices regarding which geographical area to choose for normalisation is dealt with in chapter 3.

2.4 Which impact categories to choose?

LCA is used for many purposes. The commissioner can be authorities, companies, consumer organisations and many other interested parties. The authorities can apply LCA in order to provide environmentally conscious public purchase, community action plans e.g. priority of packaging for beers and soft drinks and for consumer information. Companies can apply LCA in product development, environmental product information and product-oriented environmental policy. (Consumer) Organisations can apply LCA when providing environmental conscious consumption. Thus it is obviously not possible to set up specific guidelines that apply to every purpose of LCA.

2.4.1 Inclusion of different impact categories and standardisation

In the work of standardisation, great efforts have been made in order not to develop different LCA methodologies for different application of LCA; e.g. product development, environmental labelling etc.

Thus, in ISO 14040 (ISO 1997) it is stated that “Definition of the scope of the study include (among others) types of impact and methodology of impact assessment, and subsequent interpretation to be used.” Further it is mentioned in connection to Life Cycle Impact Assessment that “the level of detail, choice of impacts evaluated and methodologies used depends on the goal and scope of the study.”

ISO 14042 (ISO 2000) provides the following guidance regarding selection of impact categories, category indicator and characterisation models (5.3): “For most LCA studies, existing impact categories, category indicators or characterisation models will be selected. Whenever impact categories, category indicators and characterisation models are selected in an LCA study, the related information shall be referenced. …. However, in some cases existing impact categories, category indicators or characterisation models are not sufficient to fulfil the defined goal and scope of the LCA study, and new ones have to be defined. When new impact categories, category indicators or characterisation models are defined, the requirements and recommendations in this subclause also apply”.

The category indicator can be chosen anywhere along the environmental mechanism between the LCI results and the category endpoint(s).

Further, it is stated that “the selection of impact categories, indicators and models shall be consistent with the goal and scope of the LCA study” and “the selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studied taking the goal and scope into consideration”

In addition to these general recommendations it is recommended when impact categories are selected that these are environmentally relevant, internationally accepted and that double counting should be avoided.

The ISO standard does not elaborate on which impact categories should be included in different applications of LCA.

2.4.2 Inclusion of different impact categories and different methodologies

All lists used in the section about forming a maximum list include considerations about which impact categories that should be included in LCA studies. Below the approaches recommended in the lists is presented.

2.4.2.1 The Leiden methodology

The Leiden list or methodology (SETAC-Europe 1992) does not recommend inclusion or exclusion of specific impact categories compared to other impact categories. In the Leiden "methodology" it is recommended to consider a full LCA at first hand. When a full LCA and a detailed process tree is developed it might be possible to exclude parts of a full LCA. This depends, however, of the goal and scope of the study. In the methodology it is recommended not to exclude anything before justification - due to results of an inventory - is provided. The methodology includes a framework for handling a number of impact categories, see Table 2-1. These are only suggestions and are not to be regarded as exhaustive.

2.4.2.2 The Nordic methodology

The Nordic guideline (Lindfors ***et al***. 1995) focus on "key issue identification" and therefore on studies with limited resources available. The consequence of this restriction may be that selection of a full set of impact categories is not possible due to the data requirement. The guideline conclude in general terms that:

"A "key issue identification" type LCA will never quantify all types of potential environmental impacts ….. Some impact categories will be addressed by qualitative assessments and some may even be omitted. The choice of impact categories is a subjective and free choice that depend on the goal of the study and the access to quantitative or qualitative inventory data. There is thus no strict requirement to include all potential impact types in LCA as long as: i) the choice is justified in relation to the goal of the study, ii) omitted impact categories are clearly reported, and iii) conclusions are limited to the studied impacts."

In more detailed terms the guideline presents a number of issues that should be considered when deciding which impact categories to respectively include or exclude. These considerations are i.e. completeness and practicality. Thus, it has to be ensured that all environmental problems of relevance i.e. problems which are generally regarded as major environmental problems and also problems which may be of specific significance for the systems under study, are included. On the other hand it is recommended that inclusion of too many categories should be avoided.

The Nordic methodology includes a list of potential relevant impact categories. However, the list is not claimed to be exhaustive, see Table 2-1.

2.4.2.3 The SETAC methodology of 1996

The main task of the SETAC 1996 document (Udo de Haes 1996) is impact assessment. This means that only little attention is paid to goal and scope definition and its impacts on choice of impact categories. However, it is mentioned that the default list, which is presented in Table 2-1 in this chapter, is non-exhaustive.

2.4.2.4 EDIP method

Selection of impact categories is also discussed briefly in the EDIP method, and in the light of LCA as a holistic approach, all significant resource consumption, environmental impacts and impacts on the working environment must be covered (Wenzel ***et al***., 1998). The procedure for selection of impact categories can be expressed as:

- “Include all resource types, environmental impact categories and categories on the working environment implemented in the EDIP method.
- Consider whether some of the resource consumption and impact categories, which the EDIP method has not implemented, are significant.
- If so, include such resource consumption and impact categories. Describe and assess them quantitatively, and include them in the data on which the decision will be based together with the quantitative assessment of the impact categories implemented in the EDIP method.”

In the EDIP method the procedure for selection of impact categories is followed by a list of impact categories that are ready available; see Table 2-1.

2.4.3 Summary of the advice from the methodologies

The guidance regarding choice of impact categories from all four methodologies are more or less the same, i.e. to include the impact categories that are necessary to provide a robust result. In all of the mentioned methodologies it is stressed that the default lists probably are relevant in most cases. However, the lists are not to be considered as exhaustive and other relevant impact categories can equally well be included. In conclusion, the lists do not give guidelines for when an impact category should be included or can be omitted, other than it should be determined in the goal and scope definition. Furthermore, it is stressed that LCA is an iterative process and the need for inclusion of relevant impact categories may emerge at all times during the process.

The missing guidelines apply to all applications of LCA. It is acknowledged in all lists that LCA is used for many purposes and function, but it has been an important element in the development of LCA-standards that different methods should not be used for different applications.

It is obvious that choosing to omit certain impact categories can be a way to simplify the LCA. Again, no general rules can be given and the most important aspect is that it is done in close collaboration between the practitioner and the commissioner and that the omissions are clearly stated and discussed in the report.

2.5 Consideration regarding choice of impact category

The ISO standards regarding LCA and the default lists recommend that the choice of impact categories are based on thorough considerations.

As demonstrated in Table 2-2 there is a large degree of correlation of suggested impact categories from one list to another. The lists and their underlying methodological approach do not guide the practitioner in the discussion or exclusion of impact categories for different applications of LCA. This is considered to be a never-ending task. The application of LCA is so varying that it is not meaningful to provide guidance in general term on the one hand and on the other hand it is meaningless and perhaps not possible - at least compared to the effort it would take - to prepare guidelines of the choice of impact categories per application, e.g. product comparison, eco-labelling etc.

It is recommended that the proposed impact categories in the different lists should be included in LCA studies unless there are consciously omitted. If they are omitted this should be based on sound and justified arguments. It is not an argument in itself for exclusion that a certain impact category is not quantifiable. However, this might very well in practise be an exclusion factor. If an impact category is not quantifiable it could be included qualitatively. The relevance of this depends in the end of the application of the specific LCA.

2.5.1 PC Tools

The final choice of impact categories is in the end left to the practitioner and the commissioner. In practice, however, the choice is often made along with the choice of PC-tool. Several LCA software tools exist at the market place. Best known in Denmark are undoubtedly SimaPro™, LCA Inventory Tool® and the PC-tool of EDIP (LCV). If the Danish LCV-tool is chosen for an assessment, all the impact categories in EDIP are integrated in the assessment. As the calculation of the impacts is performed automatically, there is no reason to omit some impact categories ***a priori***.

It should be noted in this context that many of the PC-tools deals with the same impact categories, although there are differences in methods for especially the local impacts like human toxicity, ecotoxicity and waste. Most tools will therefore give a broad overview of the potential impacts, but the overview is of course not complete.

Some PC-tools only deals with the inventory analysis in LCA. In order to use this kind of tools, the practitioner has to develop his own way of handling the impact assessment phase, i.e. by establishing classification and characterisation factors and – if needed – also normalisation and weighting factors. This is obviously also resource demanding and lack of time will often cause the number of impact categories to be reduced, compared to the lists described in this project. In this case, the omission of certain impact categories should be thoroughly discussed in the goal and scope definition. The standards do not require that specific impact categories ***must*** be included, and the commissioner, the practitioner and relevant stakeholders can therefore make the final decision on what to include.

2.5.2 Inclusion of “new” impact categories

If “new” impact categories are to be included in an assessment, it may be necessary to perform parallel calculations. This could e.g. be the case if noise or land use is mentioned in the goal and scope definition as relevant impacts and the proposed methods are robust enough to handle the assessment. It is obvious that this is rather demanding in terms of time/resources, and the best solution on the longer term is of course to add the impact categories to the PC-tool.

The development in LCA-methodology is rapid. New or refined methods are being developed for some impact categories, e.g. as a result of the present Danish consensus-project where changes in the EDIP-method regarding acidification, human toxicity and the working environment have been suggested. Also, methods for new impact categories are emerging, e.g. regarding noise and land use, but none of these developments have so far been integrated in a PC-tool. Whether or not to include these impact categories is - like for all other impact categories - primarily an issue between the commissioner and the practitioner. The main criteria for inclusion is of course the relevance of the impact in the given context. A main criteria for exclusion of new or changed impact categories could be that it will be very time consuming (read: costly), and the potential for added value should be related to this in the goal and scope definition.

Some have suggested general welfare parameters like prospect of women's involvement in the labour market, children labours, welfare for animals could as well as the listed in Weidema (1993). These factors could be relevant in some cases. Inclusion of "new" impact categories as well as general welfare parameters is definitely a possibility. If a LCA practitioner choose to do so, he or she should be attentive to the fact that it might cause difficulties when classification and characterisation models are not agreed upon internationally. However, if general welfare parameters are important for a decision-maker the parameter should be included elsewhere in the assessment of the product or service in question.

2.6 References

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3 Development of normalisation references for different geographic areas

In chapter 1, Introduction to the project, the basic ideas and principles in normalisation of impact categories are outlined. One of the basic ideas is that global impacts are normalised globally, regional impacts are normalised regionally and local impacts are normalised locally. In practise, however, it is not possible to obtain relevant data for specific regions all over the world. That is either because it is too big a job to provide them or because they simply do not exist.

In this chapter a method used to predict normalisation factors from one geographical area to another is presented. The specific challenge has been to establish an approximation for a world value ("world proxy") for the following local and regional normalisation factors: acidification, nutrient enrichment (eutrophication), photochemical ozone formation, ecotoxicity and human toxicity. The extrapolation is relevant due to lack of worldwide emission data for the year 1994. The applicability of the outlined method is discussed for the local and regional impact categories.

Global warming and stratospheric ozone depletion are global effects with a large amount of available data that can be used in calculations. Therefore, the normalisation factors are based on available global emission/estimates of consumption of ozone depleting substances and global emission of greenhouse gasses.

A general extrapolation method is described by using normalisation references for acidification covering approximately 40 European countries (section 3.2) due to easy availability of emission data for substances contributing to the impact category (SO_2, NO_x, NH_3). The present data have been used to identify relations between available acidification data and different technical and economical factors. The application of the outlined methodology is based on the assumption that the substances contributing to the other local and regional impact categories shows the same correlation to the tested factors. However, it is quite obvious that not all impact categories can be described equally qualified by the same parameters.

This report provides for specific impact categories relatively good data or estimates for the World, EU and Denmark. However, in many cases it is not known where the actual environmental impact takes place. In these cases, a general proxy for the world might be just as good as the Danish and EU-15 normalisation references. At least such an option could be used as part of sensitivity analysis.

The chapter is concluded with recommendations regarding the choice of normalisation references and with considerations of the advantages and limitations of the results obtained thereby.

3.1 General considerations

Extrapolation from countries/groups of countries to a larger geographic scale (e.g. EU-15/the World) has been discussed in other LCA methodology projects, and the conclusion - like in the present study - is that all extrapolation methods will be based on general assumptions and they are therefore never generally valid. The uncertainty introduced by using extrapolation is generally unknown and can only be verified by worldwide emission data i.e. by comparing results of extrapolation with real data.

It was neither the aim nor practically possible within the economic frames of the project to develop a detailed or complex model for extrapolation. An extrapolation will always be uncertain regardless of the applied methodology and the uncertainty is assumed to increase as the complexity increase. The expectation is that almost all collected data will represent some uncertainty and by adding, multiplying etc. the uncertainty will be multiplied and thereby increased. Therefore the proposed methodology is based on as few factors as possible and the same method is used for all impact categories.

The extrapolation is based on easy available quantitative or qualitative data i.e. data that are available for the whole world in one source if possible (e.g. World Bank reports, United Nations reports, OECD reports, EUROSTAT reports). Examples on available data are:

- GDP - gross domestic[1] product [US dollars]
- GNP - gross national[2] product [US dollars]
- Population
- Sector contribution to GDP (agriculture, industry, services) [%]
- Total energy consumption [million tons of oil equivalent (Mtoe)]
- Energy consumption (coal, oil, gas, nuclear energy, hydro power) [Mtoe]
- Carbon dioxide emissions [million metric tons]
- Energy efficiency [1987[3] $ per kg oil equivalent]
- Energy intensity [total primary energy supply (Mtoe) divided by GDP (in constant prices; 1990 dollars)]

Examples on advantages and disadvantages with the different data are presented in the Table 3-1.

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[1] Gross domestic product (GDP) measures the total output of goods and services for final use occurring within the domestic territory of a given country, regardless of the allocation to domestic and foreign claims.

[2] Gross national product (GNP) measures the total domestic and foreign income claimed by the residents of the economy.

[3] The World Bank statistics use 1987 as baseline in some of their surveys.

Table 3-1
Advantages and disadvantages with different statistical data.

Parameter	Advantages	Disadvantages
GDP (Gross Domestic product) [US dollars]	GDP is available for approx. 200 countries and groups of countries; World Bank/United Nations statistics	GDP depends on financial, industrial and agricultural activity; not all activities included in GDP influence on the emissions
GDP/capita	Same as above	Same as above
GNP (Gross National product) [US dollars]	GNP is available for approx. 200 countries and groups of countries; World Bank/United Nations statistics	GNP depends on financial, industrial and agricultural activity; not all activities included in GDP influence on the emissions
GNP/capita	Same as above	Same as above
Total energy consumption (per capita) [million tons of oil equivalent (Mtoe)/(capita)]	Information on total energy consumption is available in World Bank statistics	Potential emissions depend on distribution on energy sources rather that total energy consumption
Commercial energy use (per capita) in oil equivalents [million tons of oil equivalent (Mtoe)]	Information on commercial energy use available in World Bank statistics	
Energy consumption/distribution on sources [%[	Emissions to air depend on distribution of energy sources	Consumption of specific sources only known for the developed countries (OECD, European)
Energy efficiency [1987 $ per kg oil equivalent]	Information on energy efficiency is available in World Bank statistics	
Energy intensity [total primary energy supply (Mtoe)/GDP]	Emissions to air depend on distribution of energy sources	Information on energy intensity is only known for the developed countries (OECD, European)
Sector contribution to GDP (agriculture, industry, services) [%]	Information on sector contribution to GDP is available in World Bank statistics	
Agricultural activity [qualitative]	Information on agricultural activity is available in World Bank statistics	
Technological level [qualitative]	Information on technological level necessary for estimation of potential emissions	No statistics available; qualitative estimates can be used
Industrial activity [qualitative]	Information on industrial activity can be used in estimation of emissions	Information on industrial activity is only known for the developed countries (OECD, Europe)
Cleaning technology (overall) [qualitative]	Information on cleaning technology can be used in estimation of emissions using knowledge of industrialisation	No quantitative data are available
Cleaning technology (flue gas cleaning) [qualitative]	Information on flue gas cleaning technology necessary for estimation of the total emissions to air	Information on flue gas cleaning is only known for the developed countries (OECD, European)
Wastewater treatment [qualitative]	Information on wastewater treatment technology necessary for estimation of the total emissions to water	Information on wastewater treatment technology is only known for the developed countries (OECD, European)

Of the potential parameters GDP per capita, GNP per capita and energy efficiency have the best coverage, worldwide. These parameters were therefore the first choice in the efforts to establish an extrapolation procedure, while the other parameters were investigated in less detail. The report focuses on GDP and GNP per capita in the discussion while for the other parameters, only the results of the correlation calculations are presented. The possibility of combining several parameters was not tested. It is possible that this may give a better correlation, but this was not investigated.

3.2 General extrapolation method

Acidification depends to a large extend on the emissions of NH_3, NO_x and SO_2; for a detailed description of the impact category see chapter 7, Acidification. According to the CORINAIR 94 summary report (Ritter, 1997) the distribution between the above mentioned substances is 24%, 32% and 44%. The sectors responsible for the acidification in Europe are shown in Table 3-2.

Table 3-2
Distribution of emission acidifying substances from industrial sectors (Ritter, 1997).

Sector	Distribution %
Combustion in energy and transformation processes	34
Agriculture and forestry, land use and wood stock change	23
Road transport	17
Combustion in manufacturing industry	11
Other mobile sources and machinery	6
Non-industrial combustion plants	5
Production processes	3
Waste treatment and disposal	1
Extraction and distribution of fossil fuels/geothermal energy	0.4
Solvent and other product use	~ 0

Mentioned in descending order of importance in relation to acidification, the most important sector is seen to be combustion in energy and transformation processes, agriculture and forestry, land use and wood stock change, road transport and combustion in manufacturing industry. Information on the activity in these sectors is not available in statistical material covering the whole world but the three of the four most important sectors are closely related to industrial and economic activity.

Economical activity and energy consumption are parameters that are often used as a measure for activity in the different sectors. This information is available in UN or World Bank statistics.

The relation between acidification and a number of selected parameters has been tested by linear regression analysis. The parameters tested are:

- GDP/capita [US$/capita]
- GNP/capita [US$/capita]
- fossil fuel/total energy
- energy efficiency (GDP/unit of energy use) [US$ per kg oil equivalent])

Economical activity is measured as “gross domestic product” (GDP) and as “gross national product” (GNP). GDP measures the output of goods and services occurring within the domestic territory of a given country whereas GNP also includes foreign income. GDP is therefore supposed to be the best indicator to describe the activity in the above mentioned industrial sectors in a specific well-defined geographical area.

Figure 3.1 and Figure 3.2 show potential acidification potentials expressed as sulfur dioxide equivalents (i.e. kg SO_2-eq./year/capita) versus GDP/capita for EU-15 respectively Europe including the European part of Asia and Balkan (note: countries with zero values for acidification equivalents or GDP/capita are omitted in the plot and the regression line). Both parameters show very low correlation to acidification. The correlation coefficient R^2 is determined to 0.1767 and 0.0052 respectively. The very low correlation with GDP/capita for Europe may be explained by lack of industrial activity or at least lack of reported activity in some of the middle and low-income countries.

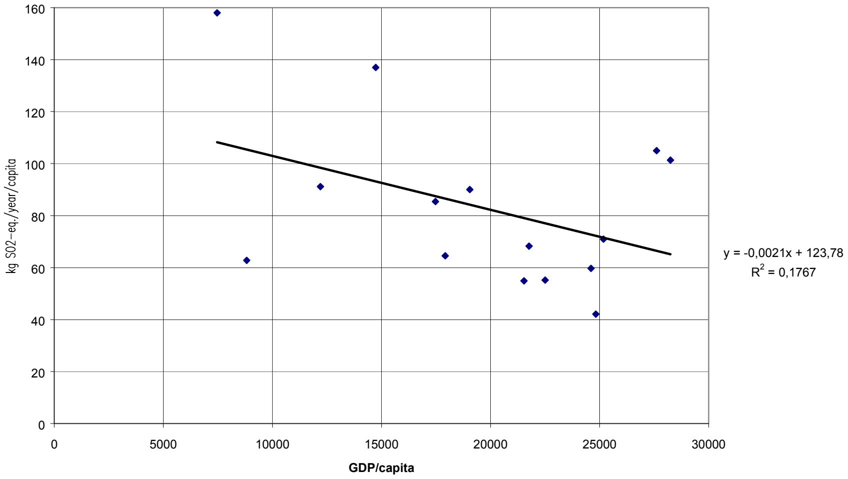

Figure 3.1
Acidification (SO_2-eq./year/capita) vs. GDP/capita (1994) for 15 European countries (EU-15).

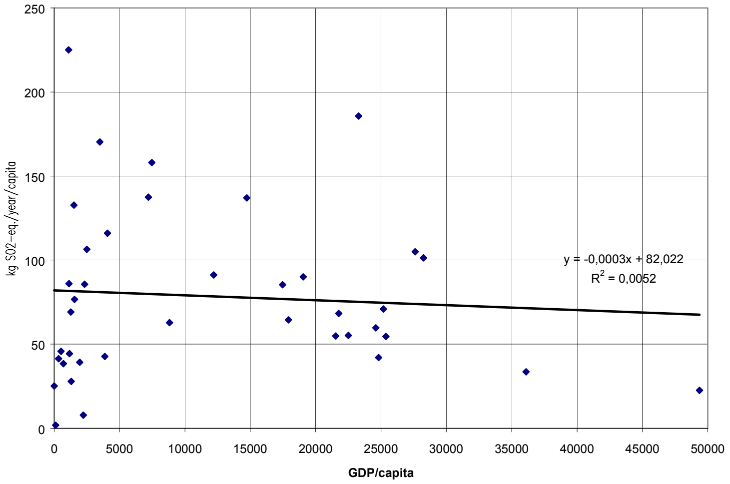

Figure 3.2
Acidification (SO_2-eq./year/capita) vs. GDP/capita (1994) for 38 European countries.

By this method the weighting of the single countries is set equal, i.e. the acidification potentials/capita for Luxembourg or Liechtenstein are equally important as the acidification potential for Germany, regardless that Germany contributes with approximately 20% of the total acidification in EU-15.

An alternative method is to calculate the acidification potential for groups of countries where the grouping is based on income. This method weighs the acidification potential in relation to the population in the group based on income and is described in the following sections.

The World Bank statistical material uses a grouping based on income expressed as ***GNP/capita*** resulting in four groups: ***high income***, ***upper middle income***, ***lower middle income*** and ***low income economies***; see Table 3-3 for a general description of the different income groups.

One argument for using GNP/capita for different income groups is that the level of economy somehow reflects the industrial activity (e.g. the consumption of fossil fuels). Another argument is that the World Bank statistics include average values for a number of other parameters for the same income groups.

Figure 3.3 and Figure 3.4 show the acidification versus GDP/capita/income group and GNP/capita/income group respectively. The European countries are divided into groups according to the grouping made by the World Bank i.e. based on GNP/capita in 1997. Average GDP/capita is also calculated for groups based on the above-mentioned grouping in order to maintain consistency in the grouping. The average GDP/capita for the different groupings is based on GDP for the European countries actually assigned to the different income groups. The grouping is presented in Table 3-3

Table 3-3
Statistical data on income groups based on GNP/capita and GDP/capita (UN 1996; World Bank 1998),

Group	Criteria GNP/capita [$/capita]	Average GNP/capita (1997) [$/capita]	Average GDP/capita (1994) [$/capita]	Countries
High income economies	above 9,656	25,700	20,323	EU-15 + Iceland, Liechtenstein, Norway, Slovenia and Switzerland
Upper middle economies	3,126 - 9,655	4,520	2,588	Croatia, Czech Rep., Estonia, Hungary, Poland, Slovak Rep., Turkey
Lower middle	786 - 3,125	1,230	1,447	Belarus, Bulgaria, FYROM (Macadonia), Latvia, Lithuania, Romania, Russian Fed., Ukraine
Low income economies	below 785	350	711	Albania, Armenia, Bosnia & Herzegovina

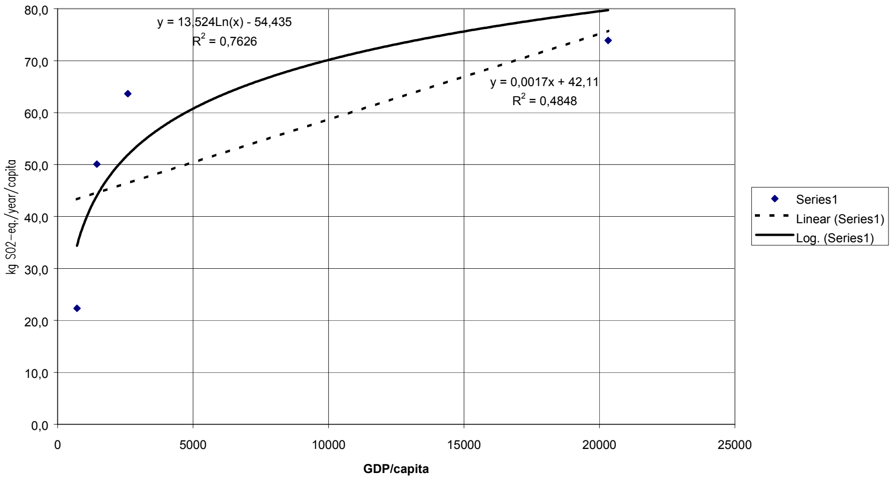

Figure 3.3
Acidification (SO_2-eq./year/capita) vs. GDP/capita for 38 European countries placed in four income groups (high income, upper middle income, lower middle income and low income). The income groups are based on GNP/capita in 1997.

The relation between acidification versus GDP/capita/income group and GNP/capita/income group is tested by regression analysis. The results are presented in Figure 3.4 and **Table 3-4** and show that there is a relatively good correlation between acidification and the logarithmic value for both GNP and GDP per capita when the countries are placed in the four income groups. The best correlation coefficient (R^2=0,9092) is seen for ln(GNP/capita) and a slightly lower coefficient (R^2=0,7626) is seen for ln(GDP/capita). Despite the lower correlation coefficient, the GNP/capita was used in the subsequent calcaulations, the argument being that GNP is a better indicator of (economic) activity in a specific geographic area.

Table 3-4
Correlations between acidification (SO_2-eq./year/capita) and GDP/capita/income group and GNP/capita/income group.

Acidification vs.	Relation	Correlation line	Correlation coefficient (R^2)
GDP/capita	Linear	y = 0.0017x + 42,11	0.4848
	Logarithmic	y = 13.524ln(x) - 54.435	0.7626
GNP/capita	Linear	y = 0.0014x + 41.624	0.5351
	Logarithmic	y = 11.593ln(x) - 38.937	0.9092

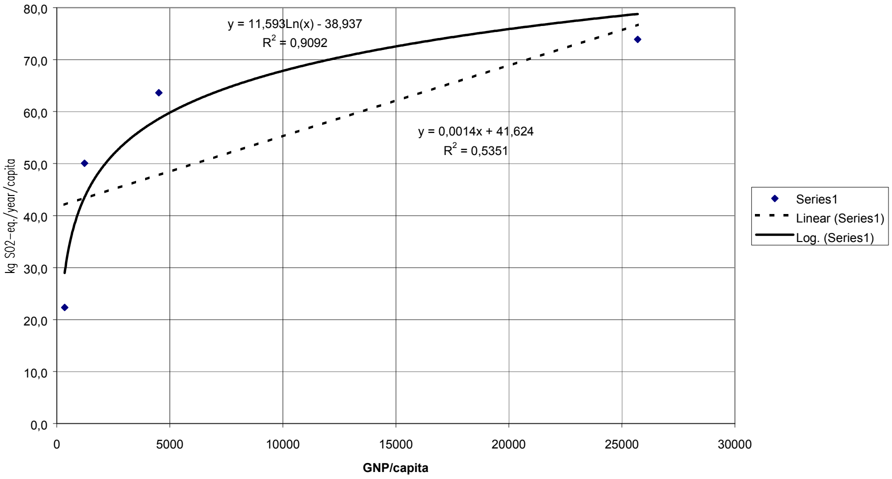

Figure 3.4
Acidification (SO_2-eq./year/capita) vs. GNP/capita (1997) for 38 European countries placed in four income groups (high income, upper middle income, lower middle income and low income).

The methodology using grouping of countries according to their GNP/capita has the disadvantage that the representation of countries in the different groups are unequal. The number of countries is 20, 7, 8 and 3 in the high income, upper middle income, lower middle income and low income countries, respectively. The average GNP/capita (worldwide) and GDP/capita (worldwide) are both slightly above the average in upper middle income countries. These conditions have not been analysed further.

Statistical data regarding consumption of fossil fuels/total energy and energy efficiency were also available in sufficient detail to perform a regression analysis. However, as shown in Table 3-5, the correlation obtained in this way was not as good when using either GNP or GDP/capita.

Table 3-5
Overview of relations between acidification and selected parameters.

	Geographical area	Correlation	Corr. coef. R^2	Comments
GDP/capita	EU-15	negative	0.1767	Figure 3.1
GDP/capita	EU-15 + 23	negative	0.0052	Figure 3.2
GDP/capita ln(GDP/capita)	38; income groups[1]	positive, linear positive, logarithmic	0.4848 0.7626	Figure 3.3
GNP/capita[2] ln(GNP/capita)	38; income groups[1]	positive, linear positive, logarithmic	0.5351 0.9092	Figure 3.4
Fossil/total energy	EU-15	positive	0.1895	Not presented
Energy efficiency	EU-13[3]	negative	0.1029	Not presented
Energy efficiency	EU-13 + 6	negative	0.4574	Not presented

1. For definition of income groups se World Bank statistics
2. GNP data for 1997.
3. EU-15 except Germany and Luxembourg.

Based on the calculations outlined in the previous sections it was determined to use GDP per capita, divided into four income groups, for the extrapolation calculations. In order to estimate the difference between use of GNP and GDP, the normalisation reference based on both papameters was calculated.

Based on world population and average income in GDP/capita[4] at 4,515 US$/capita the world normalisation reference for acidification can be calculated to:

59 kg SO_2-eq./year/capita

Based on average GNP/capita at 5,130 US$/capita (1997) (World Bank, 1998) for the world the similar value can be calculated to:

60 kg SO_2-eq./year/capita

Both methods results in a world normalisation factor at approximately 60 kg SO_2-eq./year/capita but despite a lower correlation coefficient, the method using GDP/capita is preferred as GDP is more related to a specific geographical area than GNP.

The presented method result in the normalisation factors for the different areas and the world as shown in Table 3-6.

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[4] The total GDP is calculated to 25.284 × 10^{12} $ (UN, 1996) and a midyear world population at 5,609,678,819 in 1994 (USBC, 1996). The average GDP/capita equals to *4,515 US$/capita*.

Table 3-6
Summary of the calculated normalisation factors areas.

Geographical area[1]	Average income GDP/capita	Acidification potential kg SO_2-eq./year/capita	Notes
Denmark	28,245	101[4]	Calculated; see section 7.5.1
EU-15	19,992	74[5]	Calculated as weighted average; see section 7.5.1.1
High income economies	20,323	74	Weighted average; 20 countries
Upper middle income economies	2,588	64	Weighted average; 7 countries
Lower middle income economies	1,447	50	Weighted average; 8 countries
Low income economies	711	22	Weighted average; 3 countries
World	4,515[2] 5,130[3]	59 60	GDP/capita, logarithmic GNP/capita, logarithmic

1. See Table 3-3 for description of the countries representing the income groups.
2. GDP/capita.
3. GNP/capita.
4. Based on the equation shown in Table 3-4 the normalisation reference for Denmark can be calculated to 84 kg SO_2-eq./year/capita.
5. Based on the equation shown in Table 3-4 the normalisation reference for EU-15 can be calculated to 79 kg SO_2-eq./year/capita.

3.2.1 Proposed method and assumptions

Based on the results of the acidification scenario a general extrapolation methodology is outlined based on the following assumptions:

- GDP/capita is the best indicator for for economic activity in relation to acidification as this value is based on the activities within a specific area of consideration
- There is a linear relationship between normalisation factor and ln(GDP/capita)
- The normalisation factor is zero when the average income expressed as GDP/capita is zero
- The relation between normalisation factor for EU-15 and the world is the same for the local and regional impact categories
- The relation of GDP/capita and acidification is supposed to be the same in other regions than Europe.

Based on the assumption that the relation between the normalisation reference for acidification for EU-15 and the world is the same as the relation for other local and regional impact categories, the relationship between the normalisation reference for acidification and for other local or regional normalisation references can be expressed mathematically as follows:

$$\text{Norm. ref.}_{\text{Impact cat., World}} = \frac{\text{Norm. ref.}_{\text{Acid. World}}}{\text{Norm. ref.}_{\text{Acid, EU-15}}} \times \text{Norm. ref.}_{\text{Impact cat. EU-15}}$$

where $\boldsymbol{Norm.ref}_{\boldsymbol{Impact.cat.,world}}$ is the worldwide normalisation reference for a local or regional impact category
$\boldsymbol{Norm.ref}_{\boldsymbol{Acid.,world}}$ is the worldwide normalisation reference for acidification

$\boldsymbol{Norm.ref_{Impact.cat.,EU-15}}$ is the EU-15 normalisation reference for a local or regional impact category
$\boldsymbol{Norm.ref_{Acid,EU-15}}$ is the EU-15 normalisation reference for acidification

and if $\mathrm{Norm.ref_{Acid,EU-15}}$ = 74 kg SO_2-eq./year/capita and $\mathrm{Norm.ref_{Acid,World}}$ = 59 kg SO_2-eq./year/capita then the worldwide normalisation references for local and regional impact categories can be expressed as:

$$\mathrm{Norm.\,ref}_{\mathrm{Impact\ cat.,\ World}} = \frac{59}{74} \times \mathrm{Norm.\,ref.}_{\mathrm{Impact\ cat.\ EU\text{-}15}}$$

The proposed extrapolation methodology can be expressed as:

$$\mathrm{Norm.\,ref.}_{\mathrm{Impact\ cat.,\ World}} = \mathrm{Extrapolation\ fact.} \times \mathrm{Norm.\,ref.}_{\mathrm{Impact\ cat.\ EU\text{-}15}}$$

$$\mathrm{Norm.\,ref.}_{\mathrm{Impact\ cat.,\ World}} = 0{,}8 \times \mathrm{Norm.\,ref.}_{\mathrm{Impact\ cat.\ EU\text{-}15}}$$

3.3 Extrapolation applied to different impact categories

This section describes advantages and disadvantages of the presented extrapolation method in relation to the effect categories photochemical ozone formation, nutrient enrichment, ecotoxicity and human toxicity.

3.3.1 Photochemical ozone formation

The substances contributing to photochemical ozone formation (anthropogenic emissions of NMVOC, methane and CO) have been compiled worldwide and reported in the EDGAR database. The collection, processing and publishing of 1994 data are not available and therefore only data for 1990 were used in calculating of normalisation factors. Anyway, the worldwide emission data for 1990 were expected to give a more reliable result than using the extrapolation at the European data for 1994. The worldwide normalisation factor based on 1990 data has been calculated to:

22 kg C_2H_2/capita/year

This value can be compared with the normalisation factor calculated by extrapolation, which is 20 kg C_2H_2/capita/year. Thus, for this impact category, there seem to be a good correlation between the calculated value and the value derived by the extrapolation methodology.

3.3.2 Nutrient enrichment

The worldwide normalisation factor for nutrient enrichment has been calculated by using the presented extrapolation methodology. Nutrient enrichment differs from a number of the other effect categories as wastewater treatment, agricultural areas, agricultural praxis etc. influence the emission of substances contributing to nutrient enrichment. These conditions are not reflected in the GDP/capita and therefore a systematic error may be introduced by using the presented extrapolation methodology. The worldwide normalisation reference for nutrient enrichment has been calculated to:

19 kg N-equivalents/capita/year
0.3 kg P-equivalents/capita/year

or aggregated as

95 NO_3^- - equivalents/capita/year.

3.3.3 Human toxicity

The proposed extrapolation method is very uncertain for the human toxicity impact category. The emission of toxic substances will be highly influenced by a large number of factors, which are not or poorly reflected in the GDP. For instance, it is not uncommon, that 'heavy' and very polluting production facilities are placed in low income (low GDP) regions and the facilities are usually equipped with less pollution abatement devices compared to facilities in high-income countries. Further, the fuel types used for traffic and energy production may differ substantially (for instance in heavy metal content) as may the need for transportation and energy production. Altogether, GDP is a very rough extrapolation parameter, which ideally should be supplemented with a number of infrastructure parameters. The worldwide normalisation reference for human toxicity has been calculated to:

$2.45 * 10^9$ m^3 air/capita/year (exposure via air)
$4.18 * 10^4$ m^3 water/capita/year (exposure via water)
$1.02 * 10^2$ m^3 soil/capita/year (exposure via soil)

3.3.4 Ecotoxicity

The proposed extrapolation method is very uncertain for the ecotoxicity impact category. The emission of ecotoxic substances will be highly influenced by a large number of factors, which are not or poorly reflected in the GDP. For instance, it is not uncommon, that 'heavy' and very polluting production facilities are placed in low income (low GDP) regions and the facilities are usually equipped with less pollution abatement devices compared to facilities in high-income countries. Altogether, GDP is a very rough extrapolation parameter, which ideally should be supplied with a number of infrastructure parameters. The worldwide normalisation reference for ecotoxicity has been calculated to:

$2.82 * 10^5$ m^3/capita/year (etwc; chronic ecotoxicity via water)
$2.33 * 10^4$ m^3/capita/year (etwa; acute ecotoxicity via water)
$7.71 * 10^5$ m^3/capita/year (etsc; chronic ecotoxicity via soil)

3.3.5 Uncertainties

The uncertainties have not been quantified for the worldwide normalisation reference for the individual impact categories but are expected to be considerable. There are several reasons for this.

The extrapolation methodology has been developed for an impact category depending on three emissions (SO_2, NO_x and NH_3), all of which are determined with a relatively high degree of precision. For the other impact categories, the information regarding actual emissions in the primary area, e.g.

Denmark, are not of the same quality, and this introduces a general uncertainty. For the impact categories human toxicity and ecotoxicity, the number of substances potentially contributing to the impacts is very high and the actual emissions are only known in very little detail.

At the same time, it is very difficult to relate the emissions to specific economic activities. It is therefore an open question to what extent the GNP and GDP actually can be used reflect environmental impacts and – accordingly – as an extrapolation parameter.

The use of both calculated and extrapolated normalisation references should therefore be performed with great caution. As a minimum it should be investigated whether use of other normalisation references changes the overall conclusions of a LCA, e.g. by integrating these calculations in the sensitivity analysis.

3.4 Recommendations on selection of normalisation references

The strategy so far has been to normalise global impacts globally as well as regional and local impacts regionally, based on Danish conditions. In the present project, new normalisation references have been developed for global, regional and local effects. For global warming and stratospheric ozone depletion global normalisation references have been calculated. For photochemical ozone formation, acidification, nutrient enrichment, human toxicity and ecotoxicity Danish and European (EU-15) normalisation references have been calculated and worldwide normalisation references have been extrapolated.

The intentions with updating and extension of the normalisation references are that:

- Global effects are (still) normalised globally based on global figures
- Regional effect are normalised regionally based on reliable European figures
- Worldwide normalisation references are available for the local and regional effects if found appropriate; the worldwide normalisation references are based on extrapolation

Furthermore, the new set of normalisation references allows the user to choose a normalisation reference adjusted to a specific purpose. These new possibilities give occasion for choosing the main question being when and how to apply specific normalisation references.

3.4.1 When and how to apply specific normalisation

For use of the updated EDIP97 normalisation references, the following recommendations are given for normalisation of the LCA results:

- For global impacts (global warming and stratospheric ozone depletion) always use the worldwide normalisation reference in the base case analyses
    - EU-15 or Danish normalisation references can be used in a sensitivity analyses to mirror the relative importance in highly

    developed industrial countries with a large contribution per capita

- For regional impacts (acidification, photochemical ozone formation and nutrient enrichment) and local impacts (ecotoxicity, human toxicity) use the EU-15 normalisation reference as the base reference
    - If the main impacts are known to take place in a given region, for which a more appropriate normalisation reference is available, this may be used, clearly reporting this deviation from the general recommendation. As an example, for energy consuming devices used in Denmark, the main impacts can be assumed (or verified) to arise in Denmark and accordingly, the applied normalisation reference for the energy-related impact categories could equally well be Denmark. For energy consuming products produced in Denmark and used (primarily) outside of Europe, the worldwide normalisation references could be applied. It should however be noted that the European reference probably gives the most precise results if the area of use predominantly is industrialised countries and this is therefore also an option.

- Where relevant, use normalisation references for other geographical regions as an element in the sensitivity analyses, acknowledging the inherent uncertainties. The case used in the report is an example of this, where the generally recommended normalisation reference for EU-15 could be supplemented with the Danish normalisation references in a sensitivity analysis. This is especially beneficial in relation to nutrient enrichment, human toxicity and ecotoxicity, all of which impacts have a local as well as a regional element.

The recommendations above reflect the inherent uncertainties and lack of knowledge in normalisation, especially if the step has a broad scope. Obviously, the more is known about the product (system) investigated as regards the geographical extent of its potential impacts, the more precisely the normalisation step will mirror the relative importance of different impacts.

The recommendations are a modification of earlier recommendations for EDIP97, where Danish normalisation references were recommended for regional and local impacts. The suggested shift to the EU normalisation reference is justified by the better scope for many industrial products, well knowing that the absolute precision for specific products decreases in doing so.

3.5 References

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UN 1996, ***Statistical Yearbook 1994***. Data available as of 31 March 1996. Forty-first issue. United Nations, Department for Economic and Social Information and Policy Analysis Statistics Division. New York.

World Bank 1998, ***World development indicators 1998***. (Available at http://www.worldbank.org.)

Appendix A: Data sources

Databases (paper)

UN 1996, ***Statistical Yearbook 1994***. Data available as of 31 March 1996. Forty-first issue. United Nations, Department for Economic and Social Information and Policy Analysis Statistics Division. New York.

Databases (electronic)

OECD

World Bank
World Development Indicators 1998 (available at CD-rom; extracts are available at http://www.worldbank.org)

Organisations

- Organisation for Economic Co-operation and Development (OECD)
  75775 Paris Cedex 16
  FRANCE
  http://www.oecd.org
- United Nations Office of Geneva
  http://www.unog.ch
  United Nations
  New York
  U.S.A.
  http://www.un.org
- World Bank Group
  The World Bank
  Washington, DC 20433
  U.S.A.
  Phone: [1] 202 477-1234
  http://www.worldbank.org
- EUROSTAT

4 Global warming

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4.1 Summary

This chapter summarises the presently available data of 1994 on worldwide consumption/emission of substances contribution to global warming. Global warming is a global effect. The substances or emissions included are:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxides (N_2O)
- CFCs (CFC-11, -12, -113, -114, -115)
- HCFCs (HCFC-22, -123, -124, -141b, -142b)
- HFCs (HFC-125, -134a, -152a)
- Halons
- Tetrachloromethane (CCl_4)
- 1,1,1-Trichloroethane (CCl_3CH_3)
- Carbon monoxide (CO)

The CFCs, HCFCs, HFCs, tetrachloromethane, and 1,1,1-trichloromethane are also considered as ozone depleting substances and their contribution to the stratospheric ozone depletion is described in chapter 5, Stratospheric ozone depletion. Consumption data/emission data are generally available worldwide as the substances are regulated according to the ***Kyoto Protocol*** and the ***Montreal Protocol***. The normalisation reference for global warming has been calculated to:

8.7 ton CO_2-eq./capita/year

Carbon dioxide (CO_2) and methane (CH_4) are accounting for more than 80% of the effect potential contributing to the normalisation reference for global warming. The normalisation reference is relatively certain as almost complete data are easy available due to the regulation of consumption/emission according to the ***Kyoto Protocol*** and the ***Montreal Protocol***. The ozone depleting substances are measured as consumption whereas the other greenhouse gasses are measured as emissions.

4.2 Description of the impact category

Global warming is considered as a global effect. Global warming - or the “greenhouse effect” - is the effect of increasing temperature in the lower atmosphere. The lower atmosphere is normally heated by incoming radiation from the outer atmosphere (from the sun). A part of the radiation is normally reflected from the surface of the earth (land or oceans). The content of carbon dioxide (CO_2) and other “greenhouse” gasses (e.g. methane (CH_4), nitrogen dioxide (NO_2), chlorofluorocarbons etc.) in the atmosphere reflect the infrared (IR)-radiation, resulting in the ***greenhouse effect*** i.e. an increase of temperature in the lower atmosphere to a level above normal. The energy balance is illustrated in Figure 4.1.

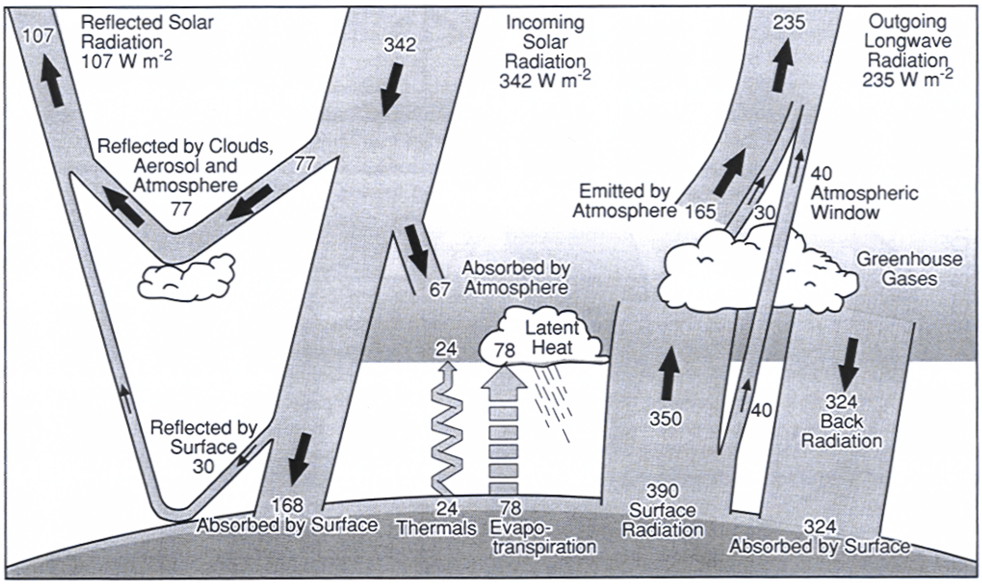

Figure 4.1
Global warming - energy balance (Trenberth et al. 1996).

The possible consequences of the greenhouse effect include an increase of the temperature level leading to increased temparatures in the oceans and melting of the polar ice caps and glaciers in mountain areas, resulting in elevated sea levels. The increasing temperature level may also result in regional climate changes.

See also Hauschild and Wenzel (1998) for further description of the impact category.

4.3 Substances contributing to the impact category

The substances contributing to global warming are defined as substances which at normal temperature and pressure are gases and:

- absorb infrared radiation or are degraded to CO_2
- have an atmospheric lifetime sufficient to allow a significant contribution to global warming

The substances considered as primary contributors to global warming are:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxides (N_2O)
- CFCs (CFC-11, -12, -113, -114, -115)
- HCFCs (HCFC-22, -123, -124, -141b, -142b)
- HFCs (HFC-125, -134a, -152a)
- Halons
- Tetrachloromethane (CCl_4)
- 1,1,1-Trichloroethane (CCl_3CH_3)
- Carbon monoxide (CO)

For CO_2 it is a special requirement that the emission must represent a net contribution, i.e. it must increase the content of CO_2 in the atmosphere beyond that would be observed if the emission did not take place. Examples of this are burning of fossil fuels and changes in land use, e.g. as a cause of deforestation. Use of biomass (wood, straw, etc.) for energy production does not give a net contribution, because it can be assumed that the materials would degrade under all circumstances.

The CFCs, HCFCs, HFCs, tetrachloromethane, and 1,1,1-trichloromethane are also considered as ozone depleting substances and their contribution to the stratospheric ozone depletion is described in chapter 5, Stratospheric ozone depletion. GWPs are normally based on ***modelling*** and are quantified for time horizons of 20, 100 or 500 years for a number of known greenhouse gasses (e.g. CO_2, CH_4, N_2O, CFCs, HCFCs, HFCs and several halogenated hydrocarbons etc.). The modelling is done by a working group under the Intergovernmental Panel on Climate Change (IPCC) and is described in a number of reports from IPCC e.g. Houghton ***et al***. (1996) and recently by Albritton and Meira Filho (2001). The emission of greenhouse gasses are regulated by the ***Kyoto Protocol*** (UN 1997) under the ***Climate Convention*** (UN 1992).

The equivalency factors for the greenhouse gasses are expressed relatively to the effect of carbon dioxide i.e. as CO_2-equivalents. The equivalency factors are compiled in Table 4-1. Please note that not all greenhouse gasses mentioned in Table 4-1 are included in the calculation of the normalisation reference due to lack of knowledge about the consumption or emissions; see Appendix B for details about the included substances. This may cause the normalisation reference to be underestimated by a few percent.

Table 4-1
Characterisation factors for global warming (in g CO_2-equivalents/g). Taken from Albritton and Meira Filho, 2001.

Gas		Lifetime (years)	Global Warming Potential Time horizon		
			20 years	100 years	500 years
Carbon dioxide	CO_2		1	1	1
Methane	CH_4	12.0	62	23	7
Nitrous oxide	N_2O	114	275	296	156
Carbon monoxide	CO	Months	2*	2*	2*
Hydrocarbons (NMHC) of fossil origin	C_xH_y	Days-months	3*	3*	3*
Partly oxidised hydrocarbons of fossil origin	$C_xH_yO_z$	Days-months	2*	2*	2*
Partly halogenated hydrocarbons of fossil origin (not listed below)	$C_xH_yX_z$	Days-months	1*	1*	1*
Chlorofluorocarbons					
CFC-11	CCl_3F	45	6300	4600	1600
CFC-12	CCl_2F_2	100	10200	10600	5200
CFC-13	$CClF_3$	640	10000	14000	16300
CFC-113	CCl_2FCClF_2	85	6100	6000	2700
CFC-114	$CClF_2CClF_2$	300	7500	9800	8700
CFC-115	CF_3CClF_2	1700	4900	7200	9900
Hydrochlorofluorocarbons					
HCFC-21	$CHCl_2F$	2.0	700	210	65
HCFC-22	$CHClF_2$	11.9	4800	1700	540
HCFC-123	CF_3CHCl_2	1.4	390	120	36
HCFC-124	CF_3CHClF	6.1	2000	620	190

Gas		Lifetime (years)	Global Warming Potential Time horizon		
			20 years	100 years	500 years
HCFC-141b	CH_3CCl_2F	9.3	2100	700	220
HCFC-142b	CH_3CClF_2	19	5200	2400	740
HCFC-225ca	$CF_3CF_2CHCl_2$	2.1	590	180	55
HCFC-225cb	$CClF_2CF_2CHClF$	6.2	2000	620	190
Hydrofluorocarbons					
HFC-23	CHF_3	260	9400	12000	10000
HFC-32	CH_2F_2	5.0	1800	550	170
HFC-41	CH_3F	2.6	330	97	30
HFC-125	CHF_2CF_3	29	5900	3400	1100
HFC-134	CHF_2CHF_2	9.6	3200	1100	330
HFC-134a	CH_2FCF_3	13.8	3300	1300	400
HFC-143	CHF_2CH_2F	3.4	1100	330	100
HFC-143a	CF_3CH_3	52	5500	4300	1600
HFC-152	CH_2FCH_2F	0.5	140	43	13
HFC-152a	CH_3CHF_2	1.4	410	120	37
HFC-161	CH_3CH_2F	0.3	40	12	4
HFC-227ea	CF_3CHFCF_3	33.0	5600	3500	1100
HFC-236cb	$CH_2FCF_2CF_3$	13.2	3300	1300	390
HFC-236ea	CHF_2CHFCF_3	10.0	3600	1200	390
HFC-236fa	$CF_3CH_2CF_3$	220	7500	9400	7100
HFC-245ca	$CH_2FCF_2CHF_2$	5.9	2100	640	200
HFC-245fa	$CHF_2CH_2CF_3$	7.2	3000	950	300
HFC-365mfc	$CF_3CH_2CF_2CH_3$	9.9	2600	890	280
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	15	3700	1500	470
Chlorocarbons					
CH_3CCl_3		4.8	450	140	42
CCl_4		35	2700	1800	580
$CHCl_3$		0.51	100	30	9
CH_3Cl		1.3	55	16	5
CH_2Cl_2		0.46	35	10	3
Bromocarbons					
CH_3Br		0.7	16	5	1
CH_2Br_2		0.41	5	1	<<1
$CHBrF_2$		7.0	1500	470	150
Halon-1211	$CBrClF_2$	11	3600	1300	390
Halon-1301	$CBrF_3$	65	7900	6900	2700
Iodocarbons					
CF_3I		0.005	1	1	<<1
Fully fluorinated species					
SF_6		3200	15100	22200	32400
CF_4		50000	3900	5700	8900
C_2F_6		10000	8000	11900	18000
C_3F_8		2600	5900	8600	12400
C_4F_{10}		2600	5900	8600	12400
$c\text{-}C_4F_8$		3200	6800	10000	14500
C_5F_{12}		4100	6000	8900	13200
C_6F_{14}		3200	6100	9000	13200
Ethers and Halogenated Ethers					
CH_3OCH_3		0.015	1	1	<<1
$(CF_3)_2CFOCH_3$		3.4	1100	330	100
$(CF_3)CH_2OH$		0.5	190	57	18
$CF_3CF_2CH_2OH$		0.4	140	40	13
$(CF_3)_2CHOH$		1.8	640	190	59
HFE-125	CF_3OCHF_2	150	12900	14900	9200
HFE-134	CHF_2OCHF_2	26.2	10500	6100	2000
HFE-143a	CH_3OCF_3	4.4	2500	750	230
HCFE-235da2	$CF_3CHClOCHF_2$	2.6	1100	340	110
HFE-245cb2	$CF_3CF_2OCH_3$	4.3	1900	580	180
HFE-245fa2	$CF_3CH_2OCHF_2$	4.4	1900	570	180
HFE-254cb2	$CHF_2CF_2OCH_3$	0.22	99	30	9
HFE-347mcc3	$CF_3CF_2CF_2OCH_3$	4.5	1600	480	150
HFE-356pcf3	$CHF_2CF_2CH_2OCHF_2$	3.2	1500	430	130

Gas		Lifetime (years)	Global Warming Potential Time horizon		
			20 years	100 years	500 years
HFE-374pc2	$CHF_2CF_2OCH_2CH_3$	5.0	1800	540	170
HFE-7100	$C_4F_9OCH_3$	5.0	1300	390	120
HFE-7200	$C_4F_9OC_2H_5$	0.77	190	55	17
H-Galden 1040x	$CHF_2OCF_2OC_2F_4OCHF_2$	6.3	5900	1800	560
HG-10	$CHF_2CHF_2OCF_2OCHF_2$	12.1	7500	2700	850
HG-01	$CHFOCFCFCHFOCFCFOCHF_2$	6.2	4700	1500	450

The potential global warming or greenhouse effect is normally quantified by using ***global warming potentials (GWP)*** for substances having the same effect as CO_2 in reflection of heat radiation. The GWP for greenhouse gases is expressed as CO_2-equivalents, i.e. the effects are expressed relatively to the effect of CO_2.

The potential greenhouse effect of a process can be estimated by calculating the product of the amount of emitted greenhouse gas per functional unit and the potential for greenhouse effect given in kg CO_2-equivalents per kg for each gas. Finally, the contribution to the potential greenhouse effect from each gas has to be summarised:

$$\mathrm{GWP} = \sum_i \mathrm{GWP}_i \times m_i \qquad [\mathrm{kg\ CO_2 - eq.}]$$

where$\boldsymbol{GWP_i}$ is the equivalency factor for the substance ***i***
$\boldsymbol{m_i}$ is the emission of the substance ***i***

4.4 Methodology

The calculation of the normalisation reference for global warming has been carried out according to the methodology described in Hauschild and Wenzel (1998). The normalisation factor is calculated as:

$$\mathrm{Normref}_{\mathrm{GWP}} = \frac{\sum_i^n m_i * \mathrm{GWP}_i}{N} \qquad [\mathrm{kg\ CO_2 - eq./capita/year}]$$

where $\boldsymbol{Normref_{GWP}}$ is the normalisation reference for the greenhouse effect
$\boldsymbol{m_i}$ is emitted quantity of substance ***i***
$\boldsymbol{GWP_i}$ is the equivalence factor for the substance ***i***
N is the number of capita in the considered area

Included in the normalisation reference are the following substances:

- Carbon Dioxide (CO_2)
- Methane (CH_4)
- Nitrous Oxides (N_2O)
- CFCs (CFC-11, -12, -113, -114, -115)
- HCFCs (HCFC-22, -123, -141b, -142b)
- HFCs (HFC-134a)
- Halons
- Tetrachloromethane (CCl_4)
- 1,1,1-Trichloroethane (CCl_3CH_3)

- Carbon Monoxide (CO)

These substances are included due to ready availability of data on emission or consumption of these substances.

4.5 Normalisation reference

Global warming is a global impact and therefore only a global normalisation reference is relevant. For comparison the Danish emission/consumption of greenhouse gasses is presented in Appendix C to this chapter, showing that the consumption pattern has changed as the consumption of CFC is nearly phased out. This tendency has continued in the subsequent years.

The data used in calculation of the normalisation reference for potential global warming is presented in Appendix B. The emissions of CO_2 and CH_4 are based on estimates made by the Oak Ridge National Laboratory in the U.S. Houghton & Hackler (2002), Marland, Boden & Andres (2002), Stern & Kaufman (1998), emissions of N_2O and CO are estimated by RIVM/TNO in the Netherlands (Olivier ***et al.*** (2002), and consumption of CFCs, HCFCs, HFCs and halogenated carbons (CCl_4 and CH_3CCl_3) are based on estimates made by the "Intergovernmental Panel on Climate Change" (IPCC) (Schimel *et al.* 1996). The information on consumption of halons is based on reports from countries that have ratified/accessed/accepted/approved the ***Montreal Protocol*** (UNEP 1987; 1999).

The normalisation reference for global warming potential can be calculated to:

8.7 ton CO_2-eq./capita/year

The value is similar to that for 1990, i.e. app. ***8.7 ton CO_2-eq./capita/year***. The total global warming potential has increased with about 5% (from $46.1*10^9$ ton CO_2-eq. in 1990 to $48.6*10^9$ ton CO_2-eq. in 1994 and the world population has increased from $5.3*10^9$ in 1990 to $5.6*10^9$ in 1994. CO_2 and CH_4 are the main contributors to the total global warming potential for both years, as they constitute approximately 80 % of the effect potential. N_2O, CFC-12 and CO constitute 15% of the impact potential.

The quality of the data varies from substance to substance. None of the emissions are measured in countries all over the world and often they are not measured in the same year or by the same method.

The total emissions of energy related substances are based on emission factors for the relevant processes (e.g. energy production) and models developed by IPCC have been used for estimation of world emissions.

Emissions of CFCs, HCFCs, HFCs, and halogenated carbons (CCl_4 and CH_3CCl_3) are not measured regularly. The potential emissions are estimated by using the assumption that all the consumed amount of the actual substances will be emitted sooner or later due to their chemical stability. This methodology is problematic as the lifetime of the substances in the products is different depending on the purpose of the actual product (substances used as degreasing agents are supposed to be emitted immediately during the use phase and substances used as cooling agents are supposed to be emitted after the use phase i.e. when the goods are disposed off). However, the last assumption is only valid for some countries. Collection of goods containing cooling agents has been established in some countries (e.g. Denmark) in order to recycle the cooling agent or to ensure proper destruction of the cooling agent.

4.6 Recommendations for future update

The future updating of the normalisation reference for global warming is recommended to be based on the same methodology and data sources as used in the present update. The statistical information used in this report is compiled by IPCC (greenhouse gasses) and for the greenhouse gasses with ozone depleting potential from the statistical information compiled by UNEP. All the data have to be reported regularly according to the ***Kyoto Protocol*** as well as the ***Montreal Protocol***.

4.7 References

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Hansen, J.H. 1995, Ozonlagsnedbrydende stoffer og HFC - forbrug i 1994. Miljøprojekt nr. 302. København: Miljøstyrelsen.

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UNEP 1999, ***Status of Ratification/Accession/Acceptance/Approval of the agreements on the protection of the stratospheric ozone layer***. The Vienna Convention for the Protection of the Ozone Layer (1985); The Montreal Protocol on Substances that Deplete the Ozone Layer (1987); The London Amendment to the Montreal Protocol (1990); The Copenhagen Amendment to the Montreal Protocol (1992); and the Montreal Amendment to the Montreal Protocol (1997). February 8 1999. UNEP: The Ozone Secretariat. (Available at: http://www.unep.ch)

Appendix A: Data sources

Databases (paper)

- CORINAIR reports (until now 1990 and 1994 data).

Databases (electronic)

- **CORINAIR database -** expected to contain data updated yearly (National as well as European databases can be expected to be public available in the future.); http://www.aeat.co.uk/netcen/corinair
- UNEP 1998, ***Data report on production and consumption of ODSs - 1986 - 1996***. United Nations Environment Programme, Ozone Secretariat. Available at: http://www.unep.org.

Organisations

The following institutions are relevant in relation to obtaining data on the consumption/emission of greenhouse gasses:

- **The Intergovernmental Panel on Climate Change (IPCC)**; The IPCC Secretariat can be contacted at:

  World Meteorological Organisation
  1211 Geneva 2
  Switzerland
  Fax: [41] 22 733 1270
  http://www.ipcc.ch
- **United Nations Environment programme UNEP), Ozone Secretariat**
  Switzerland, Geneva Executive Centre: http://www.unep.ch
  Kenya, Nairobi: http://www.unep.org
  Contact: ozoneinfo@unep.org
- **World Meteorological Organisation (WMO)**
  Information and Public Affairs Office
  1211 Geneva 2
  Switzerland
  Phone [41] 22 730 8314/15
  Fax [41] 22 733 2829
  e-post: ipa@www.wmo.ch
  http://www.wmo.ch
- **Alternative Fluorocarbons Environmental Acceptability Study (AFEAS)**
  Washington, DC 20005
  USA
  Phone: [1] 202 296-5000
  Fax: [1] 202 296-7960
  http://www.afeas.org

Appendix B: Data used in the calculation of normalisation references for global warming.

Substances	GWP100	Emis90[1] kt	Emis94 kt	Eq-emis90[1] kt CO2	%	Eq-emis94 kt CO2	%
CO2	1	2,71E+07	3,10E+07[2,3]	2,71E+07	58,74	3,10E+07	63,75
CH4	23	3,51E+05	3,71E+05[4]	8,07E+06	17,50	8,53E+06	17,55
N2O	296	7,23E+03	1,12E+04[5]	2,14E+06	4,64	3,31E+06	6,81
CFC-11	4600	2,98E+02	1,88E+02[6]	1,37E+06	2,97	8,63E+05	1,77
CFC-12	10600	3,63E+02	2,48E+02[6]	3,85E+06	8,34	2,62E+06	5,40
CFC-113	6000	1,47E+02	9,90E+01[6]	8,82E+05	1,91	5,94E+05	1,22
CFC-114	9800	1,30E+01	6,00E+00[6]	1,27E+05	0,28	5,88E+04	0,12
CFC-115	7200	7,00E+00	9,50E+00[6]	5,04E+04	0,11	6,84E+04	0,14
HCFC-22	1700	1,38E+02	4,20E+02[6]	2,35E+05	0,51	7,13E+05	1,47
HCFC-225	400	5,00E+00		2,00E+03	0,00		
HCFC-123	120		9,10E+01[6]			1,09E+04	0,02
HCFC-124	620					0,00E+00	0,00
HCFC-141b	700		4,55E+01[6]			3,19E+04	0,07
HCFC-142b	2400		1,07E+01[6]			2,57E+04	0,05
HFC-125	3400						
HFC-134a	1300		9,40E+00[6]			1,22E+04	0,03
HFC-152a	120						
Halon 1301	6900	3,00E+00		2,07E+04	0.04		
Halon 1211	1300	3,00E+00		3,90E+03	0.01		
Halon (sum)	6900		3,33E+00[6]			2,30E+04	0,05
CCl4	1800	1,19E+02	4,50E+01[6]	2,14E+05	0,46	8,10E+04	0,17
CH3CCl3	140	7,38E+02	3,20E+02[6]	1,03E+05	0,22	4,48E+04	0,09
CO	2	9,96E+05	3,14E+05[5]	1,99E+06	4,32	6,28E+05	1,29
CH3Br	5	6,30E+01	6,23E+01[6]			3,12E+02	0,00
Total				4,61E+07		4,86E+07	
Population				5,29E+09		5,61E+09	
Normalisation reference				t CO2/p/y 8,72		t CO2/p/y 8,67	

1. Hauschild & Wenzel (1998).
2. Houghton & Hackler (2002)
3. Marland, Boden & Andres (2002)
4. Stern & Kaufman (1998)
5. Olivier *et al* (2002)
6. Schimel *et al.* (1996).

See chapter 5 for description of the procedure used for estimation of emission/consumption of halon (sum). In the calculation of global warming potential the halons are assumed to be 100% halon 1301.

Appendix C: Consumption/emission of greenhouse gasses

Consumption of greenhouse gasses/ozone depleting substances and emission of greenhouse gasses in Denmark in 1994.

Substances	Consumption[1]		Emission	
	1990 kt	1994 kt	1990[2] kt	1994[3] kt
CO2			56030	62846
CH4			761.49	430.64
N2O			16.422	12.2
CFC-11	2.175	0.055		
CFC-12	0.795	0.24		
CFC-113	0.365	0.065		
CFC-115	0.055	0.025		
HCFC-22	0.84	0.75		
HCFC-141b	0	0.51		
HCFC-142b	0	0.145		
Other HCFC	0	0.005		
HFC-134a	0	0.52		
HFC-152a	0	0.05		
Halon 1301	0.075	0.005		
Halon 1211	0.005	0		
CCl4	0.002	0.0007		
CH3CCl3	0.81	0.57		
CO			789,3	715,4
CH3Br	0.039	0.012		

1. Hansen (1995).
2. Corinair 90
3. Ritter (1997).

5 Stratospheric ozone depletion

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5.1 Summary

This chapter summarises the presently available data on worldwide consumption of substances contributing to the stratospheric ozone depletion. Stratospheric ozone depletion is a global effect. The substances or emissions included are:

- CFCs (CFC-11, -12, -113, -114, -115)
- HCFCs (HCFC-22, -123, -124, -141b, -142b)
- Tetrachloromethane (CCl_4)
- 1,1,1-Trichloroethane (CCl_3CH_3)
- Halons
- Methyl bromide

Consumption data are generally available worldwide as the substances are regulated according to the ***Montreal Protocol***. The normalisation reference for stratospheric ozone depletion has been calculated to:

0.103 kg CFC-11-eq./capita/year

CFC-11, CFC-12 and CFC-113 accounts for two thirds of the effect potential contributing to the normalisation reference for stratospheric ozone depletion. The normalisation reference is relatively certain as almost complete data are easy available due to the regulation of consumption according to the ***Montreal Protocol***.

5.2 Description of the impact category

Stratospheric ozone depletion is considered as a global effect. Stratospheric ozone acts as a filter protecting the earth from incoming ultraviolet(UV)-radiation. The decomposition of ozone is enhanced by the stratospheric input of anthropogenic halogenated compounds (e.g. CFCs, HCFCs, halons etc.). The halogenated organic compounds are relatively stable and therefore a considerable amount reaches the stratosphere before they are decomposed. In the stratosphere they are decomposed to chlorine and bromine under the influence of UV-radiation. Nitrogen oxides, hydrogen oxides, methane, chlorine and bromine act as catalysing agents in the decomposition of ozone.

The presence of the stratospheric ozone layer is fundamental for life on earth, as ozone absorb UV-radiation. The natural UV-radiation will make life as known today impossible. Decomposition of the stratospheric ozone layer will cause increased incoming UV-radiation (especially UV-B-radiation) leading to impacts on humans such as increased levels of e.g. skin cancer, cataracts and decreased immune defence. The increased UV-radiation has also an impact at natural organisms and ecosystems e.g. plankton in the South Pole region, where the decomposition of the ozone layer is already significant.

The stratospheric ozone layer occurs at an altitude from 10 - 40 km, with maximum concentration from 15 - 25 km. The maximum generation of stratospheric ozone (O_3) occurs in the top of the stratosphere at the altitude of 40 km as a result of a reaction of molecular oxygen (O_2) and atomic oxygen (O). The decomposition of ozone is enhances by the stratospheric input of halogenated compounds (e.g. CFCs, HCFCs, halons etc.).

See also Albritton ***et al.*** (1998) and Hauschild and Wenzel (1998) for further description of the impact category.

5.3 Substances contributing to the impact category

The substances contributing to stratospheric ozone depletion are defined (Solomon & Albritton 1992) as substances which:

- are sufficiently stable in the atmosphere to allow a substantial fraction to reach the stratosphere, **and**
- contain chlorine or bromine which, upon release into the atmosphere, will participate in a chemical decomposition of ozone

The substances or emissions normally considered as contributors to stratospheric ozone depletion are:

- CFCs (CFC-11, -12, -113, -114, -115)
- HCFCs (HCFC-22, -123, -124, -141b, -142b)
- Tetrachloromethane (CCl_4)
- 1,1,1-Trichloroethane (CCl_3CH_3)
- Halons
- Methyl bromide

The ozone depletion potentials of the relevant substances are calculated relative to the potential of CFC-11, and therefore the ozone depletion potentials are given as ***CFC-11 equivalents***. The regulation of the production and consumption of ozone depleting substances by the ***Montreal Protocol*** (UNEP 1987) include the following substances mentioned in groups corresponding with the year for the inclusion in the protocol:

a) Annex A, Group I: chlorofluorocarbons (CFCs) and Group II: halons (Montreal Protocol 1987[5]);
b) Annex B, Group I: other fully halogenated CFCs, Group II: carbon tetrachloride and Group III: methyl chloroform (London Amendment 1990[6]);
c) Annex C, Group I: hydrochlorofluorocarbons (HCFCs) and Group II: hydrobromofluorocarbons (HBFCs); Annex E: methyl bromide (Copenhagen Amendment 1992[7])

The status for ratification, accession, acceptance and approval of the different annexes varies and therefore the availability of data varies as the countries that

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[5] The Montreal Protocol is ratified/accessed/accepted/approved by 168 countries at February 8, 1999 (UNEP 1999).

[6] The London Amendment is ratified/accessed/accepted/approved by 127 countries at February 8, 1999 (UNEP 1999).

[7] The Copenhagen Amendment is ratified/accessed/accepted/approved by 86 countries at February 8, 1999 (UNEP 1999).

have not ratified the annexes do not necessarily give information on consumption of the specific substances. In other words, the information on annex A substances are assumed to be more certain than information on annex B and C substances.

A complete list of substances included in annex A (I and II) and annex B (I) is presented in Appendix B.2 “Calculation of normalisation references”.

Ozone depletion potentials (ODP) have been presented by the World Meteorological Organisation (WMO) for a number of halogenated compounds (Solomon & Wuebbles 1995; Pyle *et al.* 1991). A report containing information on production and consumption of ozone depleting substances (UNEP 1998) also contains ozone depleting potentials on the controlled substances. The equivalence factors differ slightly from the factors used in the EDIP methodology. The UNEP-report also mentions that the ozone depleting potentials “are estimates based on existing knowledge and will be reviewed and revised periodically”. The equivalency factors are compared in Appendix C “Ozone depleting substances”. The most recent ODP factors from UNEP (2002) have been used in the present calculation of normalisation reference for stratospheric ozone depletion. The values are given in Table 5-1, where they also are compared to recent values from Monztka, Frazer *et al.* (2002).

Table 5-1
Factors for characterisation of stratospheric ozone depletion (in g CFC-11-equivalents/g). Taken from UNEP (2002) and Montzka, Frazer et al. (2002) with range representing spread of reported results from models and semi-empirical.

			UNEP (2002)[1]	Montzka, Frazer *et al* (2002)	
Substance	Formula	Life time, years	Total ODP g CFC-11 eq/g	Total ODP g CFC-11 eq/g	ODP range g CFC-11 eq/g
CFC-11	CFCl3	45	1.0	1.0	-
CFC-12	CF2Cl2	100	1.0	1.0	0.82-0.9
CFC-113	CF2ClCFCl2	85	0.8	1.0	0.9
CFC-114	CF2ClCF2Cl	300	1.0	0.94	0.85-1.0
CFC-115	CF2ClCF3	1,700	0.6	0.44	0.40-0.44
Tetrachloromethane	CCl4	26	1.1	0.73	0.73-1.20
HCFC-22	CHF2Cl	12.0	0.055	0.05	0.034-0.05
HCFC-123	CF3CHCl2	1.3	0.02-0.06	0.02	0.012-0.02
HCFC-124	CF3CHFCl	5.8	0.02-0.04	0.02	0.02-0.026
HCFC-141b	CFCl2CH3	9.3	0.11	0.12	0.037-0.12
HCFC-142b	CF2ClCH3	17.9	0.065	0.07	0.014-0.07
HCFC-225ca	C3F5HCl2	1.9	0.025	0.02	0.017-0.025
HCFC-225cb	C3F5HCl2	5.8	0.033	0.03	0.017-0.03
1,1,1-Trichloroethane	CH3CCl3	5.0	0.1	0.12	0.11-0.15
Methyl chloride	CH3Cl	1.3		0.02	-
Halon 1301	CF3Br	65	10.0	12	12-13
Halon 1211	CF2ClBr	16	3.0	6.0	5-6
Halon 1202	CF2Br2	2.9		1.3	-
Halon 2402	CF2BrCF2Br	20	6.0	<8.6	-
Methyl bromide	CH3Br	0.7	0.6	0.38	0.37-0.38

1) Where a range is given, the highest value is used in the calculations

The potential depletion of stratospheric ozone as an impact from a given process can be estimated by summarising the ODPs:

$$ODP = \sum_i ODP_i \times m_i \qquad [\text{kg CFC} - 11 - \text{eq.}]$$

where $\boldsymbol{ODP_i}$ is the equivalency factor for the substance ***i***

m_i is the emission of the substance i

5.4 Methodology

The calculation of the normalisation reference for ozone depletion has been carried out according to the methodology described in Hauschild and Wenzel (1998). The normalisation factor is calculated as:

$$\mathrm{Normref}_{ODP} = \frac{\sum_i^n m_i * \mathrm{ODP}_i}{N}$$

where $\mathbf{Normref}_{ODP}$ is the normalisation reference for the ozone depletion
m_i is emitted quantity of substance i
$\mathbf{ODP}_i$ is the equivalence factor for substance i
N is the number of capita in the considered area (the World)

Included in the normalisation reference are the following substances:

- CFCs (CFC-11, -12, -113, -114, -115)
- HCFCs (HCFC-22, -123, -141b, -142b)
- Halons
- Tetrachloromethane (CCl_4)
- 1,1,1-Trichloroethane (CCl_3CH_3)
- Methyl bromide

These substances are included due to ready availability of data on emission or consumption of these substances.

5.5 Normalisation reference

Ozone depletion is a global impact and therefore only a global normalisation reference is relevant. For comparison, the Danish consumption of ozone depleting substances is presented in appendix D “Consumption of ozone depleting substances”.

The nomalisation reference has been calculated by using information collected by UNEP (UNEP, 2002). Although the UNEP data are aggregated in classes of substances, they can be assumed to represent the most precise and up-to-date information on ozone depleting substances. The consumption of ozone depleting substances has been used as an approximation for the emission as emission data does not exist due to the character of the emissions. The emissions are in most cases diffuse and therefore not measured. The reason for using the above-mentioned approximation is that the relevant substances are chemically very stable (an important quality in the use of the substances) and therefore the consumed amounts are expected to emit sooner or later. The actual delay will vary from substance to substance depending on the actual use. The UNEP data are summarised in Table 5-2:

Table 5-2
Calculation of the normalization reference (based on UNEP, 2002)

		ODP 1990		ODP 1994	
Montreal Protocol	Substance classes	kt CFC-11-eq	%	kt CFC-11-eq	%
Annex A, Group1	CFC's	732,1	61,2	358,1	61,9
Annex B, Group 1	Other fully halog. CFC's	4,4	0,4	1,8	0,3
Annex C, Group1	HCFC	14,4	1,2	25,1	4,3
Annex B, Group II	Carbon tetrachloride	181,5	15,2	123,4	21,3
Annex B, Group III	1,1,1-trichloroethane	62,7	5,2	14,2	2,5
Annex A, Group II	Halons	162,6	13,6	34,5	6,0
Annex E	Methyl bromide	38,6	3,2	21,7	3,7
	Total ODP	**1196,3**		**578,8**	
	Population	5,29E+09		5,61E+09	
	Normalisation reference				
	kg CFC-11-eq/capita/year	**0,226**		**0,103**	
	EDIP97 Normalisation reference	0,202			

The normalisation reference for ozone depletion potential can thus be calculated as:

0.103 kg CFC-11-eq./capita/year

The similar value for 1990 can be calculated to 0.226 kg CFC-11-eq./capita/year. This means that the normalisation reference is reduced by about 55%. The decrease can be explained by a significant reduction of the consumption of ozone depleting substances and an increase of the world population. At the same time the estimated ODP's for the CFC-12 and CFC-13 have been increased, adding to a higher normalisation reference.

For 1994, the consumption of CFC-11, CFC-12 and CFC-113 constitutes approximately two thirds of the total consumption expressed as CFC-11 equivalents. With HCFCs as the exception, the contribution in absolute figures has decreased for all relevant compounds although most markedly for the CFCs. The reason for these findings are obviously that CFCs to a large extent have been replaced by HCFCs as refrigerants.

The normalisation reference is about 50% of that calculated in the original EDIP97. The difference is of course related to the actual decrease in thee total consumption of ozone depleting substances, but it is interesting to note that there also is a large difference when examining the calculations based on the information that was available at the time of the calculations. Here, it can be seen that the calculation made in EDIP97 underestimated the normalisation reference with about 20-25%. The reason for this is probably that the data collection was not fully implemented in all relevant countries. Another difference is that some of the ODP's for specific substances have been re-evaluated, which in the total picture also causes an increase in the total ODP. The development in the assessment of ODP's for different substances is illustrated in Appendix C.

5.5.1 Alternative calculations

Appendix B.1. shows an alternative calculation of the normalisation references for 1990 and 1994. The major difference from the selected database is that in this alternative calculation, a linear decrease in the consumption of ozone depleting substances from 1990-1999 has been assumed, based on the fgures in Schiemel ***et al***, 1996. Obviously, this causes a large overestimation –about 50% - of the ozone depleting potential in the reference year 1994.

Appendix B.2. shows another alternative calculation of the normalisation reference. Here, the information collected by WMO/UNEP (Schiemel ***et*** al, 1996) and UNEP (1998) is used. A comparison between Appendix B.2. and the updated figures in Table 5-2 shows that the figures for consumption of CFC's in 1994 were underestimated in the early report. The comparison, however, also shows that the consumption of CFC's in 1990 was overestimated by about 7% in 1998, compared to the 2002 report.

The two alternative calculations thus demonstrate the scientific and regulatory development in the area of stratospheric ozone depletion. The figure chosen as the normalisation reference can be assumed to represent the best possible knowledge, although there stille are some limitations in the data quality as discussed below.

5.5.2 Data quality

The general quality of the data used in the calculations can be considered as good. There are, however, some methodological problems that must be remembered.

Emissions of CFCs, HCFCs, HFCs, and halogenated carbons (CCl_4 and CH_3CCl_3) are not measured regularly. The potential emissions are estimated by using the assumption that all the consumed amount of the actual substances will be emitted sooner or later due to their chemical stability. This methodology is problematic as the lifetime of the substances in the products differs depending on the purpose of the actual product. Substances used as degreasing agents are supposed to emit immediately during the use phase and substances used as cooling agents are supposed to emit after the use phase, i.e. when the goods are disposed off. However, the last assumption is only valid for some countries as collection of goods containing cooling agents has been established in some countries (e.g. Denmark) in order to recycle the cooling agent or to ensure proper destruction of the cooling agent.

Another inherent uncertainty in calculation of the normalisation reference is that the ODP of specific substances is based on models or semi-empirical knowledge. This causes frequent changes of the ODP's, caused by the development of better models and collection of empirical data. The development is illustrated by the ODP's used for different calculations by different organisations, see Table 5-1 and Appendix C for examples.

5.6 Recommendations for future update

The future updating of the normalisation reference for ozone depletion is recommended to be based on the same methodology and data source as used in the present update. The statistical information is compiled by UNEP and this information is also expected to be available in the future i.e. yearly updates of data on production and consumption of ozone depleting substances.

5.7 References

Albritton, D.L., & Kuijpers, L. (eds.) 1999, ***Synthesis of the Reports of the Scientific, Environmental Effects, and Technology and Economic Assessment Panels of the Montreal Protocol. A Decade of Assessment for Decision Makers Regarding the Protection of the Ozone Layer: 1988-1999***. Nairobi: United Nations Environment Programme (UNEP). (Available at http://www.unep.ch or http://www.unep.org).

Hansen, J.H. 1995, ***Ozonlagsnedbrydende stoffer og HFC - forbrug i 1994***. Miljøprojekt nr. 302. København: Miljøstyrelsen.

Hauschild, M. & Wenzel, H. 1998, Stratospheric ozone depletion as a criterion in the environmental assessment of products, in ***Environmental assessment of products. Volume 2: Scientific background,*** eds. Hauschild M, Wenzel H. London: Chapman & Hall.

Pyle, J.A., Wuebbles, D., Solomon, S. & Zvenigorodsky, S. 1991, ***Ozone depletion and chlorine loading potentials***. World Meteorological Organisation: Scientific assessment of stratospheric ozone: 1991 Global ozone research and monitoring project. Report no. 25. Geneva.

Schimel, D., Alves, D., Enting, M., Heimann, M., Joos, F., Raynaud, D., Wigley, T., Prather, M., Derwent, R., Ehhalt, D., Fraser, P., Sanhueza, E., Zhou, X., Jonas, P., Charlson, R., Rodhe, H., Sadasivan, S., Shine, K.P., Fouquart, Y., Ramaswamy, V., Solomon, S., Srinivasan, J., Albritton, D., Isaksen, I., Lal, M. & Wuebbles, D. (eds.) 1996, Radiative forcing of climate change. Chapter 2 in Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A. & Maskell, K. (eds.) ***Climate change 1995 - The science of climate change***. Cambridge: Cambridge University Press.

Solomon, S. & Albritton, D.L. 1992, Time-dependent ozone depletion potentials for short- and long-term forecasts. ***Nature***, vol. 357, pp. 33-37.

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UNEP 1987, ***The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer*** as adjusted and amended by the second Meeting of the Parties (London, 27-29 June 1990) and by the fourth Meeting of the Parties (Copenhagen, 23-25 November 1992) and further adjusted by the seventh Meeting of the Parties (Vienna, 5-7 December 1995) and further adjusted and amended by the ninth Meeting of the Parties (Montreal, 15-17 September 1997). Available at: http://www.unep.org.

UNEP 1998, ***Data report on production and consumption of ODSs - 1986 - 1996***. United Nations Environment Programme, Ozone Secretariat.

UNEP 1999, ***Status of Ratification/Accession/Acceptance/Approval of the agreements on the protection of the stratospheric ozone layer***. The Vienna Convention for the Protection of the Ozone Layer (1985); The Montreal Protocol on Substances that Deplete the Ozone Layer (1987); The London Amendment to the Montreal Protocol (1990); The Copenhagen Amendment to the Montreal Protocol (1992); and the Montreal Amendment to the Montreal Protocol (1997). February 8 1999. UNEP: The Ozone Secretariat. (Available at: http://www.unep.ch).

UNEP (2002). Production and consumption of ozone depleting substances under the Montreal Protocol 1986-2000. UNEP Ozone Secretariat, Apreil 2002. (http://www.unep.org/ozone).

Appendix A: Data sources

The production and consumption of substances contributing to stratospheric ozone depletion are well registered due to the Montreal Protocol. According to the protocol the parties that have ratified the protocol has to report the consumption of ozone depleting substances every year. The data on the total production and consumption may improve in the future as more countries can be expected to ratify the protocol. The quality of the data from the countries that have ratified the protocol may also be expected to improve because more knowledge and experience is obtained.

Databases (paper/electronic)

UNEP (2002). Production and consumption of ozone depleting substances under the Montreal Protocol 1986-2000. UNEP Ozone Secretariat, Apreil 2002. (http://www.unep.org/ozone)

Organisations

The following institutions are relevant in relation to obtain data on the world production and consumption of ozone depleting substances:

- **United Nations Environment programme UNEP), Ozone Secretariat**
  Switzerland, Geneva Executive Centre: http://www.unep.ch
  Kenya, Nairobi: http://www.unep.org
  Contact: ozoneinfo@unep.org
- **World Meteorological Organisation (WMO)**
  Information and Public Affairs Office
  1211 Geneva 2
  Switzerland
  Phone [41] 22 730 8314/15
  Fax [41] 22 733 2829
  e-post: ipa@www.wmo.ch
  http://www.wmo.ch
- **UNEP IE OzonAction Programme**
  F-75739 Paris Cedex 15
  France
  Phone [33] 1 44 37 14 50
  Fax [33] 1 44 37 14 74
  http://www.unepie.org
- **Alternative Fluorocarbons Environmental Acceptability Study (AFEAS)**
  Washington, DC 20005
  USA
  Phone: [1] 202 296-5000
  Fax: [1] 202 296-7960
  http://www.afeas.org
- **The Intergovernmental Panel on Climate Change (IPCC)**; The IPCC Secretariat can be contacted at:

  World Meteorological Organisation
  1211 Geneva 2
  Switzerland
  Fax: [41] 22 733 1270
  http://www.ipcc.ch

Appendix B.1: Alternative calculation of normalisation references

Substances	ODP	Emis90 kt	Emis94[1] kt	Emis90 kt CFC-11-eq	%	Emis94 kt CFC-11-eq	%
CFC-11	1	2,98E+02	1,88E+02	2,98E+02	27,50	1,88E+02	26,75
CFC-12	1	3,63E+02	2,48E+02	3,63E+02	33,50	2,48E+02	35,30
CFC-113	1	1,47E+02	9,90E+01	1,47E+02	13,56	9,90E+01	14,12
CFC-114	0,94	1,30E+01	6,00E+00	1,22E+01	1,13	5,64E+00	0,80
CFC-115	0,44	7,00E+00	9,50E+00	3,08E+00	0,28	4,18E+00	0,60
HCFC-22	0,05	1,38E+02	4,20E+02	6,90E+00	0,64	2,10E+01	2,99
HCFC-225	0,025	5,00E+00		1,25E-01	0,01		
HCFC-123	0,02		9,10E+01			1,82E+00	0,26
HCFC-124	0,02						
HCFC-141b	0,12		4,55E+01			5,46E+00	0,78
HCFC-142b	0,07		1,07E+01			7,49E-01	0,11
Halon 1301	12	3,00E+00		3,60E+01	3,32		
Halon 1211	6	3,00E+00		1,80E+01	1,66		
Halon (sum)	10		3,33E+00			3,33E+01	4,75
CCl4	0,73	1,19E+02	4,50E+01	8,69E+01	8,02	3,29E+01	4,69
CH3CCl3	0,12	7,38E+02	3,20E+02	8,86E+01	8,17	3,84E+01	5,48
CO		9,96E+05	3,14E+05				
CH3Br	0,38	6,30E+01	6,23E+01	2,39E+01	2,21	2,37E+01	3,38
Total				**1,08E+03**		**7,01E+02**	
Population				5,29E+09		5,61E+09	
				kg OPD/p/y		kg OPD/p/y	
Normalisation reference				**0,20**		**0,125**	

[1] Schimel *et al.* (1996) except consumption data for halons and methyl bromide which originates in UNEP (1998).

A detailed description of the data originating from UNEP (1998) is given in Appendix B.2. The consumption is reported in ODPs and the consumption of halons and methyl bromide (in ton) has been calculated for the purpose of calculating the normalisation reference for ozone depletion as in Hauschild & Wenzel (1998).

The consumption of halons (as a group) is 33,300 ton CFC-11-eq./year and is assumed to be halon-1301. Based on this assumption and that the equivalency factor for halon 1301 was set at 10 ton CFC-11-eq./ton halon 1301, the amount of consumed halons can be calculated to 3,300 ton/year. The contribution to the total ozone depleting potential in 1994 is based on the total amount of halons and the revised ODP for halon 1301. Recently, the equivalency factor has been suggesteed to be increased to 12 ton CFC-11-eq./ton halon 1301 (Montzka, Frazer ***et al.*** (2002)), and this factor has been used in the update calculations.

The consumption of methyl bromide is 37,400 ton CFC-11-eq./year. Based on the equivalence factor used in 1994 (1.3 ton CFC-11-eq./ton methyl bromide), the amount of methyl bromide can be calculated to 62,300 ton/year. The new equivalence factor suggested by Montzka, Frazer ***et al.***

(2002) (i.e. 0.38 ton CFC-11-eq./ton methyl bromide) is used in the update calculations.

Appendix B.2: Calculation of normalisation references, based on 1998 information

Normalisation references calculated on basis of statistical information collected by UNEP/Ozone Secretariat from the countries that have ratified/-accessed/accepted/approved the Montreal Protocol with the London and Copenhagen Amendments (UNEP 1998). The consumption data cover some countries that have ratified/accessed/accepted/approved the Montreal Protocol but not the London Amendment (regulation of annex B substances: I: “other” fully halogenated CFCs, II: carbon tetrachloride and III: methyl chloroform) and Copenhagen Amendment (regulation of annex C substances: I hydrochlorofluorocarbons, II: hydrobromofluorocarbons and annex E substance: methyl bromide). The consequence is that data are not complete for all substances.

The production and consumption are reported in ODPs according to equivalency factors presented in the same publication; the equivalency factors are presented in appendix C.

Annex	Substances	1990		1994	
		ton ODP/year	%	ton ODP/year	%
AI	Chlorofluorocarbons (CFC-11, -12, -113, -114, -115)	789,442	60.05	353,132	71.23
AII	Halons (halon 1211, 1301, 2402)	177,668	13.52	33,354	6.73
BI	Other CFCs (CFC-13, -111, -112, -211, -212, -213, -214, -215, -216, -217)	4,050	0.31	1,776	0.36
BII	Carbon tetrachloride	228,525	17.38	34,146	6.89
BIII	1,1,1-Trichloroethane	65,763	5.00	14,226	2.87
CI	HCFCs	13,760	1.05	21,742	4.39
CII	HBFCs		0.00		0.00
EI	Methyl bromide	35,340	2.69	37,393	7.54
Total		1,314,548		495,769	
Population		5.29E+09		5.61E+09	
Normalisation reference	kg ODP/capita/year	0.25		0.09	

For some of the countries the consumption has not been required nor reported for the years of interest i.e. 1990 and 1994. A rough extrapolation has been made from the consumption before and after the year of interest; a linear correlation has been assumed.

Appendix C: Ozone depleting potentials

The table below presents ozone depleting potentials for the most common ozone depleting substances. The calculation of ODP is based on an emission scenario, a calculation model and an atmospheric scenario. Further details on different approaches can be found in Hauschild and Wenzel (1998).

Substance	Formula	Life time, years	ODP[1] EDIP97	ODP UNEP 98[2] and 2000[4]	ODP[3] WMO
CFC-11	$CFCl_3$	50±5	1.00	1.00	1.00
CFC-12	CF_2Cl_2	102	0.82	1.00	1.00
CFC-113	$CF_2ClCFCl_2$	85	0.90	0.80	1.00
CFC-114	CF_2ClCF_2Cl	300	0.85	1.00	0.94
CFC-115	CF_2ClCF_3	1,700	0.40	0.60	0.44
Tetrachloromethane	CCl_4	42	1.20	1.10	0.73
HCFC-22	CHF_2Cl	13.3	0.04	0.055	0.05
HCFC-123	CF_3CHCl_2	1.4	0.014	0.02	0.02
HCFC-124	CF_3CHFCl	5.9	0.03	0.022	0.02
HCFC-141b	$CFCl_2CH_3$	9.4	0.10	0.11	0.12
HCFC-142b	CF_2ClCH_3	19.5	0.05	0.065	0.07
HCFC-225ca	$C_3F_5HCl_2$	2.5	0.02	0.025	0.02
HCFC-225cb	$C_3F_5HCl_2$	6.6	0.02	0.033	0.03
1,1,1-Trichloroethane	CH_3CCl_3	5.4±0.4	0.12	0.10	0.12
Halon 1301	CF_3Br	65	12	10	12
Halon 1211	CF_2ClBr	20	5.1	3.0	6.0
Halon 1202	CF_2Br_2		~1.25	-	1.3
Halon 2402	CF_2BrCF_2Br	25	~7	6.0	<8.6
Halon 1201	CF_2HBr		~1.4	0.74	
Halon 2401	CF_3CHFBr		~0.25	0.7-1.2	
Halon 2311	$CF_3CHClBr$		~0.14		
Methyl bromide	CH_3Br	1.3	0.64	0.60	0.38

0. Solomon and Wuebbles (1995), Pyle ***et al***. (1991) and Solomon and Albritton (1992) cited from Hauschild and Wenzel (1998).
1. UNEP (1998).
2. Montzka, Frazer ***et al.*** (2002)
3. UNEP (2002)

Appendix D.1: Consumption of ozone depleting substances

Information on the worldwide consumption of CFC, HCFC, HFC and halons are compared in the table below.

Substances		Denmark Consumption	EU-15	World	World Production	Emission
					AFEAS	AFEAS
		kt		kt	kt	kt
CFC-11		0.055		125.0	60.2	137.4
CFC-12		0.24		165.0	133.6	211.5
CFC-113		0.065		66.0	29.5	40.1
CFC-114				6.0	3.2	4
CFC-115		0.025		6.0	6.8	11.9
HCFC-22		0.75		520.0	239.4	218.9
HCFC-225					na	na
HCFC-123				13.0	na	na
HCFC-124					0.9	0.4
HCFC-141b		0.51		65.0	81.2	24.8
HCFC-142b		0.145		10.7	38.4	10.7
Other HCFC		0.005			na	na
HFC-125					na	na
HFC-134a				9.4	50.4	9.4
HFC-152a					na	na
Halon 1301		0.005			na	na
Halon 1211		0			na	na
Halon (sum)				3.3	na	na
CCl_4		0.0007		10.0	na	na
CH_3CCl_3		0.57		120.0	na	na
CO	emission	7.15E+02	4.51E+04	9.96E+05	na	na
CH_3Br		0.012		62.3	na	na

The table contains consumption and emission survey data from AFEAS (Alternative Fluorocarbons Environmental Acceptability Study). AFEAS is an organisation representing producers of CFC, HCFC and HFC. They cover less than 35% of the worldwide CFC-production and 90% - 100% of HCFC/HFC as they primarily cover European, American (North and South) and Japanese producers whereas producers from Eastern Europe and other Asiatic countries are outside AFEAS. The conclusion is that the world consumption of ozone depleting substances reported by AFEAS is below the actual consumption and therefore not useable for the present project.

Appendix D.2: Consumption of ozone depleting substances

Consumption of greenhouse gasses/ozone depleting substances and emission of greenhouse gasses in Denmark in 1994.

Substances	Consumption[1]	
	1990 kt	1994 kt
CFC-11	2.175	0.055
CFC-12	0.795	0.24
CFC-113	0.365	0.065
CFC-115	0.055	0.025
HCFC-22	0.84	0.75
HCFC-141b	0	0.51
HCFC-142b	0	0.145
Other HCFC	0	0.005
HFC-134a	0	0.52
HFC-152a	0	0.05
Halon 1301	0.075	0.005
Halon 1211	0.005	0
CCl_4	0.002	0.0007
CH_3CCl_3	0.81	0.57
CO	▨	▨
CH_3Br	0.039	0.012

1. Hansen (1995).

6 Photochemical ozone formation

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6.1 Summary

This chapter summarises the presently available data on emission of substances to the Danish and the European environment. The emissions include:

- nmVOC - non methane volatile organic carbons
- CO - carbon monoxide
- CH_4 - methane

Emission data for these substances are generally available for Denmark and EU-15 as well as for a number of other European countries. For the time being, worldwide emission data are available for 1990 and therefore the worldwide normalisation reference is based on 1990-data. This fact is exceptional for photochemical ozone formation. The normalisation references are presented in Table 6-1.

Table 6-1
Summary of normalisation references for photochemical ozone formation for Denmark, EU-15 and Worldwide in 1994.

		Denmark	EU-15	World
1994	kg C_2H_4/capita/year	20	25	$22^{1,2}$

1. 1990.
2. Based on the extrapolation method outlined in section 3.2, General extrapolation method, the normalisation reference can be calculated to 20 kg C_2H_2/capita/year.

The worldwide normalisation reference can be calculated to 20 kg C_2H_2/capita/year by the extrapolation method outlined in 3.2, General extrapolation method. The extrapolated value is nearly the same as the value calculated by using the worldwide emission data for 1990. nmVOC accounts for 70-80% of the effect potential contributing to the normalisation reference. The Danish and EU-15 normalisation references are relatively certain, as the relevant emissions to air have been measured through many years according to the ***Convention on Long-range Transboundary Air Pollution*** and the following Protocol on nmVOC (adopted in 1991).

6.2 Description of impact category

6.2.1 Tropospheric ozone formation

Ozone is formed in the troposphere under the influence of sunlight when nitrogen oxides are present. When VOCs are also present, peroxy radicals can be produced. Peroxy radicals are highly reactive and toxic compounds, and the presence of peroxy radicals can result in an increase of the concentration of ozone through a complex reaction pattern. The primary reactions responsible for the formation of ozone in the troposphere are described in 6.3.

Ozone is a ***secondary pollutant***, as there is practically no ozone present in source emissions derived from human activity.

Tropospheric ozone, or ground level ozone, has been recognised as an important environmental impact on the regional scale. At high concentrations it is hazardous to human health, but already at lower concentrations it causes damage to the vegetation. Ozone is a trans-boundary pollutant, and it can be produced or consumed by other pollutants during transport over long ranges. The health problems caused by ozone have generally been considered to be an effect of the very high peaks of ozone concentration, known as ***ozone episodes***. Increased background levels of ozone causes damage to vegetation, and thereby ozone also imposes an economic threat through a potential reduction of crop yield. It is assumed that anthropogenic emissions have resulted in a rise in the global background of ozone concentration from around 10 ppb in the year 1900 to around 20 ppb in 1975 (Fenger 1995).

6.2.2 POCP - impact category

In the EDIP model, the photochemical ozone formation is described through POCP, the photochemical ozone creation potential, as an individual impact category (Hauschild & Wenzel 1998). POCP is used in Europe for the ranking of VOCs according to their ability to produce ozone. In the US, a slightly different approach is used for the same purpose: Incremental Reactivity (Carter ***et al***. 1995).

POCP describes the production of ozone from a VOC emission through computer modelling of a complex series of chemical reactions in the atmosphere over a given scenario. A large amount of input data is required for the calculation of POCP by the model. The input data consist of the following principal components (Derwent ***et al***. 1996):

- Emission inventories for VOCs and NO_x
- Chemical and photochemical data
- Dry deposition rates for different surfaces
- Meteorological data

The model describes the chemical composition of primary pollutants during the transport away from their sources and of secondary pollutants during the transport towards the sensitive receptors where environmental damage may occur. In the model, the chemical composition of parcels of air is followed as they travel trans-boundary across Europe. Emissions of NO_x, CO, SO_2 and VOCs are introduced into the air parcels in a series of trajectory studies. The trajectories are meant to be illustrative of the general situation during photochemical episodes in Europe, and they illustrate the photochemical production of ozone over 1-5 days (Derwent & Jenkins 1991). For a given VOC, POCP is calculated as the average of the results of the three scenarios. Most of the VOCs are oxidised more than 95% after 4-5 days, so that the calculated POCP represents the total ozone creation potential.

6.2.3 Definition of POCP

POCP is generally presented as a relative value where the amount of ozone produced from a certain VOC is divided by the amount of ozone produced from an equally large emission of ethene:

$$\text{POCP} = \frac{\text{ozone increment with the } ith \text{ VOC}}{\text{ozone increment with ethene}}$$

The unit of POCP is grams of ethene equivalents per gram of gas (g C_2H_4/g VOC). Ethene has been chosen as a reference gas as it is one of the most potent ozone precursors of all VOCs.

By definition, the calculated POCP values are not absolute values. POCP will be a function of the scenarios chosen, i.e. from one geographical area to another. As data for e.g. the chemical and photochemical reactions are often not known in great detail, their representation in the model will often be a compromise. Therefore, even for the same scenario, the POCP values can be calculated with higher precision when more accurate input data and more powerful computer tools are available.

The most commonly used POCP values have been calculated by Derwent and Jenkin (1991) and Derwent (1996), primarily from scenarios for the transport of ozone to the United Kingdom. IVL (Instituttet för Vatten- och Luftvårdsforskning) in Sweden has calculated values for POCP under Scandinavian conditions using lower NO_x concentrations and lower VOC emission rates. Because of the importance of the NO_x-level for the ozone formation, the low- NO_x values for POCP under Scandinavian conditions are found to be slightly different, but generally a good agreement with the high-NO_x values (as calculated by Derwent for UK) is found.

6.3 Substances contributing to the impact category

The principal precursors of tropospheric ozone are

- NO_x
- VOCs including CH_4
- CO

Reactions (I)-(III) govern the background level of ozone in the troposphere:

$NO_2 + h\nu \rightarrow NO + O$ (I)
$O + O_2 \rightarrow O_3$ (II)
$NO + O_3 \rightarrow NO_2 + O_2$ (III)

If VOCs are also present, they are oxidised to produce peroxy radicals. Peroxy radicals can either consume NO or convert it to NO_2 and thus compete with ozone produced by reaction (II). Less ozone is thereby destroyed through reaction (III), and the ozone concentration will then increase.

The ozone creation potential for several VOCs is dependent on the NO_x concentration. In the calculation of a 1990 normalisation reference for POCP by Hauschild and Wenzel (1998), it was chosen not to differentiate between high-NO_x and low-NO_x values in the calculation of a normalisation reference for Europe. Because of the dependency on NO_x concentration, POCP values (and the calculated of the normalisation references) will differ between areas of high NO_x and low NO_x concentrations. For this reason, high-NO_x and low-NO_x values for POCP were introduced. High NO_x values are generally used for densely populated and highly industrialised areas, where high NO_x

concentrations occur. The European Union was in this study defined as a high-NO_x area except for the Scandinavian countries and Ireland, as shown in Table 6-7.

6.4 Methodology

The calculation of normalisation references for 1994 has been carried out according to the methodology described in Wenzel ***et al***. (1997). For photochemical ozone formation (POF), the normalisation reference for 1994 is calculated as

$$\text{Normref (POF)}_{1994} = \frac{\text{IP(POF)}_{1994}}{\text{P}_{1994}}$$

where Normref $(POF)_{1994}$ is the normalisation reference for the area in question for the year 1994 [g C_2H_4-equivalents per person]
$IP(POF)_{1994}$ is the impact potential for photochemical ozone formation for the area in question for the year 1994 [g C_2H_4-equivalents]
P_{1994} is the population of the area in question [persons]

The total impact potential IP (POF) from substances contributing to the impact category is calculated according to

$$\text{IP(POF)}_{1994} = \sum_{1}^{n} E_{n,1994} \cdot \text{POCP}_n$$

where $E_{n, 1994}$ is the total emission of substances from source category ***n*** to the atmosphere in 1994 for the area in question [kt per year]
$POCP_n$ is the photochemical ozone creation potential for source category ***n*** [kt C_2H_4-equivalents per kt]

Because of the influence of NO_x on the formation of ozone from VOCs, the POCP values should be chosen according to the background concentration of NO_x in the area in question.

6.4.1 Normalisation reference for 1990

For the calculation of a 1990-normalisation reference for Denmark, Hauschild and Wenzel (1998) chose low-NO_x POCP values in the EDIP model. For the calculation of a 1985-normalisation reference for EU, high-NO_x POCP values was used. For practical reasons, the European Union was not separated into regions according to the background concentration of NO_x. The POCP values used have been calculated for each individual source category. These POCP values were calculated as weighted averages of individual POCPs for major nmVOC sources as shown in Table 6-2. A discussion of the methodology is given in section 6.6.

Table 6-2
Average POCP values (g C_2H_4/g VOC) for nmVOC mixtures from source categories as used in the EDIP model for calculation of normalisation references for Denmark in 1990 and for EU in 1985 (Hauschild & Wenzel 1998).

Source of nmVOC	POCP (DK 1990) low- NOx	POCP (EU 1985) high- NOx
Petrol-engine car, exhaust	0.5	0.6
Petrol-engine car, vapour	0.4	0.5
Diesel-engine car, exhaust	0.5	0.6
Power plants	0.4	0.5
Burning of woods or twigs	0.6	0.6
Food industry	0.4	0.4
Surface coating	0.5	0.5
Dry cleaning	0.3	0.3
Refining and distribution of oil	0.4	0.5
Natural gas leakage	0.2	0.2
Farming	0.4	0.4
Other substances to be included		
CH4	0.007	0.007
CO	0.04	0.03

6.4.2 Emission data: CORINAIR

For the purpose of updating normalisation references to 1994 for European countries, data for emissions of VOCs, CO and CH_4 were taken from the CORINAIR 1994 database (Ritter 1997). In the CORINAIR 1994 database, national emissions are summarised in main source sectors according to main source sectors as shown in Table 6-3. These main source sectors differ slightly from the source categories used in the EDIP 1985 study for EU and 1990 study for Denmark.

The main source sectors of CORINAIR 1994 was defined as the source categories to be used in updating normalisation references for European countries. Because these source categories are not identical with the source categories used in the calculations of normalisation references for Denmark and EU, this means that the weighted averages for POCP should be carefully transferred from the previously calculated values. If transfer is not justifiable, new POCP values should be calculated from an analysis of the composition of the emissions of the individual subsectors. Table 6-3 shows the main source sectors of the CORINAIR 1994 database and the equivalent sources of nmVOC applied for use of POCP values.

Table 6-3
Main source sectors as defined in CORINAIR 1994 and source categories applied for calculation of POCP from nmVOC.

#	Main source sector CORINAIR 1994 (Ritter 1997)	Suggested use of POCP values from source category as used in EDIP (Hauschild & Wenzel 1998):
1	Combustion in energy and transformation industries	Stationary combustion/power plants
2	Non-industrial combustion plants	Stationary combustion/power plants
3	Combustion in manufacturing industry	Stationary combustion/power plants
4	Production processes	Industrial processes (non specific)
5	Extraction and distribution of fossil fuels/geothermal energy	Oil refining and distribution
6	Solvent and other product use	Surface coating
7	Road transport	Petrol-engine cars
8	Other mobile sources and machinery	Diesel-engine cars
9	Waste treatment and disposal	Farming[2]
10	Agriculture and Forestry, *luwc*[3]	Farming

1. Road transport is included as emissions from petrol-engine cars (assumption in EDIP 1985/1990 inventory).
2. Best estimate for non-methane VOC from waste treatment and disposal.
3. *luwc:* land use and wood stock change

Table 6-4
Main source sectors used in the CORINAIR 1994 (Ritter 1997) emission inventory and the POCP values for nmVOC assigned to these source categories (Hauschild &Wenzel 1998).

Main source sector (source category)	nmVOC Low-NO_x POCP kt C_2H_4/kt	nmVOC High-NO_x POCP kt C_2H_4/kt
1. Combustion in Energy and transformation industries	0,4	0,5
2. Non-industrial combustion plants *(nmVOC)*	0,4	0,5
3. Combustion in manufacturing industry *(nmVOC)*	0,4	0,5
4. Production processes *(nmVOC)*	0,3	0,3
5. Extraction and distribution of fossil fuels/geothermal energy *(nmVOC)*	0,4	0,5
6. Solvent and other product use *(nmVOC)*	0,5	0,5
7. Road transport *(nmVOC)*[1]	0,4	0,6
8. Other mobile sources and machinery *(nmVOC)*	0,5	0,6
9. Waste treatment and disposal *(nmVOC)*	0,4	0,4
10. Agriculture and Forestry, *luwc*[2] *(nmVOC)*	0,4	0,4

1. Low value: road transport, Denmark; high value from petrol/diesel engine car, exhaust.
2. *luwc:* land use and wood stock change

6.5 Normalisation references

6.5.1 Denmark 1994

The calculation of a normalisation reference for Denmark is shown in detail in Appendix A. The calculated impact potential for nmVOC, CO and CH_4 is shown in Table 6-5.

Table 6-5
Impact potentials calculated for 1994 for nmVOC, CO and CH_4 for Denmark.

Substance	Total emission 1994 (kt/year)	Impact potential 1994 (kt C_2H_4/year)	% distribution
nmVOC	166.1	72.1	69
CO	715.4	28.6	28
CH_4	430.6	3.0	3
Total		103.7	100

The normalisation reference for Denmark in 1994 is calculated in Table 6-6.

Table 6-6
Impact potentials calculated for 1990 and 1994 for nmVOC, CO and CH_4 for Denmark.

	EDIP 1990[1]	This study 1994
Total impact potential (POCP) (kt C_2H_4/year)	100.9	103.7
Population (mio.)	5.14	5.20
Normalisation reference Denmark (kg C_2H_4/capita/year)	**20.0**	**19.9**

1. Hauschild and Wenzel (1998).

6.5.2 European Union 1994

The total impact potential IP(POF) from substances contributing to the impact category for a region like the EU having both areas of low-NO_x and high-NO_x background concentrations is calculated according to the formula

$$IP(POF)_{1994} = \sum_{1}^{n} E_{n,low\text{-}NOx} \cdot POCP_{n,low\text{-}NOx} + \sum_{1}^{n} E_{n,high\text{-}NOx} \cdot POCP_{n,high\text{-}NOx}$$

where $E_{n,\ low\text{-}NOx,\ 1994}$ is the total emission of substances from source category ***n*** to the atmosphere in 1994 for the given area of low-NO_x background concentration [kt per year]

$E_{n,\ high\text{-}NOx,\ 1994}$ is the total emission of substances from source category ***n*** to the atmosphere in 1994 for the given area having high-NO_x background concentration [kt per year]

$POCP_{n,\ low\text{-}NOx}$ is the photochemical ozone creation potential for source category ***n*** in low-NO_x areas [kt C_2H_4-equivalents per kt]

$POCP_{n,\ high\text{-}NOx}$ is the photochemical ozone creation potential for source category ***n*** in high-NO_x areas [kt C_2H_4-equivalents per kt]

For the area covered by EU-15, areas of high- and low-NO_x have been defined as shown in Table 6-7.

Table 6-7
Areas defined as low NO_x and high NO_x background concentration for calculation of the impact potential in EU-15.

Low-NO_x POCP factors used	Sweden, Denmark, Finland and Ireland
High-NO_x POCP factors used	Germany, United Kingdom, France, Italy, Spain, Netherlands, Greece, Belgium, Portugal, Austria, Luxembourg

The calculation of a normalisation reference for EU-15 is shown in detail in Appendix B. The calculated impact potential for nmVOC, CO and CH_4 is shown in Table 6-8.

Table 6-8
Impact potentials calculated for 1994 for nmVOC, CO and CH_4 for EU-15.

Substance	Total emission low NO_x (kt/year)	Total emission high NO_x (kt/year)	Impact potential 1994 (kt C_2H_4/year)	% distribution
nmVOC	1,288.4	14,272.1	7,769	83
CO	2,804.9	42,278.1	1,381	15
CH_4	1,749.0	20,775.7	158	2
Total			9,307	100

The normalisation reference is calculated for EU-15 in 1994 as shown in **Table 6-9**.

Table 6-9
Impact potential calculated for nmVOC, CO and CH_4 for EU-15. Comparison with 1985 values.

	EDIP 1985[1]	This study 1994
Total impact potential (POCP) (kt C_2H_4/year)	5,050	9,307
Population (mio.)	321.7	370
Normalisation reference EU-15, 1994 (kg C_2H_4/capita/year)	**18.0**	**25.2**

1. Hauschild and Wenzel (1998). Based on high-NO_x POCP values for the entire EU.

The low-NO_x countries contribute to the EU-15 normalisation with a higher POCP-emission per capita, as shown in **Table 6-10**.

There are three major source categories contributing to the total impact of nmVOC: Road transport, solvent and other product use, and agriculture and forestry. From **Table 6-10**, it is clear that the difference between the POCP emission per capita in the low-NO_x countries compared to the high-NO_x countries is due to differences in the CORINAIR 1994 emission inventory for nmVOC for the source category “Agriculture and Forestry”. This is probably due the difficulties in estimating nmVOC emissions from this category.

Table 6-10
Comparison between normalisation references for low-NOx and high NOx countries in EU-15, with and without nmVOC emissions from source category “Agriculture and forestry”.

	Normalisation reference for EU-15, 1994 (kg C_2H_4/capita/year)	Normalisation reference for EU-15, 1994 *excluding nmVOC emissions from agriculture and forestry* (kg C_2H_4/ capita /year)
Low-NO_x countries	29.5	21.3
High-NO_x countries	24.9	22.1
Total, EU-15	25.2	22.1

6.5.3 World 1990

One of the aims of this project has been to calculate a global normalisation reference for 1994. A methodology for the calculation of such a “world proxy” is proposed in chapter 3, Development of normalisation references for different geographic areas. This methodology applies to the most frequent situation for impact categories: global emission data cannot be found in an acceptable form or quality.

In the case of POCP, anthropogenic emissions of the key substances (nmVOC, methane and CO) can be found for 1990 in the EDGAR database (Olivier ***et al***. 1996). RIVM has not yet any published global emission data for

1994. Given the data from 1990, it was decided to calculate a normalisation factor for 1990 instead of 1994. Because of the undoubtedly larger uncertainties associated with the calculation of the global emissions from GDP, it is suggested that a 1994 normalisation reference for POCP is calculated when an update of the EDGAR database is at hand.

Appendix C shows the calculation of POCP emissions for the geographical areas as defined in EDGAR. For nmVOC, a division between high-NO_x and low-NO_x areas is done. High-NO_x areas are in Appendix C marked as "HN" (USA, Western Europe, Eastern Europe, Japan) and low-NO_x are marked as "LN" (Canada, Latin America, Africa, Soviet Union (CIS), Middle East, India, China, East Asia, Oceanic areas, Int. shipping). Table 6-11 shows the result of the calculation for POCP in kt C_2H_4 total and the calculated normalisation reference for 1990.

Table 6-11
Calculated normalisation reference for POCP for the world, 1990.

	World proxy 1990
Global POCP, NMVOC (kt C_2H_4)	77,000
Global POCP, methane (kt C_2H_4)	2,000
Global POCP, CO (kt C_2H_4)	37,000
TOTAL global POCP (kt C_2H_4)	116,000
Population	$5.29*10^9$
Normalisation reference World, 1990 (kg C_2H_4/capita/year)	**22**

Table 6-11 shows a very large contribution to the worldwide effect potential from CO emissions. The global CO emission per person calculated from the emissions in the EDGAR database is relatively large compared to the CO emission per person in the CORINAIR database. As low temperature combustion is assumed to be the major source of CO emissions, the reason for this deviation could be the widespread use of uncontrolled combustion in households etc. in the third world. A further assessment of the emission factors for CO used in the EDGAR database has not been pursued.

By using the extrapolation method proposed in chapter 3 the worldwide normalisation reference for photochemical ozone formation is estimated to ***20 kg C_2H_4-eq./capita/year***. The normalisation reference found by using the extrapolation method is slightly lower than the value found by using the 1990 emission inventory.

6.5.4 Comparison of updated normalisation references with previously used normalisation references

In Table 6-12 the normalisation references for photochemical ozone formation for 1994 estimated in this study are compared with the previously estimated normalisation references (Hauschild & Wenzel 1998).

Table 6-12
Summary of normalisation references for photochemical ozone formation estimated in the present study compared with previously normalisation references.

		Denmark	EU-15	World
1990[1]	kg C_2H_4/capita/year	20	18[2]	-
1994	kg C_2H_4/capita/year	20	25	22[3]

1. Hauschild and Wenzel (1998).
2. 1985.
3. 1990.

The normalisation reference for Denmark is approximately the same as the normalisation reference for 1990 whereas the normalisation reference for EU-15 has increased by 25% from 1985 to 1994. The worldwide normalisation reference has been estimated to 22 kg C_2H_4-eq./capita/year based on a worldwide inventory for nmVOC, CO and CH_4.

6.6 Recommendations for future updating

6.6.1 Quality of emission data

Any updating of normalisation references should focus on uncertainties of the data used from emission inventories. The CORINAIR database used in this study is prepared by the European Environment Agency and should as such be considered as the most validated database for European Union. The UN-ECE database is also an option as a considerable number of countries have ratified the ***Convention on Long-range Transboundary Air Pollution*** (UN-ECE, 1979) and the protocol on VOC (UN-ECE, 1991). As apparent from the differences found in section 6.5.2 between POCP (nmVOC) emissions per capita for Scandinavian countries compared to the rest of Europe, the countries reporting nmVOC data to CORINAIR have encountered difficulties in assessing the emissions from source category no. 10 (agriculture and forestry). A future updating should generally focus on the quality of the emission data used, and a special attention should be paid to data from the source category “agriculture and forestry”.

Considerable discrepancy was found between emission data from the European countries in the CORINAIR 1994 database and in the UN-ECE database[8] for 1994. This is especially the case for methane. The reason for these discrepancies has not been found.

6.6.2 NO_x inclusion/exclusion?

POCP is a parameter developed to express the potential of VOCs to create ground level ozone, and emissions of NO_x will thus not be included in the impact assessment for photochemical ozone formation in the EDIP model. The impact of NO_x is in EDIP present through the impact of acidification, nutrient enrichment and human toxicology. However, model calculations have shown that reductions of emissions of NO_x will in many cases have a larger effect than VOC reductions on the reduction of the ozone concentration levels (Fenger 1995). Hauschild and Wenzel (1998) has chosen POCP as the best existing and the most internationally accepted model for the calculation of photochemical ozone potential for emissions of individual substances, and NO_x can not be assigned as a separate factor within this model. The use of POCP as a characterisation factor is still considered as the best internationally accepted method available. The error introduced hereby should however be evaluated.

To give the highest possible ozone reduction, it is necessary not only to reduce VOC and CO emissions, but also NO_x emissions. As the impact of NO_x on ozone production is not included in EDIP, a false impact from this characterisation factor could be expressed in the assessment of a product system by EDIP. The magnitude of this error will be site dependent.

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[8] The UN-ECE database is available at http://www.unece.org.

6.6.3 Focus on most potent individual VOCs?

McBride ***et al***. (1997) has suggested that a more efficient ozone reduction could be achieved if the emission reductions focused on the most potent ozone producers instead of reducing all VOCs regardless of the species. In EDIP, the VOCs are partly divided, not according to their ozone creation potential, but according to source categories. For a more efficient abatement strategy, it might be useful to subdivide the VOCs according to their individual ozone creation potential. For practical reasons, this could be done for a reduced number of highly potential VOCs. E.g., at present solvent using industries will have the same POCP factor (0.4-0.5 as shown in Table 6-2) regardless of the potency of the individual compound in the present EDIP model. During the assessment of a specific product, individual factors applied to individual solvents will give a more realistic impact assessment of the specific tropospheric ozone formation.

6.6.4 Simplified POCP factor for nmVOC?

IVL has in a recent study concluded that POCP ranges might be more useful to introduce in stead of site-specific POCP values (i.e. high-NO_x vs. low NO_x) (Altensted & Pleijel 1998). Except for production processes, all POCP factors in low and high NO_x areas vary between 0,4-0,6 kg C_2H_4/kg for nmVOC. nmVOC from production processes is allocated a POCP factor of 0,3 kg C_2H_4/kg. In the light of the uncertainties involved in the calculation of the POCP factors and the uncertainties of the emission data, it should be considered whether one weighted factor for POCP can be used for both high and low-NO_x areas. This would simplify calculations considerably and save resources in the elaboration of normalisation references for the use in LCA.

6.6.5 Exclusion of methane in future POCP calculations?

In the light of the relatively small contribution from methane to the total impact from POCP, it should be considered whether methane should be excluded in future POCP calculations.

6.6.6 Worldwide

The calculated worldwide normalisation reference for 1990 is relatively high as compared to the normalisation references for EU and Denmark. This is due to the relatively high global CO emissions per capita derived from the EDGAR database. The uncertainties of the emission data in the EDGAR database should be compared to the uncertainties of the CORINAIR database.

The POCP factors used to calculate the worldwide normalisation reference are derived from European POCP model calculations and divided into low-NO_x and high-NO_x areas. POCP factors in tropical areas might deviate considerably from the European POCP values meteorological factors (i.e. sunlight) influence the formation of ozone. This potential source of error should be investigated in the future when calculating a worldwide normalisation reference for POPC.

6.7 References

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Appendix A.1: Calculation of normalisation reference for Denmark.

Total POCP calculated from anthropogenic NMVOC-, CO and CH_4-emissions from Denmark.

Source category	Low-NO_x factor POCP	DK 1994 VOC-emission kt/year	Photochemical ozone-formation potential kg C2H4/year	% distribution POCP
1. Combustion in Energy and transformation industries *(nmVOC)*	0.4	1.4	0.5	0.5
2. Non-industrial combustion plants *(nmVOC)*	0.4	8.2	3.3	3.2
3. Combustion in manufacturing industry *(nmVOC)*	0.4	0.8	0.3	0.3
4. Production processes *(nmVOC)*	0.3	3.4	1.0	1.0
5. Extraction and distribution of fossil fuels/geothermal energy *(nmVOC)*	0.4	6.9	2.7	2.6
6. Solvent and other product use *(nmVOC)*	0.5	40.6	20.3	19.6
7. Road transport *(nmVOC)*	0.4	74.1	29.6	28.6
8. Other mobile sources and machinery *(nmVOC)*	0.5	19.1	9.6	9.2
9. Waste treatment and disposal *(nmVOC)*	0.4	0.0	0.0	0.0
10. Agriculture and Forestry*, luwc (nmVOC)*	0.4	11.7	4.7	4.5
Total nmVOC		166.1	72.1	69.5
CO *(total)*	0.04	715.4	28.6	27.6
CH4 *(total excluding "nature")**	0.007	430.6	3.0	2.9
Total POCP, Denmark 1994			103.72	100.00

Population 1994 (Mio.)	5,2

	kg/capita/year	kg C2H4/capita/year
Emissions per capita (total NMVOC)	31,9	13,9
Emissions per capita (CO)	137,6	5,5
Emissions per capita (CH4 man made)	82,8	0,6
Normalisation reference (1994)		**19,9**

Appendix A.2: Calculation of normalisation reference for EU-15

	Total 1994 emission from low-NO_x EU countries[1, 2]	Total 1994 emission from high-NO_x EU countries	Low-NO_x POCP	High-NO_x POCP	POCP contribution from low-NOx EU countries	POCP contribution from high-NOx EU countries	Total POCP contribution from EU countries	% distri-bution
	(b)	(c) = (a)-(b)	(d)	(e)	(f) = (b)*(d)	(g) = (c)*(e)	(h)	POCP
Source category	kt/year	kt/year	kt C2H4/kt	kt C2H4/kt	kt C2H4/year	kt C2H4/year	kt C2H4/year	
1. Combustion in Energy and transformation industries *(nmVOC)*	6.8	141.1	0.4	0.5	2.7	70.5	73.3	0.8
2. Non-industrial combustion plants *(nmVOC)*	57.2	491.7	0.4	0.5	22.9	245.9	268.8	2.9
3. Combustion in manufacturing industry *(nmVOC)*	6.4	54.8	0.4	0.5	2.6	27.4	30.0	0.3
4. Production processes *(nmVOC)*	52.2	927.1	0.3	0.3	15.7	278.1	293.8	3.2
5. Extraction and distribution of fossil fuels/geothermal energy *(nmVOC)*	25.9	815.2	0.4	0.5	10.3	407.6	418.0	4.5
6. Solvent and other product use *(nmVOC)*	253.5	3,659.3	0.5	0.5	126.8	1,829.6	1,956.4	21.0
7. Road transport *(nmVOC)*	329.5	4,696.3	0.4	0.6	131.8	2,817.8	2,949.6	31.7
8. Other mobile sources and machinery *(nmVOC)*	71.8	772.6	0.5	0.6	35.9	463.6	499.5	5.4
9. Waste treatment and disposal *(nmVOC)*	2.7	214.6	0.4	0.4	1.1	85.9	86.9	0.9
10. Agriculture and Forestry, *luwc (nmVOC)*	482.4	2,500.0	0.4	0.4	192.9	1,000.0	1,192.9	12.8
Total nmVOC	1,288.4	14,272.7			542.7	7,226.4	7,769.0	
CO *(total)*	2,804.9	42,278.1	0.04	0.03	112.2	1,268.3	1,380.5	14.8
CH_4 *(total excluding "nature")**	1,749.0	20,775.7	0.007	0.007	12.2	145.4	157.7	1.7
Total POCP					667.5	8,640.6	9,307.3	100.0

	Low-NOx countries	High-NOx countries			Low-NOx countries	High-NOx countries	Total EU-15
Population 1994 (Mio.)	22.6	347.4			22.6	347.4	**370.0**
Emissions per capita (total nmVOC) (kg/capita/year)	57.0	41.1					
Emissions per capita (CO) (kg/capita/year)	124.1	121.7					
Emissions per capita (CH_4 man made) (kg/capita/year)	77.4	59.8					
					Low-NOx EU countries	High-NOx EU countries	Total EU-15
Normalisation reference (1994) (kg C_2H_4/capita/year)					**29.5**	**24.9**	**25.2**
Normalisation reference (1994) (kg C_2H_4/capita/year) *excluding luwc*					21.3	22.1	22.1

1. CORINAIR 94 Summary report, Report from the European Topic Centre on Air Pollution (1997)
2. Low NOx countries include Denmark, Sweden, Finland and Ireland
3. 75% of the CH_4 emissions listed arise from agriculture and forestry
4. nmVOC contribution from luwc is 21 kg nmVOC/person/year in low-NOx countries, and in high-NOx countries only 6,8 kg nmVOC/person/year.

Appendix A.3: Calculation of a worldwide normalisation reference

Source/sub-sector			TOTAL	CAN.	USA	LAT. AM.	AFRICA	W. EUR.	E. EUR.	CIS	M. EAST	INDIA+	CHINA+	E ASIA	OCEAN.	JAPAN	INT. HIP
	Low-NO_x POCP (LN)	High-NO_x POCP (HN)		LN	HN	LN	LN	HN	HN	LN	LN	LN	LN	LN	LN	HN	
			Tg nmVOC	Tg nmVOC	Tg nmVOC	Tg nmVOC	Tg nmVOC	Tg nmVOC	Tg nmVOC	Tg nmVOC	Tg nmVOC	Tg nmVOC	Tg nmVOC	Tg nmVOC	Tg nmVOC	Tg nmVOC	Tg nmVOC
Total			177.5	2.9	19.0	20.3	30.2	17.7	3.1	17.0	12.3	18.7	18.2	11.0	1.6	5.4	0.0
Fossil fuel: combustion			41.6	1.2	8.8	3.7	1.4	8.1	1.3	5.3	2.0	1.2	2.7	2.5	0.8	2.5	0.0
Fossil fuel: non-combustion			27.3	0.8	1.4	3.1	2.8	1.8	0.3	6.9	7.4	0.3	1.2	1.0	0.3	0.0	0.0
Biofuel			30.7	0.1	0.9	2.3	8.3	0.2	0.0	0.1	0.7	8.5	6.3	3.3	0.1	0.0	0.0
Industrial processes/solvents			33.5	0.5	6.4	2.3	2.0	5.9	1.0	2.9	0.9	2.9	3.9	1.8	0.3	2.6	0.0
Landuse/waste treatment			44.4	0.3	1.5	9.0	15.7	1.7	0.5	1.8	1.3	5.7	4.1	2.4	0.2	0.3	0.0
Total			TOTAL	CAN.	USA	LAT. AM.	AFRICA	W. EUR.	E. EUR.	CIS	M. EAST	INDIA+	CHINA+	E ASIA	OCEAN.	JAPAN	INT. HIP
	Low-NO_x POCP (LN) value (TgC_2H_4/Tg)	High-NO_x POCP (HN) value (TgC_2H_4/Tg)	Tg C_2H_4	LN Tg C_2H_4	HN Tg C_2H_4	LN Tg C_2H_4	LN Tg C_2H_4	HN Tg C_2H_4	HN Tg C_2H_4	LN Tg C_2H_4	LN Tg C_2H_4	LN Tg C_2H_4	LN Tg C_2H_4	LN Tg C_2H_4	LN Tg C_2H_4	HN Tg C_2H_4	LN Tg C_2H_4
Fossil fuel: combustion	0.4	0.5	18.7	0.5	4.4	1.5	0.5	4.0	0.6	2.1	0.8	0.5	1.1	1.0	0.3	1.3	0.0
Fossil fuel: non-combustion	0.4	0.5	11.3	0.3	0.7	1.2	1.1	0.9	0.1	2.8	3.0	0.1	0.5	0.4	0.1	0.0	0.0
Biofuel	0.4	0.4	12.3	0.0	0.4	0.9	3.3	0.1	0.0	0.0	0.3	3.4	2.5	1.3	0.0	0.0	0.0
Industrial processes/solvents	0.5	0.5	16.7	0.3	3.2	1.2	1.0	2.9	0.5	1.5	0.5	1.5	2.0	0.9	0.1	1.3	0.0
Landuse/waste treatment	0.4	0.4	17.8	0.1	0.6	3.6	6.3	0.7	0.2	0.7	0.5	2.3	1.6	1.0	0.1	0.1	0.0
TOTAL POCP, Tg C2H4			76.8														

Global anthropogenic methane emissions in 1990 (EDGAR Database ver. 2.0, RIVM 1996)

	TOTAL	CAN.	USA	LAT. AM.	AFRICA	W. EUR.	E. EUR.	CIS	M. EAST	INDIA+	CHINA+	E ASIA	OCEAN.	JAPAN	INT. SHIP
Total (Tg CH4)	320.2	3.9	41.6	32.4	26.8	23.4	10.8	47.0	10.3	49.9	46.7	18.6	5.7	3.2	0.02
POCP factor (TgC2H4/Tg CH4)	0.007														
Total, POCP Tg C2H4	**2.2**														

Global anthropogenic CO emissions in 1990 (EDGAR Database ver. 2.0, RIVM 1996)

Source/sub-sector	POCP factor	TOTAL	CAN.	USA	LAT. AM.	AFRICA	W. EUR.	E. EUR.	CIS	M. EAST	INDIA+	CHINA+	E ASIA	OCEAN.	JAPAN	INT. SHIP
Total, Tg CO		974.3	10.9	95.1	148.5	239.2	68.5	16.9	65.6	32.3	110.0	111.5	57.0	6.8	11.8	0.1
POCP factor (Tg C_2H_4/Tg)			0.04	0.03	0.04	0.04	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.04
Total, POCP Tg C_2H_4		**37.0**	0.4	2.9	5.9	9.6	2.1	0.5	2.6	1.3	4.4	4.5	2.3	0.3	0.4	0.0

7 Acidification

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7.1 Summary

This chapter summarises the presently available data on emissions of acidifying substances to the Danish and the European environment. The contributing emissions include:

- SO_x - oxides of sulfur
- NO_x - nitrogen oxides
- NH_3 - ammonia

Emission data for these substances are generally available for Denmark and the European countries (EU-15) as well as number of other European countries. The normalisation references for acidification are presented in **Table 7-1**. The worldwide normalisation references is calculated by extrapolation from the normalisation factor for EU-15.

Table 7-1
Summary of normalisation references for acidification for Denmark, EU-15 and Worldwide in 1994.

		Denmark	EU-15	Worldwide
Acidification	kg SO_2-eq./capita/year	101	74	59

SO_x accounts for 30-45%, NO_x for 30-35% and NH_3 for 25-40% of the effect potential contributing to the normalisation reference. The normalisation reference is relatively certain as the relevant emissions to air have been measured through many years according to the ***Convention on Long-range Transboundary Air Pollution*** and the following Protocols.

7.2 Description of the impact category

Acidification is a local and regional effect. Acidification is caused by releases of protons in the terrestrial or aquatic ecosystems. The acidifying substances are only contributing to acidification if the anion is leached out from the system. If the anion stays in the system, natural processes usually neutralise the acid. In certain areas acidification leads to increased mobility of heavy metals and aluminium.

In the terrestrial ecosystem the effects are seen in softwood forests (e.g. spruce) but also in hardwood forests (e.g. beech) as inefficient growth and as a final consequence dieback of the forest. These effects are mainly seen in Scandinavia and in the middle/eastern part of Europe. In the aquatic ecosystem the effects are seen as clear acid lakes without any wildlife. These effects are mainly seen in Scandinavia. Buildings, constructions, sculptures and other objects worthy of preservation are also damaged by e.g. acid rain.

The potential effects are dependent on the acidification potential of the specific substance as well as the nature of the receiving ecosystem e.g. nitrogen oxides (NO_x) can be fixed in the ecosystem due to uptake in plants. This effect depends on the actual geographical area.

Acidifying substances can be divided in different groups according to their chemical nature: strong acids, acidic anhydrides, ammonia, and organic acids. Examples on ***strong acids*** are hydrochloric acid (HCl), nitric acid (HNO_3), and sulfuric acid (H_2SO_4) and they react with water as shown in the following example:

$H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$

i.e. one mole of sulfuric acid release 2 mole of protons (H^+).

Examples on ***acidic anhydrides*** are SO_2, SO_3, and NO_x and they react as e.g.:

$SO_2 + H_2O \rightarrow H_2SO_3 \rightarrow 2H^+ + SO_3^{2-}$

i.e. one mole of sulfur dioxide release 2 mole of protons (H^+).

Ammonia is normally considered as a base but in the presence of certain bacteria, ammonia is mineralised (nitrification) to nitrite and nitrate releasing protons:

$NH_3 + 2O_2 \rightarrow H^+ + NO_3^- + H_2O$

Organic acids are assumed to be mineralised rather than dissociated and leached. They are therefore not classified as contributors to acidification.

See also Hauschild and Wenzel (1998) for further description of the impact category.

7.3 Substances contributing to the impact category

Substances are considered to have an acidification effect if they result in (Hauschild & Wenzel 1998):

- Supply or release of hydrogen ions (H^+) in the environment
- Leaching of the corresponding anions from the concerned system

The substances normally considered as contributors to acidification are:

- Sulfur Dioxide (SO_2)
- Sulfur Trioxide (SO_3)
- Nitrogen Oxides (NO_x)
- Hydrogen Chloride (HCl)
- Nitric Acid (HNO_3)
- Sulfuric Acid (H_2SO_4)
- Phosphoric Acid (H_3PO_4) (note: the anion does not leach and the contribution to acidification is in practice equal to zero)
- Hydrogen Fluoride (HF)
- Hydrogen Sulfide (H_2S)
- Ammonia (NH_3)

SO_2 is used as basis for determination of the acidification potential or the equivalence factor. The method of establishing effect factors for acidifying substances is based on stoichiometric considerations and it is internationally accepted. The equivalency factors are determined as:

$$EF = \frac{n}{2 * M_W} * 64.06 = \frac{n}{M_W} * 32.03$$

where **M_w** is the molecular weight of the substance emitted [g/mole]
n is the number of hydrogen ions released in the recipient as a result of conversion of the substance
64.06 g/mole is the molecular weight of SO_2

The equivalency factors for the acidifying substances are compiled in Table 7-2.

Table 7-2
Equivalency factors (EF) for acidifying substances [kg SO2-eq./substance] (Hauschild & Wenzel, 1998).

Substance	Formula	Reaction	Molar weight g/mole	n	EF kg SO_2/kg
Sulfur dioxide	SO_2	$SO_2+H_2O \rightarrow H_2SO_3 \rightarrow 2H^++SO_3^{2-}$	64.06	2	1
Sulfur trioxide	SO_3	$SO_3+H_2O \rightarrow H_2SO_4 \rightarrow 2H^++SO_4^{2-}$	80.06	2	0.80
Nitrogen dioxide	NO_2	$NO_2+½H_2O+¼O_2 \rightarrow H^++NO_3H^-$	46.01	1	0.70
Nitrogen oxide	NO_x^1	$NO_2+½H_2O+¼O_2 \rightarrow H^++NO_3H^-$	46.01	1	0.70
Nitrogen oxide	NO	$NO+O_3+½H_2O \rightarrow H^++NO_3^- +¾O_2$	30.01	1	1.07
Hydrogen chloride	HCl	$HCl \rightarrow H^++Cl^-$	36.46	1	0.88
Hydrogen nitrate	HNO_3	$HNO_3 \rightarrow H^++NO_3^-$	63.01	1	0.51
Hydrogen sulfate	H_2SO_4	$H_2SO_4 \rightarrow 2H^++SO_4^{2+}$	98.07	2	0.65
Hydrogen phosphate	H_3PO_4	$H_3PO_4 \rightarrow 3H^++PO_4^{3-}$	98.00	3	0.98
Hydrogen fluoride	HF	$HF \rightarrow H^++F^-$	20.01	1	1.60
Hydrogen sulfide	H_2S	$H_2S+3/2O_2+H_2O \rightarrow 2H^++SO_3^{2-}$	34.03	2	1.88
Ammonium	NH_3	$NH_3+2O_2 \rightarrow H^++NO_3^-+H_2O$	17.03	1	1.88

1. x is assumed to have an average value of 2.

The ***acidification potential (AP)*** can be estimated as SO_2-equivalents:

$$AP = \sum_i EF_i * m_i \left[SO_2 - eq.\right]$$

where **EF_i** is the equivalency factor for the substance i
m_i is the emission of the substance i

7.4 Methodology

The calculation of the normalisation reference for acidification has been carried out according to the methodology described in (Hauschild & Wenzel, 1998). The normalisation reference is calculated as:

$$\text{Normref}_{\text{acid}} = \frac{\sum_i^n m_i * EF_{i,\text{acid}}}{N} \qquad \left[\frac{\text{kg } SO_2 - \text{eq.}}{\text{person} * \text{year}}\right]$$

where: ***Normref*$_{acid}$** is the normalisation reference for acidification

mi is emitted quantity of the substance i
EF$_i$ is the equivalence factor for the substance i
N is number of capita in the considered area

Included in the normalisation reference are the following substances:

- Sulfur Dioxide (SO_2)
- Nitrogen Oxides (NO_x)
- Ammonia (NH_3)

as the substances are the only substances considered in the international regulations of acidifying substances.

7.5 Normalisation reference

7.5.1 Denmark

The emission data used in the calculation of the normalisation reference is presented in Table 7-3.

Table 7-3
Danish emission of acidifying substances in 1990 and 1994.

Substance	Formula	EF	Emission		Impact potential	
		g SO2/g	1990[1] kt/year	1994[2] kt/year	1990 kt SO2/year	1994 kt SO2/year
Oxides of sulfur	SOx	1	180	158	180	158
Nitrogen oxides	NOx	0.7	269	276	188	193
Ammonia	NH3	1.88	140	122	263	176
Hydrogen chloride	HCl	0.88	3.8	-	3.3	-
Total					634	527

1. Hauschild and Wenzel (1998).
2. Ritter (1997).

The Danish normalisation reference for acidification (1994) can be calculated as:

101 kg SO_2-equivalents/year/capita

The similar value for 1990 was 124 kg SO_2-equivalents/year/capita. This means that the normalisation factor is reduced by 20%.

The contribution of acidifying impact from the four substances included in the 1990 normalisation factor is 28%, 30%, 41%, and <1% for SO_x, NO_x, NH_3, and HCl, respectively. In 1994 the distribution can be calculated to 30%, 37%, and 33% for SO_x, NO_x, and NH_3 respectively.

The quality of the data used for calculation of the Danish normalisation reference is expectedly of high quality, as the registration of the actual emissions has been performed in a number of years. According to Ritter (1997) the emission estimates are made on highest level e.g. level A (the emission estimates are ***fully detailed***).

7.5.1.1 EU-15

The emission data used in the calculation of the normalisation reference is presented in Table 7-4. Emission data for approximately forty European countries is presented in Appendix B.

Table 7-4
European emission of acidifying substances in 1990 and 1994.

Substance	Formula	EF	Emission		Impact potential	
		g SO2/g	1990[1] kt/year	1994[2] kt/year	1990 EU-12 kt SO2/year	1994 EU-15 kt SO2/year
Oxides of sulfur	SOx	1	12,450	12,000	12,450	12,047
Nitrogen oxides	NOx	0.7	11,960	12,500	8,372	8,781
Ammonia	NH3	1.88	3,188	3,530	5,993	6,645
Total					26,815	27,473

1. Hauschild and Wenzel (1998).
2. Ritter (1997).

The European (EU-15) normalisation reference for acidification (1994) can be calculated as:

74 kg SO_2-equivalents/year/capita

The similar value for 1990 was 83 kg SO_2-equivalents/year/capita. This means that the normalisation factor is reduced by 10%.

The contribution of acidifying impact from the three substances included in the 1994 normalisation factor is 44%, 32%, and 24% for SO_x, NO_x, and NH_3 respectively. Normalisation references for the fifteen European countries included in EU-15 are presented in Appendix C.

The quality of the data used in the calculation of the European normalisation reference depends on the actual countries as the emission estimates are provided by the national authorities/national reference centres. Similar data can be found in a number of sources all based on the same national information. The CORINAIR report inform about the status of the presented emission estimates, and the 1994 emission are assessed as follows:

- A (the emission estimates are ***fully detailed***): Austria, Belgium, Denmark, Greece, Ireland, Luxembourg, Sweden, United Kingdom
- B (the emission estimates are ***detailed***): Germany, Netherlands
- C (the emission data cover the ***main source sectors***): Finland, France, Italy, Portugal, Spain

According to the update report including 1995 emissions (Koch 1998), the assessment of the status of the estimates are decreased for two countries and the data are missing for four countries at the time of publication. The process of making and publishing the emission estimates is continuous i.e. the national estimates are improved when better emission factors become available.

7.5.2 World

Acidification has been used as case for investigation and illustration of relations between normalisation factors and different general available data as economical data, population, and production data etc. (see chapter 3, Development of normalisation references for different geographic areas, for details). By testing different relations between kg SO_2-eq./capita/year and the considered factors the best relation is shown to be kg SO_2-eq./capita/year vs. ln(GDP/capita). This extrapolation method results in the following worldwide normalisation reference for acidification:

59 kg SO_2-eq./capita/year

The quality of the data used as basis for the extrapolation method is described in chapter 3.

7.5.3 Summary

The normalisation references for acidification covering different geographical areas compared with the previous normalisation references; see Table 7-5.

Table 7-5
Summary of normalisation references for acidification for different areas in 1990 and 1994.

		Denmark	EU-15	World
1990[1]	kg SO2-eq./capita/year	124	83	-
1994	kg SO2-eq./capita/year	101	74	59

[1] Hauschild and Wenzel (1998).

The normalisation references for Denmark and EU-15 are decreased by 10 - 20% in the years 1990 to 1994.

7.6 Recommendations for future update

As mentioned above the information on and quality of emissions depend on the national estimates. The limit for improvement of the normalisation references is the speed of national collection/estimation of emissions. The national reporting to e.g. ***European Topic Centre on Air Emissions*** (ETC Air Emissions) or the ***Co-operative programme for monitoring and evaluation of the long range transmission of air pollutants in Europe*** (EMEP) is also a limiting factor. These centres collect and evaluate national information on air pollutants according to the ***Convention on Long-range Transboundary Air Pollution*** (UN-ECE 1979). Potential data sources to be used in future updating of the normalisation reference for acidification is compiled in Appendix A.

7.7 References

Hauschild, M. & Wenzel, H. 1998, Acidification as a criterion in the environmental assessment of products in ***Environmental assessment of products. Volume 2 Scientific background*** eds. Hauschild, M. & Wenzel, H. London: Chapman & Hall.

Koch, D. 1998, ***Air emissions - Annual topic update 1997.*** Topic Report no.4. European Environment Agency.

Ritter, M. 1997, ***CORINAIR 94 - Summary Report - European Emission Inventory for Air Pollutants***. Copenhagen: European Environment Agency.

UN-ECE 1979, ***Convention on Long-range Transboundary Air Pollution***. United Nations, Economic Commission for Europe. Available: http//:www.unece.org.

Appendix A: Data sources

The substances contribution to acidification (SO_2, NO_x, and NH_3) are all systematically registered due to different conventions on air pollution (e.g. “Convention on Long-range Transboundary Air Pollution” (UN-ECE 1979)). Therefore, these emissions can be expected to be updated regularly e.g. yearly for most of the countries. The data sources can be divided in databases (paper) databases (electronic), and organisations.

Databases (paper)

- CORINAIR reports (until now 1990 and 1994 data).

- Topic reports. Air emissions - Annual Topic Update. Reports made by European Topic Centre on Air Emissions (ETC Air Emissions) and published by European Environment Agency.

Databases (electronic)

- **CORINAIR database** - expected to contain data updated yearly (National as well as European databases can be expected to be public available in the future.); http://www.aeat.co.uk/netcen.
- **EMEP** - Tables of anthropogenic emissions in the ECE region (SO_2, NO_x, NH_3. http://www.emep.int.

Organisations

- **EMEP** - co-operative programme for monitoring and evaluation of the long range transmission of air pollutants in Europe. Contact:
  Det norske meteorologiske institutt (DNMI)
  Postboks 43, Blindern,
  0313 Oslo
  Phone [47] 22 96 30 00
  Fax [47] 22 96 30 50
  e-post: met.inst@dnmi.no
  Homepage: http:/www.dnmi.no

- **ETC Air Emissions**
  Umweltbundesamt UBA
  Contact person: Dietmar Koch
  Bismarckplatz 1
  D-14193 Berlin
  Germany
  Phone: [49] 30 8903 2392
  Fax: [49] 30 8903 2178
  E-mail: dietmar.koch@uba.de
  Homepage: http://www.aeat.co.uk/netcen.

- **National Reference Centres for Air Emissions**

Appendix B: Emission data

The date presented in the table is based on Ritter (1997)/Eurostat (1998) except where other references are given.

	Population	SO_2 ton/year	NO_x ton/year	NH_3 ton/year
Denmark, 1990[1]	5,14E+06	1,80E+05	2,69E+05	1,40E+05
Denmark, 1994	5,20E+06	1,58E+05	2,76E+05	9,36E+04
Austria	8,00E+06	5,49E+04	1,71E+05	8,62E+04
Belgium	1,01E+07	2,79E+05	3,74E+05	7,89E+04
Finland	5,10E+06	1,11E+05	3,88E+05	4,10E+04
France	5,77E+07	1,01E+06	1,68E+06	6,67E+05
Germany	8,11E+07	3,00E+06	2,27E+06	6,23E+05
Greece	1,04E+07	5,56E+05	3,57E+05	4,45E+05
Ireland	3,60E+06	1,77E+05	1,17E+05	1,25E+05
Italy	5,70E+07	1,44E+06	2,16E+06	3,89E+05
Luxembourg	4,00E+05	1,28E+04	2,26E+04	7,12E+03
Netherlands	1,53E+07	1,46E+05	5,29E+05	1,72E+05
Portugal	9,90E+06	2,73E+05	2,49E+05	9,26E+04
Spain	3,91E+07	2,06E+06	1,22E+06	3,44E+05
Sweden	8,70E+06	7,42E+04	4,44E+05	5,06E+04
UK	5,82E+07	2,70E+06	2,39E+06	3,20E+05
EU15	3,70E+08	1,20E+07	1,25E+07	3,53E+06
Albania	3,38E+06	5,50E+04	2,40E+04	3,10E+04
Armenia	3,63E+06	4,00E+03	4,00E+03	0,00E+00
Azerbaijan	7,53E+06	0,00E+00	0,00E+00	0,00E+00
Belarus	1,04E+07	3,24E+05	2,03E+05	4,00E+03
Boz&Herz	3,57E+06	3,20E+04	1,30E+04	3,10E+04
Bulgaria	8,51E+06	1,48E+06	2,30E+05	1,46E+05
Croatia	4,51E+06	8,90E+04	5,90E+04	3,30E+04
Cypres	0,00E+00	4,60E+04	2,10E+04	0,00E+00
Czech Rep.	1,03E+07	1,27E+06	4,35E+05	9,20E+04
Estonia	1,49E+06	1,41E+05	4,30E+04	1,40E+04
FYROM	2,16E+06	1,06E+05	3,90E+04	1,70E+04
Georgia	5,45E+06	0,00E+00	0,00E+00	0,00E+00
Hungary	1,01E+07	7,41E+05	1,87E+05	1,60E+05
Iceland	2,69E+05	2,40E+04	2,90E+04	3,00E+03
Latvia	2,54E+06	5,10E+04	4,50E+04	1,60E+04
Lichtenstein	3,10E+04	0,00E+00	1,00E+03	0,00E+00
Lithaunia	3,74E+06	1,17E+05	7,70E+04	8,00E+04
Malta	3,67E+05	0,00E+00	0,00E+00	0,00E+00
Moldova	4,44E+06	9,90E+04	1,80E+04	0,00E+00
Norway	4,33E+06	3,40E+04	2,22E+05	2,50E+04
Poland	3,86E+07	2,61E+06	1,11E+06	3,84E+05
Romania	2,27E+07	9,12E+05	3,49E+05	2,21E+05
Russian Fed.	1,48E+08	2,98E+06	2,00E+06	7,72E+05
Slovak Rep.	5,34E+06	2,40E+05	3,10E+05	0,00E+00
Slovenia	1,93E+06	1,77E+05	6,60E+04	2,20E+04
Switzerland	7,17E+06	3,10E+04	1,39E+05	6,00E+04
Turkey	6,08E+07	3,54E+05	1,75E+05	0,00E+00
Ukraine	5,18E+07	1,72E+06	5,68E+05	1,50E+04

1. Hauschild and Wenzel (1998).

Appendix C: Normalisation references for EU-15 countries

Country	Normalisation reference kg SO2-eq./person/year	Reference
Austria	42	1
Belgium	68	1
Denmark 1994	101	1
Finland	90	1
France	60	1
Germany	71	1
Greece	158	1
Ireland	137	1
Luxembourg	105	1
Netherlands	55	1
Portugal	63	1
Spain	91	1
Sweden	55	1
UK	85	1
EU-15	74	1

1. Ritter (1997).

8 Nutrient enrichment

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8.1 Summary

The actual emissions for the same reference year, 1994, are inventoried for all environmental impact categories.

In addition to point source loading, nutrients are also input to inland and marine waters by diffuse loading and atmospheric deposition. The normalisation references are shown in Table 8-1.

Table 8-1
Normalisation references for nutrient enrichment for Denmark, EU-15, and worldwide.

	Denmark	EU-15	Europe-24	Worldwide
kg N-equivalents/capita/year	53	24	24	19
kg P-equivalents/capita/year	0.8	0.4	0.4	0.3
kg NO_3^--equevalents/capita/year	260	119	119	95

The most significant diffuse sources of nutrient input to the aquatic environment are leaching of nitrogen from cultivated land and the deposition from the atmosphere of gaseous nitrogen compounds. Because of the ongoing reduction in direct point source discharges, diffuse loading and atmospheric deposition will eventually come to account for a relatively greater share of inputs to inland and marine waters, and hence be of correspondingly greater importance for the state of the environment.

8.2 Description of the impact category

The injurious effects of extensive quantities of nutrient salts have been observed regularly in lakes for many years. However, the discovery that the bottom of large bodies of water was practically oxygen-free and lifeless in some part of the year came as an unpleasant surprise to many people and triggered serious discussion of nutrient salt emissions and their potential impact on the environment. In connection with the 1987 Action Plan on the Aquatic Environment, a Danish nation-wide programme was established to monitor nutrient loading of aquatic areas from point sources, agriculture and the atmosphere to enable the expected reduction in loading to be followed. By point sources are understood discharges from sewage works, separate industrial discharges, storm water outfalls, freshwater, marine and terrestrial saltwater fish farms, and sparsely built-up areas.

8.2.1 Cause of oxygen depletion

The cause of oxygen depletion found in the bottom layers of lakes and coastal waters is nutrient enrichment. It can thus be defined as “an enrichment of the aquatic environment with nutrient salts leading to an increased production of planktonic algae and higher aquatic plants, which in time leads to a reduction in the water quality and in the value of the exploitation which occurs in the area" (Christensen ***et al***. 1993). The algae sink to the bottom and are broken down consuming oxygen in the bottom layer. If fresh oxygen-rich water from the surface does not reach the bottom layers, the oxygen concentration near the bottom will gradually be reduced until the bottom-dwelling organisms move away or die.

The classification step defines nutrient enrichment as the man-made impact on aquatic or terrestrial systems of nitrogen, N, or phosphorus, P.

The total nutrient enrichment potential expresses the emissions as an equivalent emission of the reference substance NO_3^-.

The total impact potentials of the Danish emissions of nutrient salts in 1994 are used as reference for the normalisation of the potentials for nutrient enrichment. The normalisation references are presented as the average nutrient enrichment potential per Dane.

In a tripartite division of environmental impact categories into global, regional and local, nutrient enrichment is designated a local and a regional impact. For local and regional impact categories, the Danish or European emissions and populations are used to calculate normalisation references. To apply a comparable scale to impact potentials for the global impact categories (based on estimated global emissions) and the regional impact categories (based on Danish or European emissions), the environmental impact potentials found as the background impact are divided by the population of the region for which they were calculated. The environmental impact potential is thus expressed as the person-equivalent, i.e. the average contribution from each individual person in the area concerned.

8.3 Substances contributing to the impact category

8.3.1 Macro-nutrients

One of the two macro-nutrients nitrogen and phosphorus is usually the limiting element for the growth of primary producers, and it is therefore reasonable to consider only the elements nitrogen and phosphorus as contributors to nutrient enrichment. In Danish lakes, phosphorus deficiency, or a combination of nitrogen and phosphorus deficiencies, is typically limiting for growth, and their addition promotes algae growth. In Danish coastal waters and seas, nitrogen is often the limiting nutrient. Substances containing nitrogen or phosphorus in a biologically available form are therefore classified as potential contributors to nutrient enrichment.

Three equivalence factors are defined for use in the calculation of the potential contributions from a given substance:

- the N potential, which expresses the substance's nitrogen content,
- the P potential, which expresses the substance's phosphorus content, and
- the equivalence factor for the total nutrient enrichment potential, where the nitrogen and phosphorus contents are aggregated in a figure based on the assumption of an average ratio of 16:1 between the nitrogen and phosphorus contents in aquatic organisms.

8.3.2 Reference substance

The total nutrient enrichment potential expresses the emissions as an equivalent emission of the reference substance NO_3^-.

As it is evident from the formula on the average composition of aquatic organisms, the ratio of nitrogen to phosphorus is of the order of 16. If the concentration of bio-available nitrogen is significantly more than 16 times the concentration of bio-available phosphorus in an ecosystem, it is thus reasonable to assume that phosphorus is the limiting nutrient and vice versa. Since most of the atmosphere consists of free nitrogen, N_2, further addition of N_2 will not have any effect. N_2 is therefore not classified as contributor to nutrient enrichment. The most important airborne emissions include oxides of nitrogen, NO_x, which are predominantly emitted from incineration processes, and ammonia, NH_3, which is especially emitted from agricultural activities. Airborne emissions of phosphate are quite small and are therefore not included in the calculations.

Most of the nitrogen loading to the aquatic environment is mainly attributable to leaching from the root zone of agricultural land. An important part of the nitrogen loading is related to the use of nitrogen fertilisers and the number of livestock. Apart from the man-made emissions from agriculture an important loading of nitrogen comes from various point sources such as waste water treatment plants, industry, fish farming and from sparsely built-up areas.

Most of the phosphorus loading of surface water is attributable to discharges from point sources, especially municipal sewage and industrial effluent. Only a small part of the industrial sector is responsible for the majority of wastewater containing phosphorus. To name just a few important industries the fertiliser industry and other related chemical industries manufacturing products containing phosphorus (e.g. pesticides and detergents), as well as the pulp and paper industry and fish processing industry should be mentioned. However, leaching from agricultural land also plays a significant part.

8.4 Updating of the normalisation reference for Denmark

For nutrient enrichment, the Danish emissions of N and P are used as normalisation references. These are summarised, and their environmental impact potentials calculated in Table 8-2.

8.4.1 Nitrogen loading to the aquatic environment

The total loading of the Danish aquatic environment with nitrogen and phosphorus in 1994 is summarised by the Danish National Environmental Research Institute (Larsen ***et al***. 1995).

Part of this loading is emitted via the fresh waters and some of the nitrogen is removed on the way to the marine systems by denitrification in watercourses and lakes. Loading of the fresh waters with nitrogen is thus greater than the quantity conveyed to the marine areas via the watercourses.

It has not been possible to find comprehensive accounts for losses on its way towards the sea and thus for the loading of fresh waters. However, it could easily be a third greater than the quantity of nitrogen added to the marine areas via watercourses (Kirkegaard 1995).

With this reservation, the normalisation reference for nitrogen loading is based on the figures for loading of the marine areas in 1994:

- 119.100 kt N/year from watercourses and
- 9.300 kt N/year from direct emissions (Larsen ***et al***. 1995; Miljøstyrelsen 1995)

The direct emissions are man-made, but apart from the man-made emissions from agriculture and various point sources such as waste water treatment plants, industry and fish farming, the loading from watercourses also includes some natural leaching of nitrogen.

It is necessary for normalisation to know the anthropogenic loading. The natural background loading with nitrogen is estimated to be about 12% (Larsen ***et al***. 1995). Thus, 88% of the waterborne emissions of nitrogen are man-made.

This gives a total man-made waterborne loading with nitrogen in 1994 of:

- 0.88 x 119.100 kt N/year + 9.300 kt N/year = 114.108 kt N/year

8.4.2 Diffuse nitrogen loading from cultivated land

Nitrogen loading of groundwater and surface water is mainly attributable to leaching from the root zone of agricultural land. An important step towards reducing nitrogen leaching is that storage capacity for animal fertiliser has been expanded considerably. Measurements and calculations of actual nitrogen leaching from the root zone have revealed considerable inter-annual variation. Measurements of nitrogen loss to watercourses reveal correspondingly large variation that is also attributable to climatic variation. Diffuse nitrogen loading is closely tied to the amount of precipitation that falls in the winter half year. As a consequence, the general decline in point source loading is blurred by the climatic variation in diffuse loading, especially that from cultivated land. It should be noted that the mean precipitation in Denmark was 880 mm in 1994, which is more than normal.

It is estimated that changes in agricultural practice (that the storage capacity for animal fertiliser has been expanded considerably) have led to a small reduction in nitrogen leaching from the root zone. However, it has not been possible to demonstrate this directly by means of measurements. In this connection, it should be noted that the majority of the measures decided in the “Action Plan on the Aquatic Environment” and the “Action Plan for Sustainable Agricultural Development” have now been implemented. Any further reduction in nitrogen loss as a result of these changes in agricultural practice is therefore likely to be limited (Miljøstyrelsen 1997).

8.4.3 Air emissions of nitrogen

A large part of nutrient input to Danish marine waters takes place via the atmosphere.

In the present study, the airborne emissions of nitrogen compounds are used for the normalisation references because it is assumed that the emissions have the potential to contribute to the nutrient enrichment. The airborne emissions of nitrogen compounds inventoried for Denmark in Table 8-2 include oxides of nitrogen, NO_x, which is emitted predominantly from incineration processes, and ammonia, NH_3, which is emitted especially from agricultural activities.

The goal, as stipulated in the EU declaration on the NO_x Protocol, is to reduce Danish emissions from the 1986 level of 312,000 tonnes to 218,000 in 1998, corresponding to a reduction of approx. 30%. International agreements to reduce NO_x emissions and national endeavours to reduce ammonia volatilisation will, in the long term, help reduce atmospheric deposition on Danish marine waters.

Danish emissions of nitrogen compounds to air in 1994 are estimated to 159.9 kt N/year. Airborne emissions of nitrogen and phosphate from “nature” are small and in the calculations we assume that 100% are man-made.

8.4.4 Phosphorus loading to the aquatic environment

The Aquatic Environment Plan’s monitoring programme 1994 gives the total loading with phosphorus as

- 2.960 kt P/year from watercourses and
- 1.530 kt P/year from direct emissions (Larsen ***et al***. 1995)

In contrast to nitrogen, there are no natural removal mechanisms for phosphorus. However, the emission of phosphorus in watercourses typically occurs in pulses, as phosphorus accumulates in the watercourses sediment during drier periods and is then completely washed out into marine environment when the water flow increases, e.g. after a thunderstorm. This type of pulse emission is difficult to include in a monitoring, and the emission of phosphorus in watercourses is therefore believed to have been underestimated (Kirkegaard 1995). It has not been possible to obtain any estimate of how large the emission of phosphorus to marine areas actually is. However, the composition of raw sewage has changed during the last 5 years. The change concerns the phosphorus content of the sewage, which has decreased significantly due to greater use of phosphate-free detergents.

It is estimated that 84% (Larsen ***et al***. 1995) of the waterborne emissions of phosphorus are man-made. This gives a total man-made waterborne phosphorus loading in 1994 of:

- 0.84 x 2.960 kt P/year + 1.530 kt P/year = 4.016 kt P/year.

8.4.5 Airborne emissions of phosphate

Airborne emissions of phosphate are quite small and are therefore not included in the calculations.

8.4.6 Danish emissions of N and P

Total man-made riverine nutrient loading of marine waters in 1994 is estimated at approx. 104.808 kt nitrogen and 2.486 kt phosphorus. The overall trend in loading of inland waters is a decrease in both nitrogen and phosphorus loading from point sources.

Direct discharges to marine waters from point sources amounted in 1994 to 9.300 kt nitrogen and 1.530 kt/phosphorus. A decrease has also been seen in both nitrogen and phosphorus loading from point sources. Point source loading has decreased considerably since 1990. This is primarily attributable to the requirements stipulated in the Action Plan on the Aquatic Environment with regards to reducing discharges from municipal sewage works and industrial outfalls (Miljøstyrelsen 1994).

Nearly all emissions of nitrogen to the air are assumed to be man-made and are estimated to consist of 159.9 kt N/year.

Total loading of marine waters in 1994 from watercourses, direct point-source discharges and atmospheric deposition is calculated to be approx. 274 kt nitrogen and approx. 4 kt phosphorus.

Signs of reduced primary production of plankton and algae are seen in many areas, together with improved oxygen conditions. In general, however, no major changes have been detected in the level of nutrient enrichment in Danish marine waters relative to 1990 (Hauschild & Wenzel 1998).

Table 8-2
Danish emissions of nutrients in the form of nitrogen and phosphorus compounds to air and water. The unit is kt/year. Emissions to air from Ritter (1997); waterborne emissions from Larsen et al. (1995).

Substance	Formula	1994	EF(N)	EF(P)	Impact potential 1994	
		kt/year	g N-eq./g	g P-eq./g	kt N-eq./year	kt P-eq./year
Airborne emissions						
Nitrogen oxides	NO_x	276	0.30	0	82.8	0
Ammonia	NH_3	94	0.82	0	77.1	0
Waterborne emissions						
Total P	PO_4^{3-}-P	4.016	0	1	0.0	4.0
Total N	N	114.108	1	0	114.1	0
Total					274.0	4.0

NO_x as NO_2

8.4.7 Normalisation references for 1994

Based on the total Danish emission (1994) of 274 kt N-equivalents, and 4 kt P-equivalents and a population (1994) of 5.2 million (Ritter 1997), the Danish normalisation references for nutrient enrichments are:

Person equivalents:

53 kg N-equivalents/capita/year
0.8 kg P-equivalents/capita/year

or aggregated as

260 kg NO_3^-***-equivalents/capita/year***

8.5 The normalisation reference for EU-15

For the normalisation reference for EU-15, the emissions of nutrients are estimated from the EU-15 countries. These are summarised, and their environmental impact potentials calculated, in Table 8-9. In the following sections, the basic data are presented in some detail.

8.5.1 Air emissions of nitrogen and phosphorus compounds

A large part of the nutrient input to marine waters takes place via the atmosphere. Nutrient enrichment via the atmosphere primary depends on the emissions of NO_x and NH_3. The total emissions for the EU-15 countries in 1994 are shown in Table 8-3.

Table 8-3
National total[1] emissions 1994 (Ritter 1997).

Country	Population (Mio)	NO_x (kt/year)	NH_3 (kt/year)
Germany	81.1	2,266	623
United Kingdom	58.2	2,387	320
France	57.7	1,682	667
Italy	57.0	2,157	389
Spain	39.1	1,223	344
Netherlands	15.3	530	172
Greece	10.4	357	445
Belgium	10.1	374	79
Portugal	9.9	249	93
Sweden	8.7	444	51
Austria	8.0	171	86
Denmark	5.2	276	94
Finland	5.1	288	41
Ireland	3.6	117	125
Luxembourg	0.4	23	7
EU-15	370	12,544	3,535

1. National total emissions follow the UN-ECE/EMEP guidelines. However, emissions from sector “nature” are excluded to ensure inter country comparison.

According to UN-ECE/EMEP requirements, sources of emissions to air have to be reported according to 11 main source sectors. The emissions in the EU-15 countries from these 11 main source sectors are given in Table 8-4.

Table 8-4
EU-15 main source sectors 1994 (Ritter 1997).

Sector		NO_x (kt/year)	NH_3 (kt/year)
1	Combustion in energy and transformation industries	2,400.3	3.3
2	Non-industrial combustion plants	552.9	1.3
3	Combustion in manufacturing industry	1,184.7	1.7
4	Production processes	215.2	100.9
5	Extraction and distr. of fossil fuels/geothermal energy	113.5	-
6	Solvent and other product use	0.6	2.0
7	Road transport	6,052.0	32.1
8	Other mobile sources and machinery	1,892.8	0.1
9	Waste treatment and disposal	96.9	36.0
10	Agriculture and forestry, land use and wood stock change	34.5	3,357.7
11	Nature	19.7	0.5
	EU-15 total[1]	12,544.4	3,534.6

1. The EU-15 totally excludes emissions from sector “nature” (SNAP 11).

As shown in Table 8-4 the emission of nitrogen to the air from the sector “nature” constitutes less than 1% of the total emissions, therefore the exclusion of the emissions from “nature” is not assumed to course significant errors.

Airborne emissions of phosphate are quite small and are therefore not included in the calculations.

8.5.2 Direct discharges and riverine inputs of total nitrogen and phosphorus compounds

The direct discharges and riverine inputs of total nitrogen and phosphorus into the different sea areas surrounding Europe are depicted in the Table 8-5 and Table 8-6. All data are finally aggregated in Table 8-8, which illustrate the total direct discharges and riverine inputs to the sea of total nitrogen and phosphorus in the 15-EU countries.

Table 8-5
Direct discharges and riverine inputs of total nitrogen and total phosphorus into the OSPAR area (kt/year)[1] in 1994, Estimated from EEA (1998a) and Excessive anthropogenic nutrients in European ecosystems, EEA (in press).

Country	Total Nitrogen (kt/year)	Total Phosphorus (kt/year)
Germany	355.0	12.5
United Kingdom	376	36
France	67	-
Netherlands	490.0	27.5
Belgium	47	2.0
Portugal	15.7	14.2
Sweden	6.9	0.3
Denmark	74.1	2.2
Ireland	179.1	10.5
EU-15	1610.8	105.2

1. High estimates used; some countries have given low and high estimates.

Table 8-6
Direct discharges and riverine inputs of total nitrogen and total phosphorus into the Baltic Sea area (kt/year)[1] in 1995, Estimated from EEA (1998a) and Excessive anthropogenic nutrients in European ecosystems, EEA (in press). These data are estimates from 1995 and not from 1994; however, the error caused by this factor is expected to be of minor importance.

Country	Total Nitrogen (kt/year)	Total Phosphorus (kt/year)
Germany	21.4	0.6
Sweden	130.9	4.7
Denmark	66.5	2.3
Finland	66.1	3.6
EU-15	284.9	11.2

1. High estimates used; some countries have given low and high estimates.

Table 8-7
Estimated direct discharges and riverine inputs of total nitrogen and total phosphorus into the Mediterranean Sea from the EU-15 countries (kt/year) (Kristensen 1999).

Country	Total Nitrogen (kt/year)	Total Phosphorus (kt/year)
Spain	185	11
France	118	8
Italy	346	29
Greece	117	7
EU-15	766	55

The Mediterranean Sea atmospheric inputs of nitrogen have been estimated to be about 1249 k tonnes/year, which are greater than those from direct discharges and riverine inputs.

Table 8-8
Direct discharges and riverine inputs to the sea of total nitrogen and phosphorus in 15-EU countries (kt/year)[1] in 1994. Estimated from EEA (1998a) and Excessive anthropogenic nutrients in European ecosystems, EEA (in press).

Country	Total Nitrogen (kt/year)	Total Phosphorus (kt/year)
Germany	376.4	13.1
United Kingdom	376	36
France	185	8
Italy	346	29
Spain	185	11
Netherlands	490.0	27.5
Greece	117	7
Belgium	47	2.0
Portugal	15.7	14.2
Sweden	137.8	5
Austria		
Denmark	140.6	4.5
Finland	66.1	3.6
Ireland	179.1	10.5
Luxembourg		
EU-15	2661.7	171.4

1. High estimates used; some countries have given low and high estimates.

8.5.3 EU-15 emissions of nutrients to air and water

It is necessary for normalisation to know the man-made loading, but the inventory published in "Excessive anthropogenic nutrients in European ecosystems" from the EEA (in press) does not admit the possibility of assessing the natural contribution. However based on Danish calculations, it is estimated that 85-90% (Tygesen 1998) of the waterborne emissions of nitrogen and phosphorus are man-made. In this calculation for the EU-15 emissions we assume that 88% are man-made as found for Denmark. However, it should be stressed that this is a rough estimate and that the actual amount differs significantly from country to country. This gives total man-made waterborne nitrogen and phosphorus loading in 1994 of:

- 0.88 x 2661.7 kt N/year = 2342.3 kt N-equivalents/year
- 0.88 x 171.4 kt P/year = 150.8 kt P-equivalents/year.

Airborne emissions of nitrogen and phosphate from "nature" are small and in the calculations we assume that 100% are man-made. Furthermore, airborne emissions of phosphate are quite small and are therefore not included in the calculations.

Table 8-9
EU-15 emissions of nutrients in the form of nitrogen and phosphorus compounds to air and water. The unit is kt/year. Emissions to air from Ritter (1997). Waterborne emissions from EEA (1998a).

Substance	Formula	1994	EF(N)	EF(P)	Impact potential 1994	
		Kt/year	g N-eq./g	g P-eq./g	kt N-eq./year	kt P-eq./year
Airborne emissions						
Nitrogen oxides	NO_x[1]	12544	0.30	0	3763.2	0
Ammonia	NH_3	3535	0.82	0	2898.7	0
Waterborne emissions						
Total P	PO_4^{3-}-P	150.8	0	1	0.0	150.8
Total N	N	2342.3	1	0	2342.3	0.0
Total					9004.2	150.8

1. NO_x as NO_2

8.5.4 Normalisation references for EU-15 in 1994

Based on a total EU-15 emission (1994) of 9004 kt N-equivalents and 151 kt P-equivalents and a population (1994) of 370 million (Ritter 1997), the EU-15 normalisation references for nutrient enrichment are:

Person equivalents:

24 kg N-equivalents/capita/year
0.4 kg P-equivalents/capita/year

or aggregated as

119 kg NO_3^- ***- equivalents /capita/year***

8.6 The normalisation reference for selected European countries

For the purpose of calculating a normalisation reference for selected European countries, the emissions of nutrient are estimated from these countries. These are summarised, and their environmental impact potentials calculated in Table 8-14. The calculation has been made to establish whether a widening of the EU-15 area would change the normalisation reference.

8.6.1 Air emissions of nitrogen and phosphorus compounds

Table 8-10
National total[1] emissions 1994 (Ritter 1997; EEA 1998b).

Country	Population (Mio)	NO_x (kt/year)	NH_3 (kt/year)
Germany	81.1	2,266	623
United Kingdom	58.2	2,387	320
France	57.7	1,682	667
Italy	57.0	2,157	389
Spain	39.1	1,223	344
Netherlands	15.3	530	172
Greece	10.4	357	445
Belgium	10.1	374	79
Portugal	9.9	249	93
Sweden	8.7	444	51
Austria	8.0	171	86
Denmark	5.2	276	94
Finland	5.1	288	41
Ireland	3.6	117	125
Luxembourg	0.4	23	7
Norway	4.2	218	25
Switzerland	6.7	140	60
Poland	38.4	1,105	384
Croatia	4.7	59	24
Slovenia	1.9	66	22
Lithuania	3.8	77	80
Latvia	2.7	45	16
Estonia	1.6	43	14
Russia[1]	3	50	20
Total	437	14,347	4,180

1. Rough estimate of the population and emissions from the part of Russia that has direct discharges and riverine inputs to the Baltic Sea. Air emissions and populations are assumed to be comparable to that found in Latvia based on the data of aquatic N inputs to the Baltic Sea.

8.6.2 Direct discharges and riverine inputs of total nitrogen and phosphorus compounds in selected countries in Europe

The direct discharges and riverine inputs of total nitrogen and phosphorus into the different sea areas surrounding Europe are depicted in the tables below. All data are finally aggregated in Table 8-13 illustrating the total direct discharges and riverine inputs to the sea of total nitrogen and phosphorus in the selected countries.

Table 8-11
Direct discharges and riverine inputs of total nitrogen and total phosphorus into the OSPAR area (kt/year)[1] in 1994 estimated from EEA (1998a) and EEA (in press).

Country	Total Nitrogen (kt/year)	Total Phosphorus (kt/year)
Germany	355.0	12.5
United Kingdom	376	36
France	67	-
Netherlands	490.0	27.5
Belgium	47	2.0
Portugal	15.7	14.2
Sweden	6.9	0.3
Denmark	74.1	2.2
Ireland	179.1	10.5
EU-15	1610.8	105.2
Norway	97.2	4.1
Total	1708.0	109.3

1. High estimates used; some countries have given low and high estimates.

Table 8-12
Direct discharges and riverine inputs of total nitrogen and total phosphorus into the Baltic Sea area (kt/year)[1] in 1995 Estimated from EEA (1998a) and EEA (in press). This data are estimates from 1995 and not from 1994; however, the error caused by this factor is expected to be of minor importance.

Country	Total Nitrogen (kt/year)	Total Phosphorus (kt/year)
Germany	21.4	0.6
Sweden	130.9	4.7
Denmark	66.5	2.3
Finland	66.1	3.6
EU-15	284.9	11.2
Estonia	46.5	1.3
Latvia	91.1	2.2
Lithuania	36.8	1.4
Poland	214.7	14.2
Russia	84.6	7.1
Total	758.6	37.4

1. High estimates used; some countries have given low and high estimates.

The direct discharges and riverine inputs of total nitrogen and total phosphorus into the Mediterranean Sea from Europe are estimated to be about 823 kt N and 60 P kt/year (Kristensen, 1999). Discharges of nitrogen and phosphorus are of the order of 270 and 24 kt/year, respectively, in the Adriatic region including discharges from Italy, Croatia and Slovenia (UNEP 1996).

The annual total discharges in the Black Sea, mid 1990s are estimated to about 406 kt nitrogen and about 55 kt phosphorus (EEA 1998a). Of this amount, about 236 kt nitrogen and 43 kt phosphorus come from international rivers, thus, the total annual discharges for nitrogen and phosphorus from all the countries surrounding the Black Sea region are less than half of the total discharges from international rivers (EEA 1998a). The annual discharges of the Danube alone are estimated to be 230 kt total nitrogen and 40 kt total phosphorus (EEA, in press).

Table 8-13
Direct discharges and riverine inputs to the seas around Europe of total nitrogen and phosphorus in (kt/year)[1] in 1994, Estimated from EEA (1998a) and EEA (in press).

Country	Total Nitrogen (kt/year)	Total Phosphorus (kt/year)
Germany	376.4	13.1
United Kingdom	376	36
France	185	8
Italy	346	29
Spain	185	11
Netherlands	490.0	27.5
Greece	117	7
Belgium	47	2.0
Portugal	15.7	14.2
Sweden	137.8	5
Austria		
Denmark	140.6	4.5
Finland	66.1	3.6
Ireland	179.1	10.5
Luxembourg		
Norway	97.2	4.1
Estonia	46.5	1.3
Latvia	91.1	2.2
Lithuania	36.8	1.4
Poland	214.7	14.2
Russia[2]	84.6	7.1
Croatia and Slovenia	76.0	5.0
Total	3308.6	206.7

1. To the Baltic Sea area.
2. High estimates used; some countries have given low and high estimates.

8.6.3 Emissions of nutrients to air and water in selected European countries

It is estimated that 85-90% of the waterborne emissions of nitrogen and phosphorus is man-made. In this calculation, we assume that 88% (as the figure of Denmark) are man-made; however, it should be stressed that the actual amount differs significantly from country to country. This gives total man-made waterborne nitrogen and phosphorus loading in 1994 of:

- 0.88 x 3308.6 kt N-eq./year = 2911.6 kt N-eq./year
- 0.88 x 206.7 kt P-eq./year = 181.9 kt P-eq./year.

Airborne emissions of nitrogen and phosphate from “nature” are small and in the calculations we assume that 100% are man-made. Furthermore, airborne emissions of phosphate are quite small and are therefore not included.

Table 8-14
Emissions of nutrients in the form of nitrogen and phosphorus compounds to air and water. The unit is kt/year. Emissions to air from Ritter (1997). Waterborne emissions from EEA (1998a).

Substance	Formula	1994	EF(N)	EF(P)	Impact potential 1994	
		Kt/year	g N-eq./g	g P-eq./g	kt N-eq./year	kt P-eq./year
Airborne emissions						
Nitrogen oxides	NO_x[1]	14297	0.30	0	4289.1	0
Ammonia	NH_3	4160	0.82	0	3411.2	0
Waterborne emissions						
Total P	PO_4^{3-}-P	181.9	0	1	0.0	181.9
Total N	N	2911.6	1	0	2911.6	0.0
Total					10611.9	181.9

1. NO_x as NO_2

8.6.4 Normalisation references for selected European countries in 1994

Based on the total emission (1994) of 10611.9 kt N-equivalents, and 181.9 kt P-equivalents and a population (1994) of 437 million, the normalisation references for nutrient enrichment in the selected European countries are:

Person equivalents:

24 kg N-equivalents/capita/year
0.4 kg P-equivalents/capita/year

or aggregated as

119 kg NO_3^- - equivalents/capita/year

8.7 Worldwide normalisation reference for nutrient enrichment

The worldwide for normalisation reference for nutrient enrichment is calculated by a simple extrapolation from the EU-15 data to a world basis by use of the GDP (Gross Domestic Product). A general extrapolation method is described in chapter 3, Development of normalisation references for different geographic areas. The general methodology is based on the following assumptions:

- linear relationship between normalisation factor and ln(GDP/capita)
- the normalisation factor is zero when the average income expressed as GDP/capita is zero.

Because of the lack of worldwide data the world-proxy presented in this report does not consider the differences between countries regarding degree of industrialisation, wastewater treatment, agricultural area, agricultural practice like livestock production etc.

The worldwide normalisation reference for nutrient enrichment can be calculated as:

$0.8 \times \text{Normref}_{\text{Nutrient enrichment, EU-15}}$

i.e:

19 kg N-equivalents/capita/year

0.3 kg P-equivalents/capita/year

or aggregated as

95 NO_3^- - equivalents/capita/year.

8.8 Evaluation of uncertainties

The uncertainties are scored in three categories: “low”, i.e. an uncertainty expected to be considerably lower than one order of magnitude, “medium”, i.e. an uncertainty expected to be up to one order of magnitude, and “high”, i.e. an uncertainty expected to be higher than one order of magnitude. The uncertainties are scored as “low” for the normalisation reference for Denmark, “medium” for EU-15, and “high” for the world-proxy. The uncertainties are due to the applied methodology and limitations of data. It should be stressed that these uncertainties are subjective and based on the authors experiences obtained during the project. Within the frame of this project it has not been possible to estimate the size of the uncertainties more precisely.

8.9 Recommendation for future updating

Most of the data sources used in the estimates are linked to international or national statistics, which are regularly updated. It should therefore be relatively simple to update the calculations for Denmark and the EU-15 countries.

Extrapolation from EU-15 to the world has been discussed in other LCA projects, and the conclusion is that all extrapolation methods will be based on general assumptions and generally they will therefore never be valid (see chapter 3, Development of normalisation references for different geographic areas). It is recommended to validate the estimated world-proxy for the normalisation reference for nutrient enrichment by comparison with an alternative method like the one described below. It was, however, not possible within the frame of the present project to perform this validation.

An alternative method is to calculate the nutrient enrichment potential for a few reference groups of countries or geographical areas that differ in the important parameters in relation to nutrient enrichment. When a normalisation reference for nutrient enrichment is calculated for a given country or region the selected factors of the specific country or region should be compared with the most comparable reference country or geographical area. After the comparison the nutrient enrichment potential (NO_3^- - equivalents/capita/year) can be estimated. Some of the important parameters, which should be considered when selecting the country reference groups or geographical areas, are listed in Appendix A.

8.10 References

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Skov, H., Ellermann, T., Hertel, O., Manscher, H., & Fohn, M. 1996, ***Atmosfærisk deposition af kvælstof. Vandmiljøplanens Overvågningsprogram***

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[9] Most of the reports from Miljøstyrelsen (the Danish Environmental Protection Agency) contain English summaries.

1995. Hovedrapport. Danmarks Miljøundersøgelser. Faglig rapport fra DMU nr. 173.

Tygesen Niels 1998, Personal communication. European Environment Agency.

Appendix A: Important parameters in relation to nutrient enrichment

- Emissions to air:

  The main sources of emission to air in relation to nutrient enrichment are NO_x and NH_3. The main emissions of NO_x to air are from road transport, combustion in energy and transformation industries, and other mobile sources and machinery. These three main source sectors constituted more than 80% of the total emissions of NO_x in the EU-15 countries in 1994 and should therefore some how be included in the evaluation.

  For NH_3 the main source sectors are agriculture and forestry, land use and wood stock change which constituted about 95% of the total NH_3 emission in the EU-15 countries in 1994.

  Information on the activity in these sectors is not available in statistics covering the whole world; however, it should be available for different selected groups of countries or geographical areas that differ in industrial and agricultural activities.

  Airborne emissions of phosphate are quite small and are therefore not included.

- Waterborne emissions:

  The main sources of emission of nitrogen to the aquatic environment are mainly due to leaching from agricultural land. An important parameter to estimate the emission of nitrogen is therefore to evaluate the agricultural land and compare it with the total area. Furthermore, the use of nitrogen fertiliser and the number of livestock should be included in the evaluation.

  Most of the phosphorus loading of surface water is attributable to discharges from point sources, especially municipal sewage and industrial effluent cf. waste water below. However, leaching from agricultural land also plays a significant part and an estimation of the agricultural land and the use of phosphorus containing fertiliser should be made. Data might be available for different selected groups of countries or geographical areas that differ in industrial and agricultural activities.

- Wastewater:

  Industrial production and household consumption result in wastewater containing nutrients. The nutrient content of wastewater from households is primarily determined by excreta from humans and phosphorus from detergents. Generally the amount of wastewater produced is proportional to the population and only to a little extent dependent on the economic development (Kristensen, 1998). The nutrient content of the wastewater from the industries is highly dependent on the type of industry. Only a small part of the industrial sector is responsible for the majority of wastewater containing phosphorus. To name just a few important industries the fertiliser industry and other related chemical industries manufacturing products containing phosphorus (e.g. pesticides and detergents), as well as the pulp and paper industry and fish processing industry should be mentioned. The extent to which the nutrients in wastewater are discharged into surface waters depends on the wastewater treatment facilities available. The majority of the households in the EU Member States are connected to sewers and municipal wastewater treatment plants (Kristensen 1998). However, in other parts of the world only a small part of the households may be connected to a wastewater treatment plant.

For waste water from households it might be an idea to estimate the emission of the nutrient content to the aquatic environment by looking at the population density, the amount of phosphorus sold in detergents, and percent of people connected to a waste water treatment plant. For an evaluation of the emissions from industries it is important determine the industries that are present and the wastewater treatment facilities that are available.

9 Human toxicity

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9.1 Summary

The overall aim of this chapter is to update the present EDIP human toxicity normalisation references for air, water and soil according to Danish conditions and to establish similar European (EU-15) references. A global normalisation reference for human toxicity has been estimated based on the principles described in chapter 3, Development of normalisation references for different geographic areas. The EDIP-methodology (Hauschild ***et al***. 1998) has been used to calculate the reference values. The normalisation references are shown in Table 9-1.

Table 9-1
Normalisation references for toxicological impact as a result of exposure via air, water and soil for Denmark, EU-15 and worldwide.

	Denmark	EU-15	Worldwide
Air; m^3 air/capita/year	$5.53*10^{10}$	$6.09*10^{10}$	$4.87*10^{10}$
Water; m^3 water/capita/year	$1.79*10^{5}$	$5.22*10^{4}$	$4.18*10^{4}$
Soil; m^3 soil/capita/year	$1.57*10^{2}$	$1.27*10^{2}$	$1.02*10^{2}$

The normalisation references for human toxicity by exposure through airborme emissions have changed significantly, compared to the values in EDIP 97. The main reason for this is that it has been possible to include a speciation of the nmVOC emitted from road transport in the calculation. Some of the species emitted have a large toxicity potential as reflected by its effect factor and this – combined with the large amounts being emitted – have caused an increase in the normalisation references of about a factor 25, compared to the situation where no speciation of nmVOC is included. In practice, this means that the updated normalisation references have increased with a factor 6 instead of decreasing with a factor 4. The database and the calculations is described in more detail in section 9.3.1.2 and in Appendix B2.

The importance of road transport is also evident when looking at the relative contribution of different substances to the normalisation reference. At the EU-15 level, nmVOC from road transport accounts for about 95% of the total impacts. On the national level a similar contribution is observed in all EU-countries with Luxembourg as an exception with “only” about 86% of the normalisation reference being related to nmVOC from road transport.

In this context, the contribution from other substances becomes less important, although they still should be targeted for reductions. Lead and particulate matter (PM_{10}) accounts for 3.1% and 0.3%, respectively, at the EU-15 level. The two substances are important for all individual Member States, but in some countries also PAH and NO_x are equally important. In Denmark, lead, NO_x and PM_{10} are the most significant contributors besides nmVOC from road transport.

The normalisation reference for human toxicity via air can, however, only be determined with a large degree of uncertainty and some of the main sources for this uncertainty are discussed in more detail in the following sections. As a general rule, the normalisation reference is believed to provide the right order of magnitude, but more knowledge about the toxicity of emissions of nmVOC and particulate matter (both PM_{10} and $PM_{2.5}$) may cause significant changes of the normalisation reference in a future update.

The substances contributing with more than one percent to the normalisation reference for human toxicity by water for EU-15 are mercury (air and water emissions; 90%), dioxins (air emission; 4%), lead (water and air emissions) and zinc. For Denmark mercury is the only substance contributing with more than one percent. The substances contributing with more than one percent to the normalisation reference for soil for EU-15 are arsenic (air; 60%), mercury (air; 24%), tetrachloroethylene, arsenic (sludge), mercury (sludge), chromium (air), tetrachloromethane, lead and cadmium (both air).

9.2 Description of the impact category

The normalisation references for human toxicity via the environment[10] should reflect the total human toxic load in the reference area caused by human activity, i.e. the potential risk connected to exposure from the environment (via air, soil, provisions and drinking water) as a result of emissions to the environment from industrial production, traffic, power plants etc.[11]

Ideally, all emissions of substances potentially affecting human health should be quantified and assessed. However, the multitude of known substances (>100.000) and an even larger number of emission sources logically makes that approach unfeasible. The inventory used for calculating the normalisation references is therefore based on available emission registrations for substances, which are believed to contribute significantly to the overall load. However, some significant emissions may still be missing. Further, the contribution from the multitude of minor emissions is not included. The contribution to the overall toxic load from these substances is unknown. A more detailed discussion of included substances and available data sources is given in section 9.3.

There are also uncertainties connected to the methodology for estimating the toxic load of the substances and thereby the calculated normalisation references. They are discussed in section 9.5 and 9.6.

See Hauschild ***et al***. (1998) for a further description of the impact category.

9.3 Substances and data sources

Data and data sources used for calculating the normalisation references for air, water and soil are outlined in this section. Data included are discussed for each emission route. Then, the extrapolation method used to estimate lacking

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[10] In this context ‘environment’ does not cover indoor consumer exposure nor work environment.

[11] It should be noticed that only actual emissions are included. Releases from environmental pools created in the past (for instance mercury from sediments and leaks from landfills) are not included. Whether or not these releases should be included is controversial and should be discussed further in connection with a future updating of the methodology.

data for some countries is briefly described, and finally, some general omissions are outlined.

9.3.1 Substances included

This section present and comments different exposure routes. Groups of substances of special interest (VOC and particulate matter) is also presented.

9.3.1.1 Air

Major contributions to toxicity via air are assumed to be emissions from transport and energy production, waste incineration plants, industrial releases of POPs (Persistent Organic Pollutants) and other HPV (High Production Volume) chemicals. Corinair 94 (Ritter 1997) is a key reference including many of the above emissions and it is assessed to be a good quality data source. However, heavy metal and POP emissions from a number of countries are lacking. The lacking data have been extracted from other references as indicated in Appendix B.1 (e.g. POP and heavy metal emissions from 1995 and dioxin emissions from an European survey) or estimated by extrapolation, see paragraph 9.3.2. The Corinair data has, where relevant, been supplemented with more exact data, se also Appendix A and C for detailed references.

The quantification of emission of chemicals other than heavy metals, POPs and other traditional air pollutant (like NO_x and SO_2) from the (chemical) industry at the European level is poor. Data from Dutch emission registrations (van der Auweraert ***et al.*** 1996) from major chemical enterprises have been investigated. However, apart from nmVOCs (non-methane Volatile Organic Compounds) discussed below and vinylchloride, equivalence factors (EQFs) for these substances are lacking in the present EDIP “toxicity database” (Hauschild ***et al***. 1998) and it has not been within the scope of this project to establish these factors.

Potentially - when the necessary EQFs become available - the Dutch emission figures can be used as a basis for extrapolation to other European countries and to an overall European level. Initially, a pragmatic approach is to evaluate whether the individual substances contribute significantly to the Dutch normalisation reference. Emission quantities for substances contributing less than 1% should not be extrapolated to other countries. This approach has been used for vinyl chloride in this project, see section 9.5. The uncertainty connected to the Dutch emission registrations is difficult to quantify. The Dutch registrations cover major emission sources.

9.3.1.2 VOC

VOCs from industrial point sources usually consist of one or a limited number of specific substances/solvents, whereas VOCs from combustion processes are a very complex mixture, usually containing a major fraction of alkanes, medium amounts of methane, olefins, ethene and monocyclic aromatics, minor amounts of aldehydes (some of it being formaldehyde), and trace amounts of PAHs (between others benzo(a)pyrene and naphthalene) (van der Ven 1995).

According to Corinair94 (Ritter 1997), the major European outdoor emission sources of nmVOCs are: approx. 30% from road traffic, 30% from solvent and other product use, about 20% from agriculture, forestry, land use and wood stock exchange and approx. 10% from different energy production and manufacturing combustion activities[12]. It is difficult to assign a specific toxicity for VOCs as a group, as it covers a wide range of substances. In the original EDIP method, nmVOC emissions were evaluated based on ***one*** equivalence factor for unspecified toxic action. This is clearly a simplification and has underestimated the toxicity of VOCs with specific actions, as evidenced by the significantly higher normalisation reference established in the update in the current project by applying specific factors for a large number of substances emitted from road transport. The establishing of specific effect factors for nmVOC from road transport and the importance of the emissions is described in detail in Appendix B.2.

9.3.1.3 Particles

Particle emissions were not included in the previous EDIP methodology, but the increasing evidence that particles contribute significant to human health impact has called for the inclusion of particles in the normalisation reference. In terms of measuring particle emission/concentration, quite a few parameters can be applied. Traditionally, suspended particles have been measured as TSP (total suspended particulates) or as Black Smoke (BS)[13]. A more recent indicator for suspended particles is PM10 (particles with diameter below 10 μm). It measures particles, which are believed to cause the major health concerns as these may penetrate deeply into the airways. However, measurement data of this parameter are still very incomplete (EEA, 1997). Particle emissions are not included in Corinair, but a Dutch report identifying some preliminary values has been identified (Berdowski ***et al.*** 1997b). This data source is not complete, many data have been estimated and the data are thus subject to some uncertainty, see the reference for further details.

As can be seen from the above, more references may be relevant for a given emission depending on the country. General data sources for the different impact categories are presented in Appendix A. Specific references for the individual emission estimates are given in the calculation sheets in Appendix C.

9.3.1.4 Water

Included in this normalisation reference are:

- Deposition of heavy metals and POPs from air. According to the EDIP methodology, substances emitted to air contribute to water and soil toxicity if the atmospheric half life is > 1 day. It is assumed that 80% is deposited on soil and thereby contributes to soil toxicity, while 20% is assumed deposited on water.
- Deposition of other chemicals emitted to air - data from previous section
- Emissions from sewage treatment plants; detergents, metals, others

See chapter 10, Ecotoxicity, for a discussion of data sources, data uncertainties and relevant contacts.

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[12] Corinair94 operates with 10 sector sources: 1. Combustion in energy and transformation industries, 2. Non-industrial combustion plants, 3. Combustion in manufacturing industry, 4. Production processes, 5. Extraction and distribution of fossil fuels/geothermal energy, 6. Solvent and other product use, Road transport, 8. Other mobile sources and machinery, 9. Waste treatment and disposal, 10. Agriculture and forestry, land use and wood stock change.

[13] BS represents the black soot particles from combustion, and is dominated by coal smoke and diesel soot. BS is a relevant indicator to assess health effects, but the measurement technique provides fairly inaccurate results (EEA 1997).

9.3.1.5 Soil

Included in this normalisation reference are:

- Deposition of heavy metals and POPs
- Deposition of other chemicals emitted to air
- Sludge from sewage treatment plants

See chapter 10, Ecotoxicity, for a discussion of data sources, data uncertainties and relevant contacts.

9.3.2 Extrapolation method applied

For a number of countries, data are missing. Therefore, it has been necessary in relation to extrapolation to estimate these data to calculate national normalisation references as well as an EU-15 reference. Special aspects in relation to extrapolation methodology applied for air emissions are described in Appendix B.1, whereas soil and water emissions have been dealt with in chapter 10, Ecotoxicity.

9.3.3 General omissions

No specific action has been taken in order to quantify emissions of substances, which are assumed to cause endocrine disruption, although these effects have lately been a major issue in the public and scientific debate. This attitude is due to the substantial present uncertainty of the actual extent of these effects also including the contributing substances and their potencies. Thus, at the moment, it does not seem possible to select substances to be included nor to assign these an equivalence factor (reflecting the potency).

The major human problem for pesticides is believed to be exposure via contaminated drinking water (this exposure route is not yet operationalised in the EDIP methodology). However, toxic effects via other exposure routes cannot be excluded. Pesticides have not been included in the present project due to the lack of exposure data and effect factors for the multitude of pesticides applied. A proposed methodology for future inclusion is outlined in section 9.6.

Emissions from the off-shore industry have not been quantified as they are is believed to cause minor effects compared with other emissions.

Application of anti-fouling agents has been a major debate issue lately, but mainly in relation to potential effects on wildlife. Thus, in relation to human toxicity, the same consideration as for off-shore emissions is assumed.

Photochemical ozone is included in the effect category on Photochemical ozone formation. As “double-counting” should be avoided, it is therefore - although definitely toxic - not included here. See also the discussion on impact categories in chapter 2, Selection of impact categories.

9.4 Methodology

9.4.1 Toxicity in LCA

In LCA, different ‘types’ of toxicity (irritation, cancer, neurotoxicity etc.) are described in a single figure. This is scientifically questionable. However, as with many aspects of LCA, the assessment should be made as good as possible based on the existing tools. In many LCA’s, assessment of toxicity has been left out to make decisions causing an increased toxic load. EDIP (Hauschild ***et al***. 1998) is one of the tools developed for assessment of toxicity in LCA. A few others have been developed internationally, and as to quality, there seem to be no or little difference.

The impact potentials for human toxicity can be calculated as:

$$EP_{hum,m} = \sum_i^n EQF_{i,m} \times m_i$$

where $EP_{hum,m}$ is the effect potential (human toxicology) caused be exposure via the medium m (water, soil, air)
$EQF_{i,m}$ is the equivalency factor for the substance i caused by exposure via the medium m (water, soil, air)
m_i is the emission of substance i

9.4.2 EDIP

EDIP is used in present project. It is important that the results are used with caution as it appears from the uncertainty discussions during the remaining parts of the chapter. The EDIP method could be improved. Methodological problems are further discussed in section 9.6.

Normalisation references are calculated based on EDIP (Hauschild ***et al***. 1998):

$$Normref_{hum,m} = \frac{\sum_i^n m_i \times EQF_{i,m}}{N}$$

where $\boldsymbol{Normref_{hum,m}}$ is the normalisation reference for human toxicity caused by exposure via the medium m (water, soil, ait)
$\boldsymbol{m_i}$ is emitted quantity of substance i
$\boldsymbol{EQF_{i,m}}$ is the equivalence factor for the substance i caused by exposure via the medium m (water, soil, air)
$\boldsymbol{N}$ is the number of capita in the considered area

Quantification of emissions is carried out as outlined in section 9.3.

9.4.3 Equivalence factors (EQF’s)

The current EDIP equivalence factors (EQF’s) given in Hauschild ***et al***. (1998) will be used in assessing individual substances. As particles are regarded as a significant new emission, an EQF has been estimated, see Appendix B.2. Some EQF’s cover “category” emissions as for instance nmVOC, PAH and dioxins[14]. How VOC is dealt with was discussed in paragraph 9.3.1. PAH as well as dioxins are groups of substances of different toxicity. In order to sum up the human toxicological potential of PAH's and dioxins to a single number, ***toxic equivalence factors*** have been developed and adapted internationally (e.g. I-TEQ). By using these equivalence factors, the total PAH emission can be expressed as ***benzo(a)pyrene equivalents***, and the total dioxin emission can be expressed as ***2,3,7,8-tetrachloro-p-dioxin equivalents*** (2,3,7,8-TCDD-eq. (I-TEQ)).

The dioxin equivalence factors have been used for some years and are internationally accepted whereas the PAH equivalence factors are still under development. This means that emissions of dioxins normally are reported in I-TEQ while emissions of PAH are still reported as Σ PAH. By using the distribution of PAH's in calculation of benzo(a)pyrene-eq. and the Danish Σ PAH, a equivalency factor has been developed to transform Σ PAH to benzo(a)pyrene (detailed information on the distribution of PAH's is available for Denmark; see Table 9-10 in Appendix B.1):

Benzo(a)pyrene-eq. = $F \times \Sigma$ PAH = $0.12 \times \Sigma$ PAH

The information on emissions of PAH in the Corinair94 database is supposed to be Σ PAH and is transformed to benzo(a)pyrene-eq. by using the above-mentioned equation.

Finally, the EQF's for dichlorobenzene and tetrachloroethylene have been used for assessing the toxicity of different chlorinated hydrocarbons for which EQF's are missing.

9.5 Normalisation references

Due to changes in, for instance, traffic load, industrial activity and remediation actions, the overall emission of toxic substances to the environment is changing in time. The normalisation references calculated in this project are based on 1993-95 data i.e. 1993 or 1995 data has been used when 1994 data were not available. Some uncertainty in the normalisation references and the underlying data is therefore connected to the reference year chosen.

It should be mentioned that not all substances contributing potentially to the overall toxic load have been included. The quantity of the toxic load captured is uncertain, as it is difficult to quantify the contribution from the multitude of substances used in minor amounts.

Only emission of substances contributing more than 1% to the normalisation references presented in this section have been included in the tables. More detailed calculation sheets including data references are found in Appendix C. The following (and appendix C) "Original EDIP97" refer to the normalisation values presented in the original Danish version of the method (Hauschild ***et al***. 1996), 'EDIP English' to the reference values in Hauschild ***et al***. (1998) and 'EDIP revision' to the references calculated within this project.

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[14] Also EQF's for heavy metals are "category" EQF's as the metal may be present in the environment as pure element or as a part of various compounds with different toxicity. The EDIP EQF's for heavy metals are calculated based on reasonable worst case assumptions.

9.5.1 Denmark

9.5.1.1 Air

The overall Danish toxicity impact potential has been calculated to: $2.91*10^{17}$ m^3 air, which gives the normalisation reference

$5.53*10^{10}$ m^3 air/capita/year

Table 9-2 summarises the substances assessed to contribute significantly to the normalisation reference.

Table 9-2
Substances contributing by more than 1% to the normalisation reference for air.

Substance	Fraction (%)
nmVOC – transport	96.5
Lead (Pb)	1.4

Compared to the normalisation reference calculated in EDIP English (based on 1990 emission figures), the normalisation reference has approximately increased by a factor of 6 from 9.18×10^9 to 5.53×10^{10} m^3 air/capita/year.

The increase is caused by the inclusion of different species of nmVOC from road traffic. It is not surprising that the higher level of detail causes an increase in the normalisation reference, but it was rather unexpected that the increase was of this magnitude.

Further comparison of the normalisation references from 1990 and 1994 shows that air lead emissions are rapidly decreasing due to the substitution of lead additives in gasoline. The lead contribution must be assessed to be even smaller today, as lead has been entirely substituted in petrol. According to the collected data, also the cadmium emission has dropped dramatically. It is also mentioned that if nmVOC from transport had not been included in the update, other “new” substances such as PAH, benzene emissions to water and particulate matter would have contributed significantly.

As explained in the methodology section 9.4, an equivalence factor (EQF) for particles has been proposed, see Appendix B.2. However, it was difficult to assign an EQF as the toxicity of particles is very complex and highly depends on the type of particles in question. The assignment of an EQF became further complicated by the recent evidence indication that there is no threshold limit for particle exposure. Therefore, it was decided as a first pragmatic approach to use the US one year average guidance limit as a basis for the EQF calculation, see appendix B.2. Future updates of the normalisation references should, however, have particulate matter as one of the focus points. Drivsholm ***et al***. (2002) thus argue that an effect factor of $5.5*10^8$ m^3/g (a factor 25,000 more than used in the present study!) may be realistic for at least some of particles emitted. If this factor is applied, the normalisation references will once more increase significantly, perhaps by a factor 100.

If a safety factor of 10 is assigned to the particle EQF used in the present study, the contribution from particles will exceed 3%, indicating the importance of this emission. None of the particle EQF’s can be judged more correct than the other, but it can be seen that determination of EQF’s is very crucial in relation to the magnitude of the normalisation reference and in relation to which substances will contribute to the reference.

This can also be seen when comparing the figures for Original EDIP97 and EDIP English in Appendix C.1.1. Due to re-evaluation of the EQFs between the two versions (applying the same emission figures), the relative importance of the substances has changed considerably, with N_2O being the dominant in Original EDIP97 and lead in EDIP English.

9.5.1.2 Dutch experiences

Further methodological considerations can be made by comparing with a normalisation project which has been carried out in Holland (Blonk ***et al.*** 1997). In that project, the Dutch LCA toxicity methodology, which differs substantially from the EDIP methodology, was applied. Two significant methodology differences are that the Dutch method uses a continuous modelling of the environmental fate of the chemicals and that all toxicity contributions are condensed into ***one*** figure. EDIP applies a simple semi-quantitative fate modelling and operates with toxicity via air, water and soil, separately. A further investigation of the Dutch figures shows that the air toxicity contribution is by far the dominating; exceeding the water toxicity contribution by about two decades. A comparison between the air toxicity for Dutch conditions as calculated by the EDIP methodology (see Appendix C.1.8) and by the Dutch methodology (distribution fraction shown in Table 9-3) seems interesting.

Table 9-3
Substances contributing by more than 1% to the normalisation reference in The Netherlands according to the Dutch LCA-methodology (Blonk et al. 1997).

Substance	Fraction (%)
NO_x	49
SO_2	22
Rest. non-halog. arom. CH[a]	5
Nickel (Ni)	5
Lead (Pb)	5
Xylene	4
Benzene	3
Methane	3
Arsenic (As)	1
Rest. non-halog. alif. HC[b]	1
1,1,1-trichloroethane	1

[a] Resistant non-halogenated aromatic hydrocarbons
[b] Resistant non-halogenated aliphatic hydrocarbons

It can be seen that the SO_2 and NO_x contributions are by far the dominating when applying the Dutch methodology, whereas lead contributes by only about 5%. This distribution differs significantly from any of the normalisation references developed so far in the EDIP method, and it is striking how much the method and EQF's applied affect the toxicity assessment outcome.

The methodology uncertainties (some of which are further discussed in section 9.6), therefore seem to be of major importance and probably exceed the emission data uncertainties substantially. However, there will always be methodology uncertainties as toxicity evaluations, especially in connection with LCA, are crude simplifications of reality.

As previously described, nmVOC emissions have so far been assessed as one fraction with an EQF based on unspecified toxic action. In this way specific toxic action of some of the VOC's have been underestimated. Dutch emission data obtained from van der Auweraert ***et al.*** (1996) gives the possibility to examine a different approach to include nmVOC on a more detailed level.

When using the Dutch registration of emissions, formaldehyde and benzene contributes with 52% and 33%, respectively (Appendix C.1.8). The normalisation reference is, however, only about 25% of that calculated by using the even more detailed approach applied in the present study.

The calculated Dutch normalisation reference was also intended to figure out which other chemicals (industrial releases) could be assumed to contribute significantly to the overall toxic load. However, EQF's were missing for most of these substances. Only vinyl chloride could be assessed and it turned out to be of minor importance, see Appendix C.1.8. The significance of the other chemical releases may or may not be significant. However, a cautious comparison with the Dutch normalisation project (Blonk ***et al***. 1997; see also Table 9-3) indicates that these emissions are of minor importance.

9.5.1.3 Water

The overall Danish toxicity impact potential has been calculated to: $9.29*10^{11}$ m^3 water, which gives the normalisation reference

$1.79*10^5$ m^3 water/capita/year

Table 9-4 summarises the substances assessed to contribute significantly to the normalisation reference.

Table 9-4
Substances contributing by more than 1% to the normalisation reference for water.

Substance	Fraction (%)
Mercury (Hg) from air deposition	90
Mercury (Hg); water emission	9

The normalisation reference has increased by a factor 3 compared to EDIP English; from $5.9*10^4$ to $1.79*10^5$ m^3 water/capita/year. This increase is mainly due to a 5-fold increase in mercury emission to air (and the assumed deposition). The reason may be difference in the methods for emission quantification. This is also illustrated in the data behind EDIP English, where it is assumed that about 1 ton Hg is emitted directly to the water and 0.5 ton is deposited, i.e. the major Hg toxicity was assumed to be via water.

The rationale behind the effect factor for mercury is that the distribution between air, water and soil as recipient is the same regardless of the primary recipient. The potential effects in e.g. the aquatic environment will be the same for emissions to air, water and soil as reflected in the equivalency factors.

In EDIP English, air deposition of mercury was also the dominating contributor, but lead and Cd were also significant. However, the emission of Pb and Cd has decreased by a factor 9 and 5, respectively, which along with the increase in mercury air emissions gives the very high mercury contribution. The dioxin contribution that was 9% in EDIP English has dropped to below 1%.

The results are striking. Firstly because mercury seems to be the only significant contributor to toxicity via water and secondly because air emissions seem to be the dominating factor for water toxicity due to deposition of the emitted heavy metals.

As for air toxicity, the major uncertainty seems to be considerably related to the EDIP toxicity methodology, including the applied EQF's, though emission quantities are also uncertain.

9.5.1.4 Soil

The overall Danish toxicity impact potential has been calculated to: $8.19*10^8$ m^3 soil, which gives the normalisation reference

$1.57*10^2$ m^3 soil/capita/year

Table 9-5 summarises the substances assessed to contribute significantly to the normalisation reference.

Table 9-5
Substances contributing by more than 1% to the normalisation reference for soil.

Substance	Fraction (%)
Mercury (Hg) from air deposition	75
Arsenic from air deposition	9.1
Arsenic from sludge	7.6
Mercury from sludge	3.1
Tetrachloroethylene from air deposition	1.7

The normalisation factor has decreased from $3.1*10^2$ to $1.6*10^2$ m^3 soil/capita/year i.e. by a factor 2.

Mercury and arsenic from air deposition and sludge are the main contributors to the normalisation reference for toxicity via soil. The figures are not directly comparable with the previous survey as the emissions are compiled in different groups. Mercury from air deposition and sludge are counted as total emissions of lead, cadmium and mercury, which constitute 29% of the previous normalisation reference. Arsenic is counted in the groups named metals from sludge (50% of the total potential impact) and metals from electricity generation (<1% of the total potential impact).

The potential atmospheric deposition also includes a number of organic substances (POP's) of which only tetrachloroethylene contribute with 1.7% of the total potential environmental impact.

9.5.2 EU-15

9.5.2.1 Air

The overall EU-15 toxicity impact potential has been calculated to: $2.25*10^{19}$ m^3 air, which gives the normalisation reference

$6.09*10^{10}m^3$ air/capita/year

Table 9-6 summarises the substances assessed to contribute significantly to the normalisation reference. A detailed survey of the distribution of the contributions of different substances to the toxicity potential for different European countries and EU-15 can bee seen in appendix D.1.

Table 9-6
Substances contributing by more than 1% to the normalisation reference for air.

Substance	Fraction (%)
NmVOC – transport	95.2
Lead (Pb)	3.1

A comparison can not be made with EDIP English as EU-15 was not previously included in EDIP.

The EU-15 normalisation factor is approx. 10% higher than the Danish factor. As the main contributor is nmVOC from road transport this indicates that the traffic load in the EU in average is higher than in Denmark. The distribution between other substances indicates a higher lead contribution in Europe than in Denmark. This may partly be due to a higher lead substitution percentage in petrol for the Danish market. Contributions from other substances are consequently lower compared to Danish conditions.

The same assumptions and uncertainty discussions as for Danish conditions applies also to EU-15, see paragraph 9.5.1.

9.5.2.2 Water

The overall EU-15 toxicity impact potential has been calculated to: $1.93*10^{13}$ m^3 water, which gives the normalisation reference

$5.22*10^4$ m^3 water/capita/year

Table 9-7 summarises which substances have been assessed to contribute significantly to the normalisation reference.

Table 9-7
Substances contributing by more than 1% to the normalisation reference for water.

Substance	Fraction (%)
Mercury (Hg) from air deposition	80
Mercury (Hg); water emission	10
Dioxin from air deposition	4.2
Lead (Pb); water emission	2.1
Lead (Pb) from air deposition	1.9
Zinc (Zn); water emission	1.0

A comparison can not be made with EDIP English as EU-15 was not previously included in EDIP.

The EU-15 normalisation factor is approximately one third of the Danish factor. The toxicity impact potential in EU-15 as well as in Denmark are dominated by air deposition and effluent of mercury, but the air emission of mercury on EU-15 level are lower per capita than the Danish emission. As a consequence, dioxins, lead and zinc contribute with more than 1%. The reason why mercury emission to air is higher in Denmark may be due to the application of fossil fuels with high mercury content.

9.5.2.3 Soil

The overall EU-15 toxicity impact potential has been calculated to: $4.71*10^{10}$ m^3 soil, which gives the normalisation reference

$1.27*10^2$ m^3 soil/capita/year

Table 9-8 summarises which substances have been assessed to contribute significantly to the normalisation reference.

Table 9-8
Substances contributing by more than 1% of the normalisation reference for soil.

Substance	Fraction (%)
Arsenic from air deposition	60
Mercury (Hg) from air deposition	24
Tetrachloroethylene from air deposition	3.8
Arsenic from sludge	3.8
Mercury from sludge	1.5
Chromium from air deposition	1.3
Tetrachloromethane from air deposition	1.3
Lead from air deposition	1.3
Cadmium from air deposition	1.0

A comparison can not be made with EDIP English as EU-15 was not previously included in EDIP.

The EU-15 normalisation factor is approx. one half of the Danish. Mercury and arsenic dominate both normalisation factors but for EU-15 arsenic is the dominating substance and for Denmark mercury is the dominating substance.

9.5.3 Worldwide

The worldwide normalisation references for human toxicity are calculated as proposed in chapter 3, Development of normalisation references for different geographic areas, by using a factor 0.8 × normalisation reference for EU-15.

9.5.3.1 Air

The worldwide normalisation reference for exposure via air has been calculated to:

$4.87*10^{10}$ m^3 air/capita/year

9.5.3.2 Water

The worldwide normalisation reference for exposure via water has been calculated to:

$4.18*10^{4}$ m^3 water/capita/year

9.5.3.3 Soil

The worldwide normalisation reference for exposure via soil has been calculated to:

$1.02*10^{2}$ m^3 soil/capita/year

9.5.4 Comparison with the previously used normalisation reference

In Table 9-9 the estimated normalisation references are compared with the values for 1990-1992 calculated by Hauschild ***et al***. (1998).

Table 9-9
The estimated total human toxicity normalisation references for Denmark compared to the values for the years 1992-1994 in Hauschild et al. (1998).

		Denmark	EU-15	World
Air, 1990	m^3 air/capita/year	$9.18*10^{9}$	-	-
1994		$5.53*10^{10}$	$6.09*10^{10}$	$4.87*10^{10}$
Water, 1990	m^3 water/capita/year	$5.9*10^{4}$	-	-
1994		$1.79*10^{5}$	$5.22*10^{4}$	$4.18*10^{4}$
Soil, 1990	m^3 soil/capita/year	$3.1*10^{2}$	-	-
1994		$1.57*10^{2}$	$1.27*10^{2}$	$1.02*10^{2}$

9.6 Recommendations for future updating

As can be seen from the discussions of different types of uncertainties in the previous paragraphs, the focus for future updates should be on a better understanding of the emissions from combustion sources, i.e. both the amounts emitted from different activities and their toxicity potential. Emissions of nmVOC and particulate matter from road transport have emerged as the most important contributors to human toxicity via air, but their assessment is still associated with a large degree of uncertainty.

One of the main tasks is to establish more precise knowledge about the amounts of different species of nmVOC being emitted. The approach used in the current project is rather straightforward, but the results are in practice dependent on the composition of nmVOC in exhaust from different vehicles. Here, a closer examination of available scientific literature may lead to identification of better inventories than those identified and used in Corinair.

Another main task is to establish a more precise overview of the amounts of particulate matter being emitted and distributed in the environment. Little is presently known regarding the distribution of the size of particles being emitted from various combustion sources, but because of the assumed importance it can be anticipated that more information becomes available in the coming years.

Thirdly, better effect factors for particulate matter are needed. As described previously, it can be argued that the effect factor for fine and ultrafine particles perhaps ought to be a factor 25,000 higher than the one used in the present study. Also here better knowledge is emerging continuously and can probably be used to establish more precise effect factors in a future update of the normalisation reference.

The three issued described above are assumed to be the major concerns of a future update. There are, however, some additional points that can be addressed in order to provide more insight into the overall toxic load. These are mentioned briefly in the following sections.

9.6.1 Substances presently included

Emission data on the substances presently included are more or less frequently updated. However, it is believed that Corinair data and possibly data from the “Indicator project” (Eurostat, 1998) will be improved in the future. Data on POP’s and heavy metals may contain more details for more countries, and data on particle emission is assumed to be upgraded considerably in the coming years. Appendix A lists relevant contact information in connection with a future updating.

9.6.2 Inclusion of new substances

9.6.2.1 Industrial releases

Quantification of emissions from the chemical industry may be improved. It should be investigated whether emission registrations have been made for other countries than Holland. In Germany, the database “Sysiphus” may in the future serve as a basis for emission quantification from the German industry. It is confidential as such, but emissions at country level may be obtainable. The database does not presently cover substantial amounts of emission data (information about Sysiphus and other data sources on use and releases from industrial chemicals can be found on: http://appli1.oecd.org).

9.6.2.2 Equivalence factors

Inclusion of the chemicals requires new EQF’s to facilitate an assessment of the emissions. The stepwise methodology described in section 9.3 could be used for the selection of substances to be included in an extrapolation to counties no having available data.

9.6.2.3 HPV chemicals

An alternative approach for HPV (High Production Volume) chemical emissions could be estimations based on assumptions on emission of given fractions of the production volumes (emission factors). For instance, the key figures on emission ratios in the Technical Guidance Document (TGD) (EC-TGD, 1996) could be applied. These figures will give a worst case estimate, but can be highly relevant when used as an indicator of whether or not the considered chemical contributes significantly to the overall toxic load. However, this approach demands several data on production facilities and on application of the products, and would therefore be rather time consuming.

Further, the possibility and relevance of including the omitted data (described in section 9.3.3) should be investigated. Suggestions are presented below.

9.6.2.4 Proposal for the inclusion of pesticides

1. Exposure assessment. In order to get an idea of the distribution between environmental media (air, ground water, surface water and soil) an exposure model can be used. USES 2.0 (RIVM/VROM/VWS, 1998) has been developed to include modelling of pesticide fate.
2. Effect factors are calculated according to the existing EDIP methodology (Hauschild ***et al***. 1998).

9.6.2.5 Other emissions

Other emissions assessed to be of importance at the time when the normalisation references were updated, should of course be included. As also described in the sections 9.2 and 9.5, the quantity of missing toxic load in the normalisation references is uncertain due to the load from the diffuse use of many substances in minor quantities. The lack of emission data will tend to result in too small normalisation references.

9.6.3 Methodological issues

As indicated in the methodology section 9.4, quite a few uncertainties are connected to the EDIP human toxicity assessment method. The equivalence factors for each substance contain both information of the fate of the substance in the environment (exposure assessment) and of the toxicity of the substance per see (effect assessment).

9.6.3.1 Exposure method

The exposure scenarios used in the methodology causes some uncertainty. The applied semi-quantitative exposure method is rather simple. Other methods apply more sophisticated models, which should be used with caution in LCA as they are developed for risk assessments purposes. An interesting assumption in the methods is that the contribution of air depositions is 80% on soil and 20% and water. This is a European average and does not apply to Danish conditions. If these differences were to be included, it would mean that individual EQFs would have to be calculated for each country. That approach, however, seems unfeasible.

An intrinsic problem with exposure assessment in LCA is caused by the marginal nature of LCA (consideration of ***one*** functional unit). Therefore, it is difficult to include local exposure levels. Consequently, normalisation references and effect potentials are representing ***potential*** and not actual effects. This problem is dealt with in sub-project V, which should be consulted for further details.

9.6.3.2 Effect assessment

A number of uncertainties are connected to the effect assessment of the EDIP/LCA methodology. When calculating the overall normalisation references, a multitude of emissions (and thereby toxic modes of actions for the different substances) is added. This is also a problem, as different toxic responses are not additive and also because, the relative severity of different effects - as for instance irritation, reversible effects and carcinogenicity - is not considered. Also the application of safety factors when calculating the EQF’s may be questioned. In LCA a realistic goal for human toxicity is to be “correct on average”. LCA can not be used to obtain safe exposure levels (as is the intention in risk assessment) for all substances emitted in the product life cycle. Finally, it should be remembered that toxicity data for a lot of substance are lacking. It might therefore be very difficult to establish a good EQF for substances, which have been poorly studied in toxicological tests.

The uncertainties involved in the exposure and effect assessment described above are not only connected to calculation of normalisation references but also to calculating effect potentials for a product or a product system.

Due to the uncertainties in the described data, exposure and effect assessment, the normalisation references and effect potentials should be regarded as an order of magnitude rather than a numerical correct scientific number.

Further, as discussed in section 9.5, the methodology uncertainties are probably more important in connection with assessing toxicity in LCA and thereby also in establishing normalisation references. For instance, it seems strange that almost the entire toxicity via the water environment is caused by deposition of mercury emitted to air, and it also seems questionable that 1,3-butadiene – the most important nmVOC species - is responsible for a main part of the toxicity via air, being highly reactive and therefore having only a short life in the environment.

Many of the problems discussed above will probably disappear when the EU-funded OMNIITOX-project is completed in 2005. The project aims at creating a common method for inclusion of toxicity and ecotoxicity in LCA and can therefore provide a significant step forward for the EDIP method as well as other impact assessment methods. The development in the project can be followed at www.omniitox.net.

Therefore it seems necessary to carry out an in depth analysis of the EDIP LCA toxicity method, including identification of sensitive parameters therefore seems needed. Further, the most important EQFs in relation to calculation of the normalisation references should be reviewed thoroughly in connection with a future updating.

9.7 References

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Appendix A: Data sources

Overview of data sources and contacts for air emissions

Overview of substances included in the normalisation and corresponding data sources.

Substances	Reference/source
SO_2, NO_x, nmVOC, CO, N_2O, NH_3, heavy metals[1], POP[1]	• Corinair 94 (Ritter 1997)/ Internet: www.aeat.co.uk/netcen • Europe's Environment second assessment (EEA, 1998a,b) • Eurostat: ESEPI (Index-project) - Draft reports (Eurostat 1998) • EMEP-reports (EMEP/MSC-W 1997, 1998a,b; EMEP/MSC-E 1998a,b,c) • More detailed heavy metal emission data in Koch (1998) • Older (1990) and more detailed data can be found in Berdowski *et al.* (1997a) for heavy metals and POPs and for a number of substances on ftp://info.rivm.nl/pub/lae/edgarv20/. • Dioxins - Europe: The European Dioxin inventory (Quass & Fermann 1997) - DK: Dioxin. Sources, levels and exposures in Denmark (Jensen 1997) • PAH - "Traffic PAH and other Mutagens in Air in Denmark" (Nielsen *et al.* 1995) - DMU, Denmark (Jytte Boll Illerup, DMU, personal communication)
Particles, PM10	• TNO report (Berdowski *et al.* 1997b) • Air pollution in Europe 1997 (EEA 1997)
Chemicals/chemical industry	• Dutch emission registrations (van der Auweraert *et al.* 1996) • Dutch normalisation report (Blonk *et al.* 1997)

[1] Only available for D, UK, A, DK, L, SCH, N in CorinAir94.

Relevant contacts in relation to obtaining data on Danish and European air emissions:

- EMEP - co-operative programme for monitoring and evaluation of the long range transmission of air pollutants in Europe. Contact:
  Det Norske Meteorologiske Institutt (DNMI)
  Postboks 43, Blindern,
  0313 Oslo
  Phone [47] 22 96 30 00
  Fax [47] 22 96 30 50
  e-post: met.inst@dnmi.no
  http:/www.dnmi.no
- TNO - Department for Ecological Risk Studies:
  TNO Institute of Environmental Sciences, Energy Research and Process Innovation
  Business Park Environmental Technology Valley
  Laan van Westenenk 501
  7334 DT Apeldoorn

Netherlands
Telephone: +31 (55) 549 3493
Fax:+31 (55) 541 9837
E-mail:B.A.Heide@mep.tno.nl
http://www.mep.tno.nl

- ETC Air Emissions
  Umweltbundesamt UBA
  Contact person: Dietmar Koch
  Bismarckplatz 1
  D-14193 Berlin
  Germany
  Phone: [49] 30 8903 2392
  Fax: [49] 30 8903 2178
  E-mail: dietmar.koch@uba.de
  Homepage: http://www.aeat.co.uk/netcen
- Danish National Reference Centre for Air Emissions
  National Environmental Research Institute
  Department of Policy Analysis
  Contact person: Jytte Boll Illerup
  Frederiksborgvej 399
  P.O. Box 358
  DK-4000 Roskilde
  Denmark
  Phone: [45] 46 30 12 00
  Fax: [45] 46 30 11 14
  E-mail: jbi@dmu.dk
  Homepage: http://www.dmu.dk
- European Environment Agency (EEA)
  Kongens Nytorv 6
  DK-1050 København K
  Denmark
  Phone: [45] 33 36 71 00
  Fax: [45] 33 36 71 99
  E-mail: eea@eea.eu.int
  Homepage: http://www.eea.eu.int
- National EU focal points
- Dutch LCA methodological project
  Information and contact details can be found on: http://www.leidenuniv.nl

Appendix B.1: Extrapolations and data handling

This appendix gives a survey of the air emission data (including the availability of data) used in the estimation of the total potential human toxicological impact in EU-15; see Table 9-11. Information on air emissions is available for a number of European countries in EU-15 as well as outside EU-15. For the present purpose it is decided to use data from Norway and Switzerland (for heavy metals and persistent organic pollutants) in order to get a better basis for extrapolation to EU-15. Below, a general extrapolation method will be presented followed by comments to the data used to estimate the total potential human toxicological impact in EU-15.

General considerations concerning extrapolation from single countries or groups of countries to EU-15 and from groups of countries to the world is presented in chapter 3, Development of normalisation references for different geographic areas.

As extrapolation factor GDP[15] is chosen and a general formula can be outlined:

$$\mathrm{Emis}_{\mathrm{EU-15,substx}} = \frac{\sum_{1}^{n} \mathrm{Emis}_{\mathrm{subst.x,n}}}{\sum_{1}^{n} \mathrm{GDP}_{\mathrm{n}}} \times \mathrm{GDP}_{\mathrm{EU-15}}$$

n is the countries with available information on emission of substance (***subst x.***).

An example on extrapolation to EU-15 is shown in the box below. Emissions of TRI (trichloroethylene) from the following countries are included: Denmark, Germany, Netherlands, Norway, and United Kingdom.

$$\mathrm{Emis}_{\mathrm{EU-15,TRI}} = \frac{(11{,}000 + 478 + 1{,}040 + 20{,}349 + 469)\ \text{ton TRI/year}}{(2{,}04 \times 10^{12} + 1{,}47 \times 10^{11} + 3{,}3 \times 10^{11} + 1{,}01 \times 10^{12} + 1{,}09 \times 10^{11})\$} \times 7{,}4 \times 10^{12}\ \$$$

$$= 67{,}000\ \text{ton TRI/year}$$

The applied extrapolation methodology has not been verified and therefore it has to be considered as rather uncertain. However, the present extrapolation method is supposed to be as certain as any other methodology.

Information on emission of the general air pollutants (SO_2, NO_x, N_2O, CO and nmVOC) is available in a number of sources (e.g. CORINAIR 94[16]

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[15] Gross domestic product (GDP) measures the total output of goods and services for final use occurring within the domestic territory of a given country, regardless of the allocation to domestic and foreign claims.

(Ritter 1997)) due to different conventions on air pollution (e.g. ***Convention on Long-range Transboundary Air Pollution*** (UN-ECE 1979)). ETC/AE[17] has calculated total emissions for EU-15 for the above mentioned substances. The quality of the summary data depends on the quality and level of detail of the data delivered by the single countries. The report uses three levels of quality/details with the countries in the different groups as described below:

- A (the emission estimates are ***fully detailed***): Austria, Belgium, Denmark, Greece, Ireland, Luxembourg, Sweden, United Kingdom
- B (the emission estimates are ***detailed***): Germany, Netherlands
- C (the emission data cover the ***main source sectors***): Finland, France, Italy, Portugal, Spain

These emissions are measured regularly. This part of the estimation of the total potential human toxicological impact in EU-15 can therefore be updated regularly if preferred.

Information on emission of heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn) is available in e.g. CORINAIR 94 (Ritter 1997) supplemented by 95-update (Koch 1998) due to different conventions on air pollution (e.g. “Convention on Long-range Transboundary Air Pollution” (UN-ECE 1979)).

Data on emissions of heavy metals are only available for few countries in EU-15 (for 1994), and therefore data from Norway and Switzerland will be included in the estimates of the total potential human toxicological impact in EU-15. Norway and Switzerland are supposed to be representative for EU-15. The 95-update also includes emission estimates from Greece, Italy, Netherlands and Sweden. The quality of the information varies due to less developed estimation methodologies etc. The levels of quality/details is described below with the countries in the different groups:

- A (the emission estimates are ***fully detailed***): Norway, United Kingdom
- B (the emission estimates are ***detailed***): Austria, Germany, Switzerland
- C (the emission data cover the ***main source sectors***): Denmark, Luxembourg

In addition to the data reported by CORINAIR, data on emissions of heavy metals in Netherlands (van der Auweraert ***et al***. 1996) are included in the estimate.

Information on emission of persistent organic pollutants (POP’s) is available in e.g. CORINAIR 94 (Ritter 1997) due to different conventions on air pollution (e.g. “Convention on Long-range Transboundary Air Pollution” (UN-ECE 1979)). The group of persistent organic pollutants included in CORINAIR consist of polyaromatic hydrocarbons (PAH), dioxins, pentachlorophenol (PCP), hexachlorobenzene (HCB), tetrachloromethane (TCM), trichloroethylene (TRI), tetrachloroethylene (PER), trichlorobenzene (TCB), trichloroethane (TCE) and hexachlorobenzene (HCB).

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[16] CORINAIR means “CORe INventory AIR” and is a part of the work programme of the European Environment Agency (EEA).

[17] ETC/AE means the European Topic Centre on Air Emissions.

Data on emissions of persistent organic pollutants are only available for few countries in EU-15, and therefore data from Norway and Switzerland will be included in the estimates of the total potential human toxicological impact in EU-15. The quality of the information varies due to less developed estimation methodologies etc. The levels of quality/details is described below with the countries in the different groups:

- A (the emission estimates are ***fully detailed***): Norway, United Kingdom
- B (the emission estimates are ***detailed***): Austria, Denmark, Germany, Luxembourg, Switzerland

In addition to the data reported by CORINAIR data on emissions of persistent organic pollutant in Netherlands (van der Auweraert ***et al***. 1996) is included in the estimate.

Additional data have also been used for dioxins. EU/DG XI has financed "The European Dioxin Inventory" (Quass & Fermann 1997). Data were only taken from this source if they were not available in CORINAIR, or if they were considered better than the data in CORINAIR and dated from the chosen reference years 1994 or 1995 (i.e. Belgium, France, Norway and Sweden). CORINAIR includes dioxin data from Austria, Denmark, Germany, Luxembourg, Switzerland and UK.

PAH as well as ***dioxins*** are groups of substances of different toxicity. In order to sum up the human toxicological potential of PAH and dioxins to a single number, ***toxic equivalence factors*** have been developed. By using these equivalence factors, the total PAH emission can be expressed as benzo(a)pyrene equivalents and the total dioxin emission can be expressed as 2,3,7,8-tetrachloro-p-dioxins equivalents (2,3,7,8-TCDD-eq. (I-TEQ)). The dioxin equivalence factors have been used for a number of years and are internationally accepted whereas the PAH equivalence factors are still under development. This means that emissions of dioxins are normally reported in I-TEQ whereas emissions of PAH are still reported as Σ PAH.

By using the Σ PAH and the equivalence factor for benzo(a)pyrene for all the substances, the potential human toxicological impact of PAH will be overestimated. Therefore, detailed information on distribution of different PAH's is necessary in order to calculate a more reliable potential human toxicological impact of PAH. Detailed information on the distribution of PAH's is available for Denmark; see Table 9-10.

Table 9-10
Emissions of PAH in Denmark. Benzo(a)pyrene equivalents are calculated by using the relative potency proposed by Nielsen et al. (1996).

	Relative potency	ton/year	ton PAH-eq./year
PAH		3,70E+01	
Fluoranthen	0,05	2,30E+01	1,15E+00
Benzo(b)fluoranthen	0,05	3,62E+00	1,81E-01
Benzo(k)fluoranthen	0,05	1,36E+00	6,80E-02
Benzo(a)pyrene	1	2,67E+00	2,67E+00
Benzo(g,h,i)perylene	0,02	4,29E+00	8,58E-02
Indino(1,2,3-c,d)pyrene	0,1	2,29E+00	2,29E-01
PAH-eq. (benzo(a)pyrene)			4,38E+00

The total PAH emission (Σ PAH) is reported to 37 ton/year and the emission expressed as benzo(a)pyrene equivalents is estimated to 4,4 ton benzo(a)pyrene-equivalents/year. Assuming that the distribution of the PAH’s found in Denmark is representative, a correction factor can be determined to:

$$F = \frac{4{,}4}{37} = 0.119$$

This correction factor F is used to estimate the emission benzo(a)pyrene equivalents for the countries that only have reported Σ PAH.

Table 9-11
Air emission data available for extrapolation to EU-15.

Substance	A	B	D	DK	E	F	GR	I	IR	L	NL	P	S	SF	UK	EU-15	N	SCH
SO_2[1]																x		
NO_x[1]																x		
N_2O[1]																x		
CO[1]																x		
nmVOC[1]																x		
NmVOC – transport[1]																x		
Cd	x		x	x			95	95			x		95		x		x	95
As	x		x	x			95	95			x		95		x		x	
Cr(VI)	x		x	x			95	95			x		95		x		x	
Hg	x		x	x			95	95			x		95		x		x	95
Ni	x		x	x			95	95			x		95		x		x	
Pb	x		x	x			95	95			x		95		x		x	95
Se	x		x	x			95	95			x		95		x		x	
Cu	x		x	x			95	95			x		95		x		x	
Zn	x		x	x			95	95			x		95		x		x	95
Formaldehyde											(x)							
Benzene											(x)							
Phenol											(x)							
Styrene											(x)							
Toluene											(x)							
Xylenes											(x)							
PAH	(x)		(x)	(x)											(x)		(x)	
Fluoranthen				x							x							
Benzo(b)fluoranthen				x														
Benzo(k)fluoranthen				x														
Benzo(a)pyrene				x							x							
Benzo(g,h,i)perylene				x														
Indino(1,2,3-c,d)pyrene				x														
PAH-eq. (benzo(a)pyrene)	x		x	x							x				x		x	
Dioxin	x	x	x	x		x							x		x		x	x
PCP															x		x	
Hexachlorbenzene (HCB)			x												x		x	
Tetrachloromethane (TCM)				x							x				x		x	
Trichloroethylene (TRI)			x	x							x				x		x	
Tetrachloroethylene (PER)			x	x							x				x		x	
Trichlorobenzene (TCB)															x		x	
Trichloroethane (TCE)			x	x							x				x		x	
Hexachlorohexane (HCH)				x											x		x	
Chlorbenzenes											(x)							
Vinylchloride											x							
Particulate matter (PM10)											x							

1. Emission data are available for all the European countries.
x means that the data is used to estimate EU-15 emission.
(x) means that the data are available but are not used in the estimation of EU-15 emission in this edition; the PAH results are supposed to be ΣPAH and therefore PAH-equivalents (benz(a)pyrene) has been calculated.

Appendix B.2: Effect factors

Particulate matter (PM_{10})

Particulate matter is a chemical inhomogeneous group, and the toxicological assessment is not directly linked with the chemical composition. In most cases the heavy metals or acids emitted as particulate matter are measured as specific substances. The toxicity of particulate matter is linked with inhalation.

Therefore, the toxicity of particulate matter is only relevant for emissions to air end direct exposure via air i.e. by inhalation.

The EQF has been determined for particulate matter (< 10μm). The EQF is based on air quality criteria: 50 $\mu g/m^3$ (annual average) (US EPA 1996). The air quality criteria expressed as annual average is assumed to be equivalent to the concentration having no adverse effects throughout a whole life i.e. equal to the human reference concentration (HRC).

Emission to air Substance	CAS no.	EF(hta) m^3/g	f_{aa}	HRC mg/m^3
Particulate matter (PM_{10})	n.a.	$2*10^4$	1	0.050

It is emphasized that the suggested effect factor for particulate matter may underestimate the contribution significantly. Recent research points to fine particles (less than 2.5 μm) and ultrafine particles (less than 0.1 μm) as being of even more concern than PM_{10}. Drivsholm ***et al.*** (2002) arguess that the effect factor should be significantly higher ($5.5 * 10^8$ m^3/g) if both physical and toxic effects from inhalation of particles is taken into consideration.

As discussed in Drivsholm ***et al.*** (2002), modern motors may actually emit more fine particles than conventional motors. However, there is no science-based information available that allows to calculate a precise effect factor for particles from different types of vehicles/fuels. Nor is it possible to calculate a normalisation reference because there is no information available on the amounts of different particle sizes being emitted from human activities.

The toxicity of particulate matter should therefore be kept in focus for future updates of the normalisation reference. In the meantime, the normalisation references and the effect factors developed in this project should be used with caution.

nmVOC from road transport

Effect factors for nmVOC from road transport, jet engines and ferries were established by using information from Corinair94 (Ritter, 1997) regarding their composition and by using the existing effect factors for the single VOC-species where available and supplementing with the default factor used in the original EDIP97-calculations, i.e. 10.000 m^3/g for all species without a specific effect factor. Table 9-12 sums up the established effect factors and the most important species, while Table 9-17 to Table 9-19 gives a detailed overview of the composition and the importance for a number of fuel/vehicles.

Fuel/Vehicle	Effect factor ht(a) (m^3/g)	Most important species
Diesel – HDV	1.06 E+7	1,3-butadien (80%) Formaldehyde (10%) Acrolein (8%)
Diesel – LDV	6.9 E+6	1,3-butadien (35%) Acrolein (26%) Formaldehyde (22%) Acetone (12%)
Gasoline – EURO I	3.35 E+6	1,3-butadien (68%) Benzene (17%) Formaldehyde (6%) Acetone (5%)
Gasoline – Conventional motors	4.65 E+6	1,3-butadien (76%) Benzene (15%) Formaldehyde (6%)
Gasoline – Evaporation	1.09 E+5	Benzene (92%) Isopentane (2%)
LPG	1.19 E+6	1,3-butadien (32%) Acrolein (25%) Formaldehyde (16%)
Jet engines (Landing-Take off Cycle)	8.33 E+6	1-pentene (55%) Acrolein (23%) Other aldehydes (14%)
Ferries (can be used as surrogate for nmVOC from ship transport)	4.1 E+5 – 3.5 E+6	Benzene (97.9 –99.9%)

Table 9-12. Effect factors for human toxicity (air) for nmVOC from different fuels/vehicles

A similar approach was applied in a system analysis of road transport in Denmark (Drivsholm ***et al***, 2002). That report allows for a detailed comparison of the resulting effect factor for nmVOC from diesel exhaust, and here there is a good accordance between the findings in the two projects. The main difference between the two calculations is that Drivsholm ***et al.*** identifies the most important species by a qualitative approach whereas in the current project all species are included in the calculations.

The contribution to the updated normalisation references was established by combining different types of information from Corinair94 (Ritter, 1997; www.aeat.co.uk/netcen).

In Corinair, information is available regarding the amounts emitted from different sources (Table 9-13):

- Passenger cars (SNAP code 070100)
- Light duty vehicles < 3.5t (SNAP code 070200)
- Heavy duty vehicles > 3,5t and buses (SNAP code 070300)
- Mopeds and motorcycles < 50 cm^3 (SNAP code 070400)
- Motorcycles > 50 cm^3 (SNAP code 070500)
- Evaporation of gasoline

Four countries (Finland, Italy, Spain and Portugal) have not reported the distribution of nmVOC on the single SNAP code activities. For these four countries, it was assumed that the distribution is similar to the average distribution for the other eleven countries. One country, Germany, does not report the amounts of nmVOC from evaporation. Here, it was assumed that the relationship between the total amounts emitted from road transport and the amount evaporating is equal to the average proportion in the other fourteen countries.

	VOC Road transport (from Corinair 94)						
	Passenger	LDV	HDV+buses	Mopeds+MC	MC	Gasoline evap	Total
Austria	30157	2279	7308	2955	1321	27500	71520
Belgium	124319	1087	13162	2622	19523	15749	176462
Denmark	35227	4370	6927	2044	2058	23549	74175
Finland	29591	3819	3763	1723	2899	10105	51900
France	403625	118398	51378	30360	49368	309888	963017
Germany	546976	33477	63127	9016	24063	131749	808408
Greece	37236	17531	7387	46109	67142	44444	219849
Ireland	25280	2814	1095	443	782	27870	58284
Italy	615356	79415	78244	35837	60289	210142	1079283
Luxembourg	3641	1027	649	113	345	3286	9061
Netherlands	61000	6770	17400	6800	5100	40200	137270
Portugal	58591	7562	7450	3412	5740	20009	102764
Spain	284492	36715	36174	16568	27873	97153	498976
Sweden	87970	6139	6449		3760	40952	145270
UK	522063	48409	63845	8878	10485	107721	761401
Total	2865524	369812	364357	166880	280749	1110318	5157640

Table 9-13. nmVOC from road transport. Adapted from Corinair94 (Ritter, 1997).

The emission profiles differ significantly between diesel and gasoline fuels for the same type of vehicles, and also between countries for the same type of fuel/vehicle combination. In order to reflect these differences, the total nmVOC emissions for each country were (re)distributed on the following types of vehicles (Table 9-14):

– Gasoline LDV
– Diesel LDV
– Gasoline PC
– Diesel PC
– Diesel HDV
– Mopeds and motorcycles
– Gasoline evaporation

	VOC Road transport - redestributed (all figures in tons/year)							
	Gasoline PC	Diesel PC	Gasoline LDV	Diesel LDV	HDV + buses	Mopeds + MC	Gasoline evaporation	**Total**
Austria	28422	1735	1904	375	7308	4276	27500	71520
Belgium	107322	16997	838	249	13162	22145	15749	176462
Denmark	35006	221	3888	482	6927	4102	23549	74175
Finland	28950	641	2588	1231	3763	4622	10105	51900
France	388727	14898	93786	24612	51378	79728	309888	963017
Germany	528183	18793	25176	8301	63127	33079	131749	808408
Greece	37184	52	16275	1256	7387	113251	44444	219849
Ireland	25080	200	2007	807	1095	1225	27870	58284
Italy	603627	11729	65509	13906	78244	96126	210142	1079283
Luxembourg	3363	278	967	60	649	458	3286	9061
Netherlands	58050	2950	6770	0	17400	11900	40200	137270
Portugal	57633	958	0	7562	7450	9153	20009	102764
Spain	269252	15240	27801	8914	36174	44441	97153	498976
Sweden	87385	585	5996	143	6449	3760	40952	145270
UK	515614	6449	43672	4737	63845	19363	107721	761401

Table 9-14. nmVOC from road transport redistributed on different fuels/vehicles.

With the effect factors for different fuels/vehicles and the amounts of nmVOC being emitted from the same combinations in EU-15 countries, the overall contribution to human toxicity via air can be calculated for each of the EU-15 countries (Table 9-15).

	Contribution to Normalisation references for human toxicity (air)							
	Gasoline PC	Diesel PC	Gasoline LDV	Diesel LDV	HDV + buses	Mopeds + MC	Gasoline evaporation	Total contribution from nmVOC
Austria	1,32E+17	1,20E+16	8,85E+15	2,59E+15	7,73E+16	1,99E+16	2,99E+15	2,56E+17
Belgium	4,99E+17	1,17E+17	3,89E+15	1,72E+15	1,39E+17	1,03E+17	1,71E+15	8,65E+17
Denmark	1,63E+17	1,53E+15	1,81E+16	3,32E+15	7,32E+16	1,91E+16	2,56E+15	2,80E+17
Finland	1,35E+17	4,42E+15	1,20E+16	8,49E+15	3,98E+16	2,15E+16	1,10E+15	2,22E+17
France	1,81E+18	1,03E+17	4,36E+17	1,70E+17	5,43E+17	3,70E+17	3,36E+16	3,46E+18
Germany	2,45E+18	1,30E+17	1,17E+17	5,73E+16	6,67E+17	1,54E+17	1,43E+16	3,59E+18
Greece	1,73E+17	3,60E+14	7,56E+16	8,66E+15	7,81E+16	5,26E+17	4,82E+15	8,67E+17
Ireland	1,17E+17	1,38E+15	9,32E+15	5,57E+15	1,16E+16	5,69E+15	3,03E+15	1,53E+17
Italy	2,80E+18	8,09E+16	3,04E+17	9,59E+16	8,27E+17	4,47E+17	2,28E+16	4,58E+18
Luxembourg	1,56E+16	1,92E+15	4,49E+15	4,13E+14	6,86E+15	2,13E+15	3,57E+14	3,18E+16
Netherlands	2,70E+17	2,04E+16	3,15E+16	0,00E+00	1,84E+17	5,53E+16	4,36E+15	5,65E+17
Portugal	2,68E+17	6,61E+15	0,00E+00	5,22E+16	7,88E+16	4,25E+16	2,17E+15	4,50E+17
Spain	1,25E+18	1,05E+17	1,29E+17	6,15E+16	3,82E+17	2,06E+17	1,05E+16	2,15E+18
Sweden	4,06E+17	4,03E+15	2,79E+16	9,85E+14	6,82E+16	1,75E+16	4,45E+15	5,29E+17
UK	2,40E+18	4,45E+16	2,03E+17	3,27E+16	6,75E+17	9,00E+16	1,17E+16	3,45E+18
Total EU	**1,29E+19**	**6,33E+17**	**1,38E+18**	**5,01E+17**	**3,85E+18**	**2,08E+18**	**1,21E+17**	**2,15E+19**

Table 9-15. Contribution from nmVOC – road transport to the normalisation references for human toxicity (air).

Table 9-16 shows the relative contribution from the different fuels/vehicles and illustrates clearly that the main contribution comes from passenger cars. As nmVOC from road transport is the main contributor to human toxicity via air this means that when examining product systems (other than person transport), the relative importance of this impact category will be small, because person transport in general not is included in inventories. When comparing alternatives, however, products that are demanding with respect to transportation will have a significantly larger impact when the newly established effect factors are applied..

	Distribution of contributions in %							
	Gasoline PC	Diesel PC	Gasoline LDV	Diesel LDV	HDV + buses	Mopeds + MC	Gasoline evaporation	Total
Austria	51,7%	4,7%	3,5%	1,0%	30,2%	7,8%	1,2%	100%
Belgium	57,6%	13,6%	0,4%	0,2%	16,1%	11,9%	0,2%	100%
Denmark	58,0%	0,5%	6,4%	1,2%	26,1%	6,8%	0,9%	100%
Finland	60,6%	2,0%	5,4%	3,8%	17,9%	9,7%	0,5%	100%
France	52,2%	3,0%	12,6%	4,9%	15,7%	10,7%	1,0%	100%
Germany	68,3%	3,6%	3,3%	1,6%	18,6%	4,3%	0,4%	100%
Greece	19,9%	0,0%	8,7%	1,0%	9,0%	60,7%	0,6%	100%
Ireland	76,1%	0,9%	6,1%	3,6%	7,6%	3,7%	2,0%	100%
Italy	61,2%	1,8%	6,6%	2,1%	18,1%	9,7%	0,5%	100%
Luxembourg	49,1%	6,0%	14,1%	1,3%	21,6%	6,7%	1,1%	100%
Netherlands	47,7%	3,6%	5,6%	0,0%	32,6%	9,8%	0,8%	100%
Portugal	59,5%	1,5%	0,0%	11,6%	17,5%	9,4%	0,5%	100%
Spain	58,3%	4,9%	6,0%	2,9%	17,8%	9,6%	0,5%	100%
Sweden	76,8%	0,8%	5,3%	0,2%	12,9%	3,3%	0,8%	100%
UK	69,4%	1,3%	5,9%	0,9%	19,6%	2,6%	0,3%	100%
Average EU	**60,1%**	**2,9%**	**6,4%**	**2,3%**	**18,0%**	**9,7%**	**0,6%**	**100%**

Table 9-16. Relative contribution from different fuels/vehicles

It is once more remarked that the uncertainty in the normalisation references is relatively high. The uncertainty is demonstrated by the fact that the Corinair inventory quotes two different inventories for the composition of nmVOC from motor exhaust. They have an almost comparable level of detail, but with a little less detail in the information the effect factors for different types of fuels/vehicles decrease with about 30%. This uncertainty is, however, within the general target of precision, i.e. to provide the right order of magnitude. This claim is supported when comparing the effect factors for different fuels/vehicles with the effect factor for overall vehicle exhaust as measured in an American road tunnel. A detailed inventory for this can be found in Kirschstetter ***et al***, 1998. When applying the same calculation method as above, the effect factor for "combined exhaust" can be calculated to 2.44 E+6. This figure is smaller than that calculated for the individual types of fuels/vehicles, but is still within the same order of magnitude.

It is also remarked that no attention was given to nmVOC from other cources of combustion, the reason being that detailed information on the composition was not available and/or that the contribution – measured by weight – was small compared to the constribution from road traffic.

	Content in exhaust in %										
VOC Species	EF (hta)	HDV	LDV	Gasoline Euro I	Gasoline Conv.	Evaporation	LPG	Jet engine Total VOC	Jet engine nmVOC	Ferry 1	Ferry 2
ethane	10000	0,03	0,33	3,19	1,65		2,34				
propane	10000	0,1		0,65	0,47	1	49,85				
butane	10000	0,15		5,24	2,9	20	15,5				
isobutane	10000	0,14	0,07	1,59	1,29	10	6,95				
pentane	10000	0,06	0,04	2,15	1,78	15	0,35				
isopentane	10000		0,52	6,81	4,86	25	1,26				
hexane	1630			1,61	1,29	15					
heptane	10000	0,3	0,2	0,74	0,36	2	0,18				
octane	10000		0,25	0,53	0,56		0,04				
nonane	10000		0,67	0,16	0,06		0,01			10,0	
2-methylheptane	10000	0,21	0,12	0,57			0,09				
2-methylhexane	10000	0,63	0,45	1,48	0,8		0,25				
3-methylhexane	10000	0,35	0,22	1,14	0,56		0,19				
decane	10000	1,79	1,18	0,19	0,22					25,0	
3-methylheptane	10000	0,27	0,2	0,54	0,4		0,08				
Alkanes C10-12	10000		2,15	1,76	0,03		0,01			33,0	
Alkanes > C13	10000	27,5	17,91	1,45	0,06						
Cycloalkanes	10000	1,16	0,65	1,14	0,88		0,1				
ethylene	28,6	7,01	10,97	7,3	8,71		5,2	17,4	19,2	5,0	20,0
propylene	10000	1,32	3,6	3,82	4,87		5,19	5,2	5,8	2,0	6,0
propadiene	10000			0,05							
1-butene	10000			0,73	0,5	1					1,0
isobutene	10000	1,7	1,11	2,22	4,21		0,63	2	2,2	1,0	18,0
2-butene	10000		0,52	1,42	1,27	2	0,53				
1,3-butadiene	2,50E+08	3,3	0,97	0,91	1,42		0,15				
1-pentene	10000			0,11	0,09	2		1,8	2,0		1,0
2-pentene	10000			0,34	0,23	3					
1-hexene	10000			0,17		1,5					
dimethylhexene	10000			0,15							
1-butin	10000			0,21	0,05						
1-propin	10000			0,08	0,76						
acetylene	10000	1,05	2,34	2,81	5,5		1,28				
formaldehyde	1,25E+07	8,4	12	1,7	2,08		1,56				
acetaldehyde	3,66E+03	4,57	6,47	0,75	0,59		1,81				
acrolein	5,00E+07	1,77	3,58	0,19	0,16		0,59	15	16,6		
benzaldehyde	3,85E+04	1,37	0,86	0,22	0,6		0,03	4,6	5,1		
crotonaldehyde	10000	1,48	1,1	0,04	0,02		0,36	2,3	2,5		
methacrolein	1,43E+05	0,86	0,77	0,05			0,1				
butyraldehyde	10000	0,88	0,85	0,05			0,11				
isobútanaldehyde	10000	0,59	2,09								
proprionaldehyde	2,00E+06	1,25	1,77	0,05	0,11		0,7	1,2	1,3		
hexanal	10000	1,42	0,16								
i-valeraldehyde	10000	0,09	0,11				0,01				
vaæeraldehyde	10000	0,4	0,41								
o-tolualdehyde	10000	0,8	0,24	0,07	0,19						
m-tolualdehyde	10000	0,59	0,34	0,13	0,38						
p-tolualdhyde	10000		0,35	0,06	0,19						
acetone	3,02E+07		2,94	0,61	0,21		0,78				
methylethylketon	10000		1,2	0,05	0,11						
toluene	2,50E+03	0,01	0,69	10,98	12,84	1	1,22	2,4	2,7	5,0	15,0
ethylbenzene	10000		0,29	1,89	4,78		0,24			1,0	
m,p-xylene	6,67E+03	0,98	0,61	5,43	6,66	0,5	0,75			4,0	4,0
o-xylene	6,67E+03	0,4	0,27	2,26	4,52		0,26			2,0	
1,2,3-trimethylbenzen	10000	0,3	0,25	0,86	0,59		0,05			3,0	
1,2,4-trimethylbenzen	10000	0,86	0,57	4,21	2,53		0,25			2,0	
1,3,5-trimethylbenzen	10000	0,45	0,31	1,42	1,11		0,08			2,0	
styrene	1000	0,56	0,37	1,01	0,57		0,02				
benzene	1,00E+07	0,07	1,98	5,61	6,83	1	0,63			4,0	35,0
C9	10000	1,17	0,78	4,21	3,12		0,25				
C10	10000			3,07				1,9	2,1		
> C13	10000	20,37	13,37	3,46	6,01						
Others	10000							14,8	16,4		
C6H18O3Si3	10000							9,1	10,1		
C8H24O4Si4	10000							2,9	3,2		
Ethyne	10000							4,2	4,6		
Glyoxal	10000							2,5	2,8		
Methyl glyoxal	10000							2	2,2		
n-dodecane	10000							1,1	1,2		
Methan	10000							9,6			
TOTAL		96,71	99,2	99,64	99,98	100	99,98	100	100	99	100

Table 9-17. Composition of nmVOC in exhaust from different fuels and vehicles

	Contribution to EF(hta) in m3/g									
nmVOC Species	HDV	LDV	Gasoline EURO I	Gasoline conventional	Gasoline evaporation	LPG	Jet engine total VOC	Jet engine nmVOC	Ferry 1	Ferry 2
ethane	3	33	320	165		234				
propane	10		65	47	100	4986				
butane	16		526	290	2000	1550				
isobutane	14	7	160	129	1000	695				
pentane	6	4	216	178	1500	35				
isopentane		52	683	486	2500	126				
hexane			26	21	245					
heptane	31	20	74	36	200	18				
octane		25	53	56		4				
nonane		68	16	6		1			1010	
2-methylheptane	22	12	57			9				
2-methylhexane	65	45	149	80		25				
3-methylhexane	36	22	114	56		19				
decane	185	119	19	22					2525	
3-methylheptane	28	20	54	40		8				
Alkanes C10-12		217	177	3		1			3333	
Alkanes > C13	2844	1805	146	6						
Cycloalkanes	120	66	114	88		10				
ethylene	2	3	2	2		1	5	6	1	6
propylene	136	363	383	487		519	520	575	202	600
propadiene			5							
1-butene			73	50	100					100
isobutene	176	112	223	421		63	200	221	101	1800
2-butene		52	143	127	200	53				
1,3-butadiene	8530659	2444556	2283220	3550710		375075				
1-pentene			11	9	200		180	199		100
2-pentene			34	23	300					
1-hexene			17		150					
dimethylhexene			15							
1-butin			21	5						
1-propin			8	76						
acetylene	109	236	282	550		128				
formaldehyde	1085720	1512097	213268	260052		195039				
acetaldehyde	173	239	28	22		66				
acrolein	915107	1804435	95343	80016		295059	7500000	8296460		
benzaldehyde	545	334	85	231		12	1771	1959		
crotonaldehyde	153	111	4	2		36	230	254		
methacrolein	1272	1110	72			143				
butyraldehyde	91	86	5			11				
isobútanaldehyde	61	211								
proprionaldehyde	25850	35685	1004	2200		14003	24000	26549		
hexanal	147	16								
i-valeraldehyde	9	11				1				
valeraldehyde	41	41								
o-tolualdehyde	83	24	7	19						
m-tolualdehyde	61	34	13	38						
p-tolualdhyde		35	6	19						
acetone		894448	184763	63391		235451				
methylethylketon		121	5	11						
toluene	0	17	275	321	25	31	60	66	126	375
ethylbenzene		29	190	478		24			101	
m,p-xylene	68	41	363	444	33	50			269	267
o-xylene	28	18	151	302		17			135	
1,2,3-trimethylbenzen	31	25	86	59		5			303	
1,2,4-trimethylbenzen	89	57	423	253		25			202	
1,3,5-trimethylbenzen	47	31	143	111		8			202	
styrene	6	4	10	6		0				
benzene	7238	199597	563027	683137	100000	63013			404040	3500000
C9	121	79	423	312		25				
C10			308				190	210		
> C13	2106	1348	347	601						
Others							1480	1637		
C6H18O3Si3							910	1007		
C8H24O4Si4							290	321		
Ethyne							420	465		
Glyoxal							250	277		
Methyl glyoxal							200	221		
n-dodecane							110	122		
Methan							960			
Effect factor (m3/g)	**1,06E+07**	**6,90E+06**	**3,35E+06**	**4,65E+06**	**1,09E+05**	**1,19E+06**	**7,53E+06**	**8,33E+06**	**4,13E+05**	**3,50E+06**

Table 9-18. Contribution from single nmVOC species to the effect factors for different fuels and vehicles

Contribution to EF(hta) in %										
nmVOC Species	HDV	LDV	Gasoline EURO I	Gasoline conventional	Gasoline evaporation	LPG	Jet engines - total VOC	Jet engines - nmVOC	Ferry 1	Ferry 2
ethane	0,00%	0,00%	0,01%	0,00%		0,02%				
propane	0,00%		0,00%	0,00%	0,09%	0,42%				
butane	0,00%		0,02%	0,01%	1,84%	0,13%				
isobutane	0,00%	0,00%	0,00%	0,00%	0,92%	0,06%				
pentane	0,00%	0,00%	0,01%	0,00%	1,38%	0,00%				
isopentane		0,00%	0,02%	0,01%	2,30%	0,01%				
hexane			0,00%	0,00%	0,23%					
heptane	0,00%	0,00%	0,00%	0,00%	0,18%	0,00%				
octane		0,00%	0,00%	0,00%		0,00%				
nonane		0,00%	0,00%	0,00%		0,00%			0,24%	
2-methylheptane	0,00%	0,00%	0,00%			0,00%				
2-methylhexane	0,00%	0,00%	0,00%	0,00%		0,00%				
3-methylhexane	0,00%	0,00%	0,00%	0,00%		0,00%				
decane	0,00%	0,00%	0,00%	0,00%					0,61%	
3-methylheptane	0,00%	0,00%	0,00%	0,00%		0,00%				
Alkanes C10-12		0,00%	0,01%	0,00%		0,00%			0,81%	
Alkanes > C13	0,03%	0,03%	0,00%	0,00%						
Cycloalkanes	0,00%	0,00%	0,00%	0,00%		0,00%				
ethylene	0,00%	0,00%	0,00%	0,00%		0,00%	0,00%	0,00%	0,00%	0,00%
propylene	0,00%	0,01%	0,01%	0,01%		0,04%	0,01%	0,01%	0,05%	0,02%
propadiene			0,00%							
1-butene			0,00%	0,00%	0,09%					0,00%
isobutene	0,00%	0,00%	0,01%	0,01%		0,01%	0,00%	0,00%	0,02%	0,05%
2-butene		0,00%	0,00%	0,00%	0,18%	0,00%				
1,3-butadiene	80,68%	35,44%	68,20%	76,42%		31,61%				
1-pentene			0,00%	0,00%	0,18%		0,00%	54,52%		0,00%
2-pentene			0,00%	0,00%	0,28%					
1-hexene			0,00%		0,14%					
dimethylhexene			0,00%							
1-butin			0,00%	0,00%						
1-propin			0,00%	0,00%						
acetylene	0,00%	0,00%	0,01%	0,01%		0,01%				
formaldehyde	10,27%	21,92%	6,37%	5,60%		16,44%				
acetaldehyde	0,00%	0,00%	0,00%	0,00%		0,01%				
acrolein	8,65%	26,16%	2,85%	1,72%		24,87%	99,58%	22,72%		
benzaldehyde	0,01%	0,00%	0,00%	0,00%		0,00%	0,02%	0,00%		
crotonaldehyde	0,00%	0,00%	0,00%	0,00%		0,00%	0,00%	13,93%		
methacrolein	0,01%	0,02%	0,00%			0,01%				
butyraldehyde	0,00%	0,00%	0,00%			0,00%				
isobútanaldehyde	0,00%	0,00%								
proprionaldehyde	0,24%	0,52%	0,03%	0,05%		1,18%	0,32%	0,00%		
hexanal	0,00%	0,00%								
i-valeraldehyde	0,00%	0,00%				0,00%				
valeraldehyde	0,00%	0,00%								
o-tolualdehyde	0,00%	0,00%	0,00%	0,00%						
m-tolualdehyde	0,00%	0,00%	0,00%	0,00%						
p-tolualdhyde		0,00%	0,00%	0,00%						
acetone		12,97%	5,52%	1,36%		19,84%				
methylethylketon		0,00%	0,00%	0,00%						
toluene	0,00%	0,00%	0,01%	0,01%	0,02%	0,00%	0,00%	8,78%	0,03%	0,01%
ethylbenzene		0,00%	0,01%	0,01%		0,00%			0,02%	
m,p-xylene	0,00%	0,00%	0,01%	0,01%	0,03%	0,00%			0,07%	0,01%
o-xylene	0,00%	0,00%	0,00%	0,01%		0,00%			0,03%	
1,2,3-trimethylbenzen	0,00%	0,00%	0,00%	0,00%		0,00%			0,07%	
1,2,4-trimethylbenzen	0,00%	0,00%	0,01%	0,01%		0,00%			0,05%	
1,3,5-trimethylbenzen	0,00%	0,00%	0,00%	0,00%		0,00%			0,05%	
styrene	0,00%	0,00%	0,00%	0,00%		0,00%				
benzene	0,07%	2,89%	16,82%	14,70%	92,12%	5,31%			97,94%	99,91%
C9	0,00%	0,00%	0,01%	0,01%		0,00%				
C10			0,01%				0,00%	0,00%		
> C13	0,02%	0,02%	0,01%	0,01%						
Others							0,02%	0,02%		
C6H18O3Si3							0,01%	0,01%		
C8H24O4Si4							0,00%	0,00%		
Ethyne							0,01%	0,01%		
Glyoxal							0,00%	0,00%		
Methyl glyoxal							0,00%	0,00%		
n-dodecane							0,00%	0,00%		
Methan							0,01%			
Total	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

Table 9-19. Contribution to EF(hta) in percent

Effect factors for VOC from industrial processes

The Corinair94 Inventory allows for calculation of a number of effect factors related to the overall emissions of VOC (i.e. including methane) from specific types of plants. The level of detail is less than for traffic related emissions and some of the key emissions are either not identified in the inventory or they are not characterized in the EDIP database. The figures in the following table should therefore only be considered as crude estimates.

Process/plant type	EF(hta)	Most important emissions	Comments
Ethylene plants	2.86E+5	Benzene: 92% Methane: 5%	
Styrene plants	1.09E+5	Benzene: 98%	
Ethylbenzene production	4.42E+6	Benzene: 99.9%	EPA assumes that 100% of emissions are ethylbenzen, i.e. an EF(hta) of 1E+4
Polystyrene plants	1.9E+3	Ethylbenzene: 53% Styrene: 47%	
Polypropylene plants	1E+4	Propylene: 97%	EF(hta) equals the default value for nmVOC emissions, because no specific factors are available
SB rubber	3.25E+7	1,3-butadiene: 100%	
SB Latex	6.25E+7	1,3-butadiene: 100%	
Kraft pulping	9.76E+3	Methane: 24% Ethane: 12% butane: 10%	Most of the species have the default factor for nmVOC (1E+4)

Table 9-20. Effect factors for VOC from industrial processes.

The effect factors can be integrated in the EDIP database and used with caution. Better – or more precise – estimates can be obtained by establishing effect factors for each of the species. This would most probably mean a reduction in the effect factor for VOC from polypropylene plants, where the main emissions are propylene that is considered as almost harmless to humans.

Appendix C: Data and calculation of normalisation references

This appendix contains data used in the calculation of normalisation references concerning human toxicity. The appendix is split up in emissions contributing to respectively:

C.1 Human toxicity by inhalation
C.2 Human toxicity by intake via water
C.3 Human toxicity by intake via soil

References to the data source is given in the individual tables.

C.1.1 Denmark, normalisation reference, air

		Effect factor		Emission		UMIP classic		UMIP english.		UMIP revision	
		EF, old	EF, new	1992	1994	EP	%	EP	%	EP	%
				ton/year	ton/year						
Total						1,47E+17		4,71E+16		2,91E+17	
Population						5,13E+06		5,13E+06		5,20E+06	
Normalisation factor						2,86E+10		9,18E+09		5,59E+10	
Substance	Ref.										
SO2	a	2,50E+04	1,30E+03	2,05E+05	1,58E+05	5,125E+15	3,5	2,67E+14	0,6	2,05E+14	0,1
NOx	a	8,00E+04	8,60E+03	2,85E+05	2,76E+05	2,28E+16	15,5	2,45E+15	5,2	2,37E+15	0,8
N2O	a	1,11E+07	2,00E+03	1,01E+04	1,22E+04	1,1211E+17	76,5	2,02E+13	0,0	2,44E+13	0,0
CO	a	1,00E+02	8,30E+02	8,13E+05	7,15E+05	8,13E+13	0,1	6,75E+14	1,4	5,94E+14	0,2
nmVOC	a	1,00E+04	1,00E+04	1,64E+05	8,03E+04	1,64E+15	1,1	1,64E+15	3,5	8,03E+14	0,3
nm VOC transport	i				7,42E+04					2,80E+17	96,5
Cd	a	2,86E+07	1,10E+08	9,50E+00	1,19E+00	2,717E+14	0,2	1,05E+15	2,2	1,30E+14	0,0
As	a	5,00E+08	9,50E+06	6,66E-01	7,42E-01	3,33E+14	0,2	6,327E+12	0,0	7,05E+12	0,0
Cr(VI)	a	1,00E+08	1,00E+06	4,71E-01	3,49E+00	4,71E+13	0,0	4,71E+11	0,0	3,49E+12	0,0
Hg	a	6,67E+07	6,70E+06	1,00E+00	7,58E+00	6,67E+13	0,0	6,7E+12	0,0	5,08E+13	0,0
Ni	a	6,67E+05	6,70E+04	3,70E-01	2,21E+01	2,4679E+11	0,0	2,48E+10	0,0	1,48E+12	0,0
Pb	a	1,00E+07	1,00E+08	4,10E+02	3,95E+01	4,1E+15	2,8	4,1E+16	87,0	3,95E+15	1,4
Se	a	1,52E+07	1,50E+06	4,25E+00	1,32E-01	6,46E+13	0,0	6,38E+12	0,0	1,98E+11	0,0
Cu	a		5,70E+02		1,06E+01					6,02E+09	0,0
Zn	a		8,10E+04		1,18E+02					9,58E+12	0,0
PAH-eq. (benzo(a)pyren)			5,00E+07		4,38E+00					2,19E+14	0,1
Dioxin	a	1,00E+10	2,90E+10	4,80E-05	1,40E-05	4,8E+11	0,0	1,39E+12	0,0	4,06E+11	0,0
Tetrachloromethane (TCM)	a		2,90E+04		3,00E-01					8,70E+09	0,0
Trichloroethylene (TRI)	a		1,90E+04		4,78E+02					9,08E+12	0,0
Tetrachloroethylene (PER)	a		2,90E+04		3,54E+02					1,03E+13	0,0
Trichlorobenzene (TCB)			8,30E+03							0,00E+00	0,0
Trichloroethane (TCE)	a		9,20E+02		1,00E+01					9,20E+09	0,0
Hexachlorocyclohexane (HCH)	a		8,30E+03		9,20E+00					7,64E+10	0,0
Particulate matter (PM10)	d		2,00E+04		5,10E+04					1,02E+15	0,4
Benzene (w)			1,00E+07		7,33E+07					7,33E+14	0,3
Toluene (w)			2,50E+03		1,84E+08					4,59E+11	0,0
Xylenes (w)			6,70E+03		7,33E+07					4,91E+11	0,0
Hexachlorocyclohexane (HCH) (w)			8,30E+03		3,04E+03					2,52E+07	0,0
Tetrachloroethylene (PER) (w)			2,90E+04		3,64E+04					1,06E+09	0,0
Tetrachloromethane (TCM) (w)			2,90E+04		1,54E+05					4,46E+09	0,0
Trichloroethane (TCE) (w)			9,20E+02		2,60E+04					2,39E+07	0,0
Trichloroethylene (TRI) (w)			1,90E+04		6,93E+04					1,32E+09	0,0
Trichloromethane (w)			2,90E+04		1,05E+05					3,04E+09	0,0
Chlorobenzenes (w)			8,30E+03		4,44E+04					3,69E+08	0,0
Hexachlorobenzene (HCB) (w)			8,30E+03		6,26E+03					5,20E+07	0,0
PCP (w)			8,30E+03		5,07E+03					4,20E+07	0,0
Trichlororobenzene (TCB) (w)			8,30E+03		4,06E+02					3,37E+06	0,0
Chloroform (s)			1,00E+05		1,05E+02					1,05E+07	0,0
Dichlorobenzene (s)			8,30E+03		1,41E+03					1,17E+07	0,0
Tetrachloroethylene (PER) (s)			2,90E+04		2,28E+03					6,60E+07	0,0
Trichloroethylene (TRI) (s)			1,90E+04		3,75E+02					7,13E+06	0,0
Toluene (s)			2,50E+03		2,68E+03					6,69E+06	0,0

a Ritter (1997).
b van der Auweraert et al. (1996).
c Blonk H et al. (1997).
f Koch (1998)
g Hauschild et al. (1996)
h Hauschild et al. (1998)

d Berdowski et al. (1997)
e Quass & Fermann (1997)
i This project

C.1.2 EU-15, normalisation reference, air

		Effect factor		EU15estm	EU-15	EDIP revision	
		EF, new	Total		1994	EP	%
			ton/year	ton/year	ton/year		
Total						2,25E+19	
Population						3,70E+08	
Normalisation factor						6,09E+10	
Substance	Ref.						
SO2	a	1,30E+03			1,20E+07	1,57E+16	0,1
NOx	a	8,60E+03			1,25E+07	1,08E+17	0,5
N2O	a	2,00E+03			9,51E+05	1,90E+15	0,0
CO	a	8,30E+02			4,51E+07	3,74E+16	0,2
nmVOC	a	1,00E+04			7,42E+06	7,42E+16	0,3
nmVOC transport	i		3,31E+06		5,16E+06	2,15E+19	95,2
Cd		1,10E+08	7,60E+01	1,04E+02		1,14E+16	0,1
As		9,50E+06	1,96E+02	2,82E+02		2,68E+15	0,0
Cr(VI)		1,00E+06	3,94E+02	5,66E+02		5,66E+14	0,0
Hg		6,70E+06	1,02E+02	1,40E+02		9,35E+14	0,0
Ni		6,70E+04	1,46E+03	2,09E+03		1,40E+14	0,0
Pb		1,00E+08	5,17E+03	7,07E+03		7,07E+17	3,1
Se		1,50E+06	2,22E+02	3,19E+02		4,79E+14	0,0
Cu		5,70E+02	3,89E+02	5,60E+02		3,19E+11	0,0
Zn		8,10E+04	5,01E+03	6,86E+03		5,56E+14	0,0
PAH-eq. (benzo(a)pyren)		5,00E+07	2,33E+02	4,48E+02		2,24E+16	0,1
Dioxin		2,90E+10	2,93E-03	3,65E-03		1,06E+14	0,0
PCP		8,30E+03	5,55E+02	3,66E+03		3,04E+13	0,0
Hexachlorobenzene (HCB)		8,30E+03	1,39E+00	3,25E+00		2,70E+10	0,0
Tetrachloromethane (TCM)		2,90E+04	3,34E+03	1,55E+04		4,48E+14	0,0
Trichloroethylene (TRI)		1,90E+04	3,33E+04	6,77E+04		1,29E+15	0,0
Tetrachloroethylene (PER)		2,90E+04	2,57E+04	4,51E+04		1,31E+15	0,0
Trichlorobenzene (TCB)		8,30E+03	6,29E+02	1,10E+03		9,15E+12	0,0
Trichloroethane (TCE)		9,20E+02	5,70E+04	9,99E+04		9,19E+13	0,0
Hexachlorocyclohexane (HCH)		8,30E+03	1,23E+02	7,19E+02		5,96E+12	0,0
Chlorobenzenes		8,30E+03					
Vinylchloride		3,90E+05	1,10E+02	2,46E+03		9,59E+14	0,0
Particulate matter (PM10)	d	2,00E+04			2,89E+06	5,78E+16	0,3
Benzene (w)		1,00E+07		3,69E+09		3,69E+16	0,2
Toluene (w)		2,50E+03		9,24E+09		2,31E+13	0,0
Xylenes (w)		6,70E+03		3,69E+09		2,47E+13	0,0
Hexachlorocyclohexane (HCH) (w)		8,30E+03		1,53E+05		1,27E+09	0,0
Tetrachloroethylene (PER) (w)		2,90E+04		1,83E+06		5,32E+10	0,0
Tetrachloromethane (TCM) (w)		2,90E+04		7,74E+06		2,25E+11	0,0
Trichloroethane (TCE) (w)		9,20E+02		1,31E+06		1,20E+09	0,0
Trichloroethylene (TRI) (w)		1,90E+04		3,49E+06		6,63E+10	0,0
Trichloromethane (w)		2,90E+04		5,28E+06		1,53E+11	0,0
Chlorobenzenes (w)		8,30E+03		2,24E+06		1,86E+10	0,0
Hexachlorobenzene (HCB) (w)		8,30E+03		3,16E+05		2,62E+09	0,0
PCP (w)		8,30E+03		2,55E+05		2,12E+09	0,0
Trichlororobenzene		8,30E+03		2,05E+04		1,70E+08	0,0

		Effect factor		EU15estm	EU-15	EDIP revision	
		EF, new	Total		1994	EP	%
(TCB) (w)							
Chloroform (s)		1,00E+05		2,97E+03		2,97E+08	0,0
Dichlorobenzene (s)		8,30E+03		3,99E+04		3,32E+08	0,0
Tetrachloroethylene (PER) (s)		2,90E+04		6,44E+04		1,87E+09	0,0
Trichloroethylene (TRI) (s)		1,90E+04		1,06E+04		2,02E+08	0,0
Toluene (s)		2,50E+03		7,58E+04		1,89E+08	0,0

a Ritter (1997).
b van der Auweraert et al. (1996).
c Blonk H et al. (1997).
d Berdowski et al. (1997)
e Quass & Fermann (1997)
f Koch (1998)
I This project

C.1.3 Austria, normalisation reference, air

		Effectfactor		EDIP revision	
		EF (h)	1994	EP	%
			ton/year		
Total				2,67E+17	
Population				8,00E+06	
Normalisation factor				3,33E+10	
Substance	Ref.				
SO2	a	1,30E+03	5,49E+04	7,13E+13	0,0
Nox	a	8,60E+03	1,71E+05	1,47E+15	0,6
N2O	a	2,00E+03	1,27E+04	2,53E+13	0,0
CO	a	8,30E+02	1,18E+06	9,80E+14	0,4
nmVOC	a	1,00E+04	2,18E+05	2,18E+15	0,8
nmVOC - transport	i		7,15E+04	2,56E+17	95,9
Cd	a	1,10E+08	2,72E+00	2,99E+14	0,1
As	a	9,50E+06	3,26E+00	3,10E+13	0,0
Cr(VI)	a	1,00E+06	6,62E+00	6,62E+12	0,0
Hg	a	6,70E+06	2,18E+00	1,46E+13	0,0
Ni	a	6,70E+04	3,55E+01	2,38E+12	0,0
Pb	a	1,00E+08	2,43E+01	2,43E+15	0,9
Se	a	1,50E+06	4,71E+00	7,06E+12	0,0
Cu	a	5,70E+02	9,24E+00	5,26E+09	0,0
Zn	a	8,10E+04	2,08E+02	1,69E+13	0,0
PAH	a	5,00E+07	4,58E+02		0,0
PAH-eq. (benzo(a)pyren)	estm.	5,00E+07	5,43E+01	2,71E+15	1,0
Dioxin	a	2,90E+10	2,90E-05	8,41E+11	0,0
PCP		8,30E+03		0,00E+00	0,0
Particulate matter (PM10)	d	2,00E+04	3,70E+04	7,40E+14	0,3

a	Ritter (1997).
b	van der Auweraert et al. (1996).
c	Blonk H et al. (1997).
d	Berdowski et al. (1997)
e	Quass & Fermann (1997)
f	Koch (1998)
g	Hauschild et al. (1996)
h	Hauschild et al. (1998)
i	This project

C.1.4 Germany, normalisation reference, air

		Effectfactor		EDIP revision	
		EF (h)	1994	EP	%
			ton/year		
Total				3,73E+18	
Population				8,11E+07	
Normalisation factor				4,60E+10	
Substance	Ref.				
SO2	a	1,30E+03	3,00E+06	3,90E+15	0,1
NOx	a	8,60E+03	2,27E+06	1,95E+16	0,5
N2O	a	2,00E+03	2,18E+05	4,37E+14	0,0
CO	a	8,30E+02	6,80E+06	5,64E+15	0,2
nmVOC	a	1,00E+04	1,34E+06	1,34E+16	0,4
nmVOC - transport	i		8,08E+05	3,59E+18	96,3
Cd	a	1,10E+08	1,07E+01	1,18E+15	0,0
As	a	9,50E+06	3,25E+01	3,08E+14	0,0
Cr(VI)	a	1,00E+06	1,15E+02	1,15E+14	0,0
Hg	a	6,70E+06	3,11E+01	2,08E+14	0,0
Ni	a	6,70E+04	1,57E+02	1,05E+13	0,0
Pb	a	1,00E+08	6,25E+02	6,25E+16	1,7
Se	a	1,50E+06	2,52E+01	3,78E+13	0,0
Cu	a	5,70E+02	7,91E+01	4,51E+10	0,0
Zn	a	8,10E+04	4,51E+02	3,66E+13	0,0
PAH-eq. (benzo(a)pyren)	estm.	5,00E+07	4,98E+01	2,49E+15	0,1
Dioxin	a	2,90E+10	3,07E-04	8,90E+12	0,0
PCP		8,30E+03		0,00E+00	0,0
Hexachlorobenzene (HCB)	a	8,30E+03	9,00E-02	7,47E+08	0,0
Tetrachloromethane (TCM)		2,90E+04		0,00E+00	0,0
Trichloroethylene (TRI)	a	1,90E+04	1,10E+04	2,09E+14	0,0
Tetrachloroethylene (PER)	a	2,90E+04	1,17E+04	3,39E+14	0,0
Trichlorobenzene (TCB)		8,30E+03		0,00E+00	0,0
Trichloroethane (TCE)	a	9,20E+02	3,03E+04	2,79E+13	0,0
Particulate matter (PM10)	d	2,00E+04	1,32E+06	2,64E+16	0,7

a	Ritter (1997).
b	van der Auweraert et al. (1996).
c	Blonk H et al. (1997).
d	Berdowski et al. (1997)
e	Quass & Fermann (1997)
f	Koch (1998)
i	This project

C.1.5 Greece, normalisation reference, air

		Effect factor	Emission	EDIP revision	
		EF (h)	1994	EP	%
			ton/year		
Total				8,74E+17	
Population				1,04E+07	
Normalisation factor				8,40E+10	
Substance	Ref.				
SO2	a	1,30E+03	5,56E+05	7,23E+14	0,1
NOx	a	8,60E+03	3,57E+05	3,07E+15	0,4
N2O	a	2,00E+03	1,47E+04	2,95E+13	0,0
CO	a	8,30E+02	1,29E+06	1,07E+15	0,1
nmVOC	a	1,00E+04	1,42E+05	1,42E+15	0,2
nmVOC - transport	i		2,20E+05	8,67E+17	99,2
Cd	f	1,10E+08	2,13E+00	2,34E+14	0,0
As	f	9,50E+06	4,32E+00	4,10E+13	0,0
Cr(VI)	f	1,00E+06	9,22E+00	9,22E+12	0,0
Hg	f	6,70E+06	1,24E+01	8,28E+13	0,0
Ni	f	6,70E+04	8,80E+01	5,90E+12	0,0
Pb	f	1,00E+08	7,19E+00	7,19E+14	0,1
Se	f	1,50E+06	8,49E-01	1,27E+12	0,0
Cu	f	5,70E+02	1,63E+01	9,26E+09	0,0
Zn	f	8,10E+04	2,08E+01	1,68E+12	0,0
Particulate matter (PM10)	d	2,00E+04	5,50E+01	1,10E+12	0,0

a	Ritter (1997).
b	van der Auweraert et al. (1996).
c	Blonk H et al. (1997).
d	Berdowski et al. (1997)
e	Quass & Fermann (1997)
f	Koch (1998)
g	Hauschild *et al.* (1996).
h	Hauschild *et al.* (1998).
i	This project

C.1.6 Italy, normalisation reference, air

		Effect factor	Emission	EDIP revision	
		EF (h)	1994	EP	%
			ton/year		
Total				4,85E+18	
Population				5,70E+07	
Normalisation factor				8,51E+10	
Substance	Ref.				
SO2	a	1,30E+03	1,44E+06	1,87E+15	0,0
NOx	a	8,60E+03	2,16E+06	1,86E+16	0,4
N2O	a	2,00E+03	1,31E+05	2,62E+14	0,0
CO	a	8,30E+02	9,23E+06	7,66E+15	0,2
nmVOC	a	1,00E+04	1,16E+06	1,16E+16	0,2
nmVOC - transport	i		1,08E+06	4,58E+18	94,5
Cd	f	1,10E+08	2,99E+01	3,29E+15	0,1
As	f	9,50E+06	3,81E+01	3,62E+14	0,0
Cr(VI)	f	1,00E+06	1,63E+02	1,63E+14	0,0
Hg	f	6,70E+06	1,32E+01	8,86E+13	0,0
Ni	f	6,70E+04	5,40E+02	3,62E+13	0,0
Pb	f	1,00E+08	2,18E+03	2,18E+17	4,5
Se	f	1,50E+06	8,45E+01	1,27E+14	0,0
Cu	f	5,70E+02	1,15E+02	6,55E+10	0,0
Zn	f	8,10E+04	1,66E+03	1,35E+14	0,0
Particulate matter (PM10)	d	2,00E+04	3,00E+05	6,00E+15	0,1

a	Ritter (1997).
b	van der Auweraert et al. (1996).
c	Blonk H et al. (1997).
d	Berdowski et al. (1997)
e	Quass & Fermann (1997)
f	Koch (1998)
g	Hauschild *et al.* (1996).
h	Hauschild *et al.* (1998).
i	This project

C.1.7 Luxembourg, normalisation reference, air

		Effect factor EF (h)	Emission 1994 ton/year	EDIP revision MP	%
Total				3,68E+16	
Population				4,00E+05	
Normalisation factor				9,21E+10	
Substance	Ref.				
SO2	a	1,30E+03	1,28E+04	1,67E+13	0,0
NOx	a	8,60E+03	2,26E+04	1,94E+14	0,5
N2O	a	2,00E+03	6,89E+02	1,38E+12	0,0
CO	a	8,30E+02	1,45E+05	1,21E+14	0,3
nmVOC	a	1,00E+04	8,59E+03	8,59E+13	0,2
nmVOC - transport	i		9,06E+03	3,18E+16	86,3
Cd	a	1,10E+08	5,31E-01	5,84E+13	0,2
As	a	9,50E+06	3,50E+00	3,32E+13	0,1
Cr(VI)	a	1,00E+06	2,97E+00	2,97E+12	0,0
Hg	a	6,70E+06	2,45E-01	1,64E+12	0,0
Ni	a	6,70E+04	2,81E+00	1,88E+11	0,0
Pb	a	1,00E+08	4,39E+01	4,39E+15	11,9
Se	a	1,50E+06	7,22E+00	1,08E+13	0,0
Cu	a	5,70E+02	3,49E+00	1,99E+09	0,0
Zn	a	8,10E+04	1,51E+02	1,23E+13	0,0
PAH-eq. (benzo(a)pyren)	estm.	5,00E+07	1,30E-01	6,52E+12	0,0
Dioxin	a	2,90E+10	2,20E-05	6,38E+11	0,0
Particulate matter (PM10)	d	2,00E+04	5,90E+03	1,18E+14	0,3

a	Ritter (1997).
b	van der Auweraert et al. (1996).
c	Blonk H et al. (1997).
d	Berdowski et al. (1997)
e	Quass & Fermann (1997)
f	Koch (1998)
g	Hauschild *et al.* (1996).
h	Hauschild *et al.* (1998).
i	This project

C.1.8 Netherlands, normalisation reference, air

		Effect factor	Emission	EDIP "Dutch emissions"		EDIP revision	
		EF (h)	1994	MP	%		%
			ton/year				
Total				1,59E+17		5,94E+17	
Population				1,53E+07		1,53E+07	
Normalisation factor				1,04E+10		3,88E+10	
Substance	Ref.						
SO2	a	1,30E+03	1,46E+05	1,90E+14	0,1	1,90E+14	0,0
NOx	a	8,60E+03	5,30E+05	4,56E+15	2,9	4,56E+15	0,8
N2O	a	2,00E+03	4,59E+04	9,17E+13	0,1	9,17E+13	0,0
CO	a	8,30E+02	9,08E+05	7,53E+14	0,5	7,53E+14	0,1
nmVOC		1,00E+04	3,78E+05		0,0	3,78E+15	0,6
nmVOC - transport	i		1,37E+05			5,65E+17	95,1
Cd	b	1,10E+08	1,80E+00	1,98E+14	0,1	1,98E+14	0,0
As	c	9,50E+06	1,54E+00	1,46E+13	0,0	1,46E+13	0,0
Cr(VI)	b	1,00E+06	1,08E+01	1,08E+13	0,0	1,08E+13	0,0
Hg	f	6,70E+06	1,04E+01	6,97E+13	0,0	6,97E+13	0,0
Ni	b	6,70E+04	9,47E+01	6,34E+12	0,0	6,34E+12	0,0
Pb	b	1,00E+08	1,60E+02	1,60E+16	10,1	1,60E+16	2,7
Se	b	1,50E+06	2,88E-01	4,32E+11	0,0	4,32E+11	0,0
Cu	b	5,70E+02	6,04E+01	3,44E+10	0,0	3,44E+10	0,0
Zn	b	8,10E+04	2,79E+02	2,26E+13	0,0	2,26E+13	0,0
Formaldehyde	b	1,30E+07	4,01E+03	5,21E+16	32,8		
Benzene	b	1,00E+07	8,16E+03	8,16E+16	51,3		
Phenol	b	1,40E+06	1,54E+02	2,16E+14	0,1		
Styrene	b	1,00E+03	1,56E+03	1,56E+12	0,0		
Toluene	b	2,50E+03	2,45E+04	6,13E+13	0,0		
Xylenes	b	6,70E+03	1,16E+04	7,77E+13	0,0		
PAH-eq. (benzo(a)pyren)		5,00E+07	1,28E+01	6,39E+14	0,4	6,39E+14	0,1
Dioxin	b	2,90E+10	1,44E-04	4,18E+12	0,0	4,18E+12	0,0
PCP		8,30E+03		0,00E+00	0,0	0,00E+00	0,0
Hexachlorobenzene (HCB)		8,30E+03		0,00E+00	0,0	0,00E+00	0,0
Tetrachloromethane (TCM)	b	2,90E+04	1,51E+02	4,38E+12	0,0	4,38E+12	0,0
Trichloroethylene (TRI)	b	1,90E+04	1,04E+03	1,98E+13	0,0	1,98E+13	0,0
Tetrachloroethylene (PER)	b	2,90E+04	2,03E+03	5,89E+13	0,0	5,89E+13	0,0
Trichlorobenzene (TCB)		8,30E+03		0,00E+00	0,0	0,00E+00	0,0
Trichloroethane (TCE)	b	9,20E+02	1,85E+03	1,70E+12	0,0	1,70E+12	0,0
Hexachlorocyclohexane (HCH)		8,30E+03		0,00E+00	0,0	0,00E+00	0,0
Chlorobenzenes	b	8,30E+03	9,25E+01	7,68E+11	0,0	7,68E+11	0,0
Vinylchloride	b	3,90E+05	1,10E+02	4,29E+13	0,0	4,29E+13	0,0
Particulate matter (PM10)	b	2,00E+04	3,74E+04	7,48E+14	0,5	7,48E+14	0,1
Benzene (w)		1,00E+07	1,65E+08	1,65E+15	1,0	1,65E+15	0,3
Toluene (w)		2,50E+03	4,13E+08	1,03E+12	0,0	1,03E+12	0,0
Xylenes (w)		6,70E+03	1,65E+08	1,11E+12	0,0	1,11E+12	0,0
Hexachlorocyclohexane (HCH) (w)		8,30E+03	6,84E+03	5,68E+07	0,0	5,68E+07	0,0
Tetrachloroethylene (PER) (w)		2,90E+04	8,20E+04	2,38E+09	0,0	2,38E+09	0,0
Tetrachloromethane (TCM) (w)		2,90E+04	3,46E+05	1,00E+10	0,0	1,00E+10	0,0
Trichloroethane (TCE) (w)		9,20E+02	5,85E+04	5,38E+07	0,0	5,38E+07	0,0
Trichloroethylene (TRI) (w)		1,90E+04	1,56E+05	2,96E+09	0,0	2,96E+09	0,0

		Effect factor	Emission	EDIP "Dutch emissions"		EDIP revision	
		EF (h)	1994	MP	%		%
			ton/year				
Trichloromethane (w)		2,90E+04	2,36E+05	6,84E+09	0,0	6,84E+09	0,0
Chlorobenzenes (w)		8,30E+03	1,00E+05	8,30E+08	0,0	8,30E+08	0,0
Hexachlorobenzene (HCB) (w)		8,30E+03	1,41E+04	1,17E+08	0,0	1,17E+08	0,0
PCP (w)		8,30E+03	1,14E+04	9,46E+07	0,0	9,46E+07	0,0
Trichlororobenzene (TCB) (w)		8,30E+03	9,14E+02	7,59E+06	0,0	7,59E+06	0,0
Chloroform (s)		1,00E+05	4,13E+01	4,13E+06	0,0	4,13E+06	0,0
Dichlorobenzene (s)		8,30E+03	5,56E+02	4,61E+06	0,0	4,61E+06	0,0
Tetrachloroethylene (PER) (s)		2,90E+04	8,96E+02	2,60E+07	0,0	2,60E+07	0,0
Trichloroethylene (TRI) (s)		1,90E+04	1,48E+02	2,81E+06	0,0	2,81E+06	0,0
Toluene (s)		2,50E+03	1,05E+03	2,63E+06	0,0	2,63E+06	0,0

a Ritter (1997).
b van der Auweraert et al. (1996).
c Blonk H et al. (1997).
d Berdowski et al. (1997)
e Quass & Fermann (1997)
f Koch (1998)
g Hauschild *et al.* (1996).
h Hauschild *et al.* (1998).
i This project

C.1.10 Sweden, normalisation reference, air

		Effect factor	Emission	EDIP revision	
		EF (h)	1994	MP	%
			ton/year		
Total				5,39E+17	
Population				8,75E+06	
Normalisation factor				6,16E+10	
Substance	Ref.				
SO2		1,30E+03	7,42E+04	9,64E+13	0,0
NOx		8,60E+03	4,44E+05	3,82E+15	0,7
N2O		2,00E+03	2,36E+04	4,72E+13	0,0
CO		8,30E+02	1,32E+06	1,09E+15	0,2
nmVOC		1,00E+04	2,36E+05	2,36E+15	0,4
nmVOC - transport	i		1,45E+05	5,29E+17	98,2
Cd	f	1,10E+08	2,29E-01	2,52E+13	0,0
As	f	9,50E+06	6,46E-01	6,14E+12	0,0
Cr(VI)	f	1,00E+06	7,42E+00	7,42E+12	0,0
Hg	f	6,70E+06	5,65E-01	3,79E+12	0,0
Ni	f	6,70E+04	9,33E+00	6,25E+11	0,0
Pb	f	1,00E+08	1,56E+01	1,56E+15	0,3
Se	f	1,50E+06	1,60E-01	2,40E+11	0,0
Cu	f	5,70E+02	6,98E+00	3,98E+09	0,0
Zn	f	8,10E+04	3,00E+01	2,43E+12	0,0
Dioxin	e	2,90E+10	3,60E-05	1,04E+12	0,0
Particulate matter (PM10)	d	2,00E+04	4,10E+04	8,20E+14	0,2

a	Ritter (1997).
b	van der Auweraert et al. (1996).
c	Blonk H et al. (1997).
d	Berdowski et al. (1997)
e	Quass & Fermann (1997)
f	Koch (1998)
g	Hauschild *et al.* (1996).
h	Hauschild *et al.* (1998).
i	This project

C.1.12 United Kingdom, normalisation reference, air

		Effect factor	Emission	EDIP revision	
		EF (h)	1994	MP	%
			ton/year		
Total				3,69E+18	
Population				5,82E+07	
Normalisation factor				6,34E+10	
Substance	Ref.				
SO2	a	1,30E+03	2,70E+06	3,51E+15	0,1
NOx	a	8,60E+03	2,39E+06	2,05E+16	0,6
N2O	a	2,00E+03	9,95E+04	1,99E+14	0,0
CO	a	8,30E+02	5,97E+06	4,95E+15	0,1
nmVOC	a	1,00E+04	1,59E+06	1,59E+16	0,4
nmVOC - transport	i		7,61E+05	3,45E+18	93,6
Cd	a	1,10E+08	2,35E+01	2,59E+15	0,1
As	a	9,50E+06	1,12E+02	1,06E+15	0,0
Cr(VI)	a	1,00E+06	6,33E+01	6,33E+13	0,0
Hg	a	6,70E+06	1,95E+01	1,31E+14	0,0
Ni	a	6,70E+04	4,67E+02	3,13E+13	0,0
Pb	a	1,00E+08	1,75E+03	1,75E+17	4,8
Se	a	1,50E+06	9,93E+01	1,49E+14	0,0
Cu	a	5,70E+02	7,92E+01	4,52E+10	0,0
Zn	a	8,10E+04	1,31E+03	1,06E+14	0,0
PAH-eq. (benzo(a)pyren)	estm.	5,00E+07	9,05E+01	4,53E+15	0,1
Dioxin	a	2,90E+10	7,93E-04	2,30E+13	0,0
PCP	a	8,30E+03	5,55E+02	4,61E+12	0,0
Hexachlorobenzene (HCB)	a	8,30E+03	1,20E+00	9,96E+09	0,0
Tetrachloromethane (TCM)	a	2,90E+04	3,19E+03	9,25E+13	0,0
Trichloroethylene (TRI)	a	1,90E+04	2,03E+04	3,87E+14	0,0
Tetrachloroethylene (PER)	a	2,90E+04	1,13E+04	3,27E+14	0,0
Trichlorobenzene (TCB)	a	8,30E+03	6,29E+02	5,22E+12	0,0
Trichloroethane (TCE)	a	9,20E+02	2,47E+04	2,28E+13	0,0
Hexachlorocyclohexane (HCH)	a	8,30E+03	1,14E+02	9,46E+11	0,0
Particulate matter (PM10)	d	2,00E+04	2,70E+05	5,40E+15	0,1

a	Ritter (1997).
b	van der Auweraert et al. (1996).
c	Blonk H et al. (1997).
d	Berdowski et al. (1997)
e	Quass & Fermann (1997)
f	Koch (1998)
h	Hauschild *et al.* (1998).
i	This project

C.2.1 Denmark, normalisation reference, water

		EF(htw)	Emission (1)	EP(htw)	Distr.
		m3/g	g/yr	m3/yr	%
Total				9,29E+11	
Population				5,20E+06	
Normalisation factor				1,79E+05	
Water emissions	Substance				
Heavy metals	Hg	1,10E+05	7,26E+05	7,98E+10	8,5959
	Cd	2,80E+03	9,03E+05	2,53E+09	0,2722
	Cu	1,70E+01	4,06E+07	6,90E+08	0,0743
	Zn	2,10E+01	1,23E+08	2,58E+09	0,2782
	Pb	2,60E+02	7,43E+06	1,93E+09	0,2081
Aliphatic compounds			2,47E+09		
Aromatics			5,38E+08		
	Benzene (1)	2,30E+00	7,33E+07	1,69E+08	0,0182
	Benz(a)pyrene		1,48E+06		
	Ethylbenzene (1)		1,72E+00		
	Fluoranthene		7,02E+06		
	Phthalates		5,02E+04		
	Isopropylbenzene	2,10E-01	1,77E+05	3,72E+04	0,0000
	PAH (6 comp.) (2)		8,22E+06		
	PAH-eq. (Benzo(a)pyren)	3,20E+02	9,74E+05	3,12E+08	0,0336
	Toluene	4,00E-03	1,84E+08	7,34E+05	0,0001
	Xylenes	1,10E-03	7,33E+07	8,06E+04	0,0000
Halogenated org. Compounds			1,32E+07		
Aliphatics			1,27E+07		
	1,2-Dichloroethane	2,00E-02	1,85E+05	3,71E+03	0,0000
	Hexachlorbutadiene (1)		0,00E+00		
	Hexachlorcyclohexane (1)		3,04E+03		
	Tetrachlorethylene	3,60E-01	3,64E+04	1,31E+04	0,0000
	Tetrachlormethane	3,60E-01	1,54E+05	5,53E+04	0,0000
	1,1,1-Trichloroethane (1)	9,90E-04	2,60E+04	2,57E+01	0,0000
	Trichloroethene (1)	9,10E-04	6,93E+04	6,31E+01	0,0000
	Trichloromethane	9,10E-04	1,05E+05	9,54E+01	0,0000
	Vinylchloride	4,00E-01	8,49E+02	3,39E+02	0,0000
Aromatics			5,51E+05		
	Chlorobenzene (1)	2,70E-01	4,44E+04	1,20E+04	0,0000
	DRINS		1,33E+03		
	Hexachlorobenzene (1)	3,70E-01	6,26E+03	2,32E+03	0,0000
	PCB (1)		3,65E+02		
	Pentachlorophenol (1)	3,70E-01	5,07E+03	1,87E+03	0,0000
	Thichlorobenzene (1)	3,70E-01	4,06E+02	1,50E+02	0,0000
Air emissions	Cd	5,60E+02	1,19E+06	6,64E+08	0,0715
	As	7,40E+00	7,42E+05	5,49E+06	0,0006
	Cr(VI)	3,60E+00	3,49E+06	1,25E+07	0,0014
	Hg	1,10E+05	7,58E+06	8,34E+11	89,8324
	Ni	3,70E-03	2,21E+07	8,16E+04	0,0000
	Pb	5,30E+01	3,95E+07	2,10E+09	0,2256
	Se	2,80E+01	1,32E+05	3,70E+06	0,0004
	Cu	3,40E+00	1,06E+07	3,59E+07	0,0039
	Zn	4,10E+00	1,18E+08	4,85E+08	0,0522
	Dioxin	2,20E+08	1,40E+01	3,08E+09	0,3317

C.2.2 EU-15, normalisation reference, water

		EF(htw)	Emission (1)	EP(htw)	Distr.
	Substance	m3/g	g/yr	m3/yr	%
Total				1,93E+13	
Population				3,70E+08	
Normalisation factor				5,21E+04	
Water emissions					
Heavy metals	Hg	1,10E+05	1,69E+07	1,86E+12	9,6612
	Cd	2,80E+03	4,40E+07	1,23E+11	0,6396
	Cu	1,70E+01	1,86E+09	3,15E+10	0,1636
	Zn	2,10E+01	9,60E+09	2,02E+11	1,0459
	Pb	2,60E+02	1,54E+09	4,00E+11	2,0750
Aliphatic compounds			1,24E+11		
Aromatics			2,71E+10		
	Benzene (1)	2,30E+00	3,69E+09	8,49E+09	0,0441
	Benz(a)pyrene		7,47E+07		
	Ethylbenzene (1)		8,66E+01		
	Fluoranthene		3,54E+08		
	Phthalates		2,53E+06		
	Isopropylbenzene	2,10E-01	8,93E+06	1,87E+06	0,0000
	PAH (6 comp.) (2)		4,14E+08		
	PAH-eq. (Benzo(a)pyren)	3,20E+02	4,90E+07	1,57E+10	0,0814
	Toluene	4,00E-03	9,24E+09	3,70E+07	0,0002
	Xylenes	1,10E-03	3,69E+09	4,06E+06	0,0000
Halogenated org. Compounds			6,67E+08		
Aliphatics			6,38E+08		
	1,2-Dichloroethane	2,00E-02	9,33E+06	1,87E+05	0,0000
	Hexachlorbutadiene (1)		0,00E+00		
	Hexachlorcyclohexane (1)		1,53E+05		
	Tetrachlorethylene	3,60E-01	1,83E+06	6,61E+05	0,0000
	Tetrachlormethane	3,60E-01	7,74E+06	2,79E+06	0,0000
	1,1,1-Trichloroethane (1)	9,90E-04	1,31E+06	1,30E+03	0,0000
	Trichloroethene (1)	9,10E-04	3,49E+06	3,18E+03	0,0000
	Trichloromethane	9,10E-04	5,28E+06	4,81E+03	0,0000
	Vinylchloride	4,00E-01	4,27E+04	1,71E+04	0,0000
Aromatics			2,77E+07		
	Chlorobenzene (1)	2,70E-01	2,24E+06	6,04E+05	0,0000
	DRINS		6,71E+04		
	Hexachlorobenzene (1)	3,70E-01	3,16E+05	1,17E+05	0,0000
	PCB (1)		1,84E+04		
	Pentachlorophenol (1)	3,70E-01	2,55E+05	9,44E+04	0,0000
	Thichlorobenzene (1)	3,70E-01	2,05E+04	7,57E+03	0,0000
Air emissions	Cd	5,60E+02	1,04E+08	5,83E+10	0,3023
	As	7,40E+00	2,82E+08	2,09E+09	0,0108
	Cr(VI)	3,60E+00	5,66E+08	2,04E+09	0,0106
	Hg	1,10E+05	1,40E+08	1,54E+13	79,6572
	Ni	3,70E-03	2,09E+09	7,75E+06	0,0000
	Pb	5,30E+01	7,07E+09	3,75E+11	1,9441
	Se	2,80E+01	3,19E+08	8,95E+09	0,0464
	Cu	3,40E+00	5,60E+08	1,90E+09	0,0099
	Zn	4,10E+00	6,86E+09	2,81E+10	0,1459
	Dioxin	2,20E+08	3,65E+03	8,02E+11	4,1617

C.2.3 Netherlands, normalisation reference, water

		EF(htw)	Emission (1)	EP(htw)	Distr.
	Substance	m3/g	g/yr	m3/yr	%
Total				1,31E+12	
Population				1,53E+07	
Normalisation factor				8,44E+04	
Water emissions					
Heavy metals	Hg	1,10E+05	6,46E+05	7,11E+10	5,4310
	Cd	2,80E+03	1,84E+06	5,15E+09	0,3938
	Cu	1,70E+01	8,22E+07	1,40E+09	0,1068
	Zn	2,10E+01	4,95E+08	1,04E+10	0,7945
	Pb	2,60E+02	1,26E+08	3,28E+10	2,5038
Aliphatic compounds			5,55E+09		
Aromatics			1,21E+09		
	Benzene (1)	2,30E+00	1,65E+08	3,80E+08	0,0290
	Benz(a)pyrene		3,34E+06		
	Ethylbenzene (1)		3,87E+00		
	Fluoranthene		1,58E+07		
	Phthalates		1,13E+05		
	Isopropylbenzene	2,10E-01	3,99E+05	8,38E+04	0,0000
	PAH (6 comp.) (2)		1,85E+07		
	PAH-eq. (Benzo(a)pyren)	3,20E+02	2,19E+06	7,01E+08	0,0536
	Toluene	4,00E-03	4,13E+08	1,65E+06	0,0001
	Xylenes	1,10E-03	1,65E+08	1,82E+05	0,0000
Halogenated org. Compounds			2,98E+07		
Aliphatics			2,85E+07		
	1,2-Dichloroethane	2,00E-02	4,17E+05	8,34E+03	0,0000
	Hexachlorbutadiene (1)		0,00E+00		
	Hexachlorcyclohexane (1)		6,84E+03		
	Tetrachlorethylene	3,60E-01	8,20E+04	2,95E+04	0,0000
	Tetrachlormethane	3,60E-01	3,46E+05	1,25E+05	0,0000
	1,1,1-Trichloroethane (1)	9,90E-04	5,85E+04	5,79E+01	0,0000
	Trichloroethene (1)	9,10E-04	1,56E+05	1,42E+02	0,0000
	Trichloromethane	9,10E-04	2,36E+05	2,15E+02	0,0000
	Vinylchloride	4,00E-01	1,91E+03	7,64E+02	0,0000
Aromatics			1,24E+06		0,0000
	Chlorobenzene (1)	2,70E-01	1,00E+05	2,70E+04	0,0000
	DRINS		3,00E+03		0,0000
	Hexachlorobenzene (1)	3,70E-01	1,41E+04	5,22E+03	0,0000
	PCB (1)		8,22E+02		0,0000
	Pentachlorophenol (1)	3,70E-01	1,14E+04	4,22E+03	0,0000
	Thichlorobenzene (1)	3,70E-01	9,14E+02	3,38E+02	0,0000
Air emissions	Cd	5,60E+02	1,80E+06	1,01E+09	0,0770
	As	7,40E+00	1,54E+06	1,14E+07	0,0009
	Cr(VI)	3,60E+00	1,08E+07	3,89E+07	0,0030
	Hg	1,10E+05	1,04E+07	1,14E+12	87,4335
	Ni	3,70E-03	9,47E+07	3,50E+05	0,0000
	Pb	5,30E+01	1,60E+08	8,48E+09	0,6481
	Se	2,80E+01	2,88E+05	8,06E+06	0,0006
	Cu	3,40E+00	6,04E+07	2,05E+08	0,0157
	Zn	4,10E+00	2,79E+08	1,14E+09	0,0874
	Dioxin	2,20E+08	1,44E+02	3,17E+10	2,4212

C.3.1 Denmark, normalisation reference, soil

				EF(hts)	Emission (1)	Emission (1)	EP(hts)	Distr.
	Substance	Ref.	Eq.-factor	m3/g	g/yr	g/yr	m3/yr	%
Total							8,04E+08	
Population							5,20E+06	
Normalisation factor							1,55E+02	
Sludge	Acenaphthene		0,0005		4,71E+03	2,35E+00		
	Fluorene		0,0005		9,15E+03	4,57E+00		
	Phenanthrene		0,0005		3,97E+04	1,98E+01		
	Fluoranthene		0,0500		4,18E+04	2,09E+03		
	Pyrene		0,0010		4,00E+04	4,00E+01		
	Benzofluoranthene		0,1000		3,85E+04	3,85E+03		
	Benzo(a)pyrene		1,0000		1,97E+04	1,97E+04		
	Benzo(ghi)perylene		0,0200		1,52E+04	3,05E+02		
	Indeno(1,2,3-cd)pyrene		0,1000		8,67E+03	8,67E+02		
	PAH-eq. (Benzo(a)pyren)			1,80E-03		2,69E+04	4,84E+01	0,000
	PCB 28				5,69E+02			
	PCB 52				1,17E+03			
	PCB 101				9,93E+02			
	PCB 118				7,44E+02			
	PCB 138				9,16E+02			
	PCB 153				1,12E+03			
	PCB 180				7,46E+02			
	Sum PCB							
	Butylbenzylphthalate					2,27E+04		
	Chloroform			2,00E-01		1,05E+02	2,10E+01	0,000
	Di(ethylhexyl)phthalate					4,90E+06		
	Dichlorobenezene			3,20E-01		1,41E+03	4,52E+02	0,000
	Di-n-butylphthalate					5,02E+05		
	Di-n-octylphthalate					7,86E+04		
	Nonylphenol + 1-2EO					1,96E+06		
	Tetrachloroethylene			4,00E-02		2,28E+03	9,10E+01	0,000
	Trichlorothylene			6,90E-04		3,75E+02	2,59E-01	0,000
	LAS (2)					3,45E+05		
	Toluene			1,00E-03		2,68E+03	2,68E+00	0,000
	Dioxine (2,3,7,8-TCDD)			1,80E+04		1,29E+00	2,33E+04	0,003
	As			1,30E+02		4,80E+05	6,24E+07	7,759
	Cd			5,60E+00		2,16E+05	1,21E+06	0,150
	Cr			1,40E+00		4,58E+06	6,41E+06	0,798
	Cu			5,00E-03		3,72E+07	1,86E+05	0,023
	Pb			1,00E-01		9,42E+06	9,42E+05	0,117
	Hg			8,10E+01		3,10E+05	2,51E+07	3,127
	Ni			1,50E-01		3,85E+06	5,78E+05	0,072
	Zn			1,60E-02		1,15E+08	1,84E+06	0,228
Pesticides	Fungicides							
	Herbicides							
	Insecticides							
Air emissions	Cd			4,50E+00		1,19E+06	5,33E+06	0,663
	As			1,00E+02		7,42E+05	7,42E+07	9,228
	Cr(VI)			1,10E+00		3,49E+06	3,83E+06	0,477
	Hg			8,10E+01		7,58E+06	6,14E+08	76,396
	Ni			1,20E-01		2,21E+07	2,65E+06	0,329
	Pb			8,30E-02		3,95E+07	3,28E+06	0,408
	Se			4,40E-02		1,32E+05	5,81E+03	0,001
	Cu			4,00E-03		1,06E+07	4,22E+04	0,005
	Zn			1,30E-02		1,18E+08	1,54E+06	0,191
	Dioxin			1,40E+04		1,40E+01	1,96E+05	0,024

C.3.2 EU-15, normalisation reference, soil

				EF(hts)	Emission (1)	Emission (1)	EP(hts)	Distr.
	Substance	Ref.	Eq.-factor	m3/g	g/yr	g/yr	m3/yr	%
Total							4,44E+10	
Population							3,70E+08	
Normalisation factor							1,20E+02	
Sludge	Acenaphthene		0,0005		1,33E+05	6,66E+01		
	Fluorene		0,0005		2,59E+05	1,29E+02		
	Phenanthrene		0,0005		1,12E+06	5,61E+02		
	Fluoranthene		0,0500		1,18E+06	5,91E+04		
	Pyrene		0,0010		1,13E+06	1,13E+03		
	Benzofluoranthene		0,1000		1,09E+06	1,09E+05		
	Benzo(a)pyrene		1,0000		5,58E+05	5,58E+05		
	Benzo(ghi)perylene		0,0200		4,31E+05	8,62E+03		
	Indeno(1,2,3-cd)pyrene		0,1000		2,45E+05	2,45E+04		
	PAH-eq. (Benzo(a)pyren)			1,80E-03		7,61E+05	1,37E+03	0,000
	PCB 28				1,61E+04			
	PCB 52				3,30E+04			
	PCB 101				2,81E+04			
	PCB 118				2,11E+04			
	PCB 138				2,59E+04			
	PCB 153				3,16E+04			
	PCB 180				2,11E+04			
	Sum PCB				1,77E+05			
	Butylbenzylphthalate					6,41E+05		
	Chloroform			2,00E-01		2,97E+03	5,93E+02	0,000
	Di(ethylhexyl)phthalate					1,39E+08		
	Dichlorobenezene			3,20E-01		3,99E+04	1,28E+04	0,000
	Di-n-butylphthalate					1,42E+07		
	Di-n-octylphthalate					2,23E+06		
	Nonylphenol + 1-2EO					5,56E+07		
	Tetrachloroethylene			4,00E-02		6,44E+04	2,58E+03	0,000
	Trichlorothylene			6,90E-04		1,06E+04	7,33E+00	0,000
	LAS (2)					9,77E+06		
	Toluene			1,00E-03		7,58E+04	7,58E+01	0,000
	Dioxine (2,3,7,8-TCDD)			1,80E+04		3,66E+01	6,59E+05	0,001
	As			1,30E+02		1,36E+07	1,77E+09	3,977
	Cd			5,60E+00		6,11E+06	3,42E+07	0,077
	Cr			1,40E+00		1,30E+08	1,82E+08	0,409
	Cu			5,00E-03		1,05E+09	5,26E+06	0,012
	Pb			1,00E-01		2,67E+08	2,67E+07	0,060
	Hg			8,10E+01		8,79E+06	7,12E+08	1,603
	Ni			1,50E-01		1,09E+08	1,64E+07	0,037
	Zn			1,60E-02		3,25E+09	5,20E+07	0,117
Pesticides	Fungicides							
	Herbicides							
	Insecticides							
Air emissions	Cd			4,50E+00		1,04E+08	4,68E+08	1,055
	As			1,00E+02		2,82E+08	2,82E+10	63,545
	Cr(VI)			1,10E+00		5,66E+08	6,22E+08	1,402
	Hg			8,10E+01		1,40E+08	1,13E+10	25,465
	Ni			1,20E-01		2,09E+09	2,51E+08	0,566
	Pb			8,30E-02		7,07E+09	5,87E+08	1,322
	Se			4,40E-02		3,19E+08	1,41E+07	0,032
	Cu			4,00E-03		5,60E+08	2,24E+06	0,005
	Zn			1,30E-02		6,86E+09	8,92E+07	0,201
	Dioxin			1,40E+04		3,65E+03	5,10E+07	0,115

C.3.3 Netherlands, normalisation reference, soil

				EF(htw)	Emission (1)	Emission (1)	EP(htw)	Distr.
	Substance	Ref.	Eq.-factor	m3/g	g/yr	g/yr	m3/yr	%
Total							1,09E+09	
Population							1,53E+07	
Normalisation factor							7,10E+01	
Sludge	Acenaphthene		0,0005		1,85E+03	9,27E-01		
	Fluorene		0,0005		3,60E+03	1,80E+00		
	Phenanthrene		0,0005		1,56E+04	7,81E+00		
	Fluoranthene		0,0500		1,64E+04	8,22E+02		
	Pyrene		0,0010		1,58E+04	1,58E+01		
	Benzofluoranthene		0,1000		1,52E+04	1,52E+03		
	Benzo(a)pyrene		1,0000		7,76E+03	7,76E+03		
	Benzo(ghi)perylene		0,0200		6,00E+03	1,20E+02		
	Indeno(1,2,3-cd)pyrene		0,1000		3,41E+03	3,41E+02		
	PAH-eq. (Benzo(a)pyren)			1,80E-03		1,06E+04	1,91E+01	0,000
	PCB 28				2,24E+02			
	PCB 52				4,59E+02			
	PCB 101				3,91E+02			
	PCB 118				2,93E+02			
	PCB 138				3,61E+02			
	PCB 153				4,40E+02			
	PCB 180				2,94E+02			
	Sum PCB				2,46E+03			
	Butylbenzylphthalate					8,92E+03		
	Chloroform			2,00E-01		4,13E+01	8,25E+00	0,000
	Di(ethylhexyl)phthalate					1,93E+06		
	Dichlorobenezene			3,20E-01		5,56E+02	1,78E+02	0,000
	Di-n-butylphthalate					1,98E+05		
	Di-n-octylphthalate					3,10E+04		
	Nonylphenol + 1-2EO					7,73E+05		
	Tetrachloroethylene			4,00E-02		8,96E+02	3,58E+01	0,000
	Trichlorothylene			6,90E-04		1,48E+02	1,02E-01	0,000
	LAS (2)					1,36E+05		
	Toluene			1,00E-03		1,05E+03	1,05E+00	0,000
	Dioxine (2,3,7,8-TCDD)			1,80E+04		5,09E-01	9,17E+03	0,001
	As			1,30E+02		1,89E+05	2,46E+07	2,263
	Cd			5,60E+00		8,51E+04	4,76E+05	0,044
	Cr			1,40E+00		1,80E+06	2,53E+06	0,233
	Cu			5,00E-03		1,46E+07	7,32E+04	0,007
	Pb			1,00E-01		3,71E+06	3,71E+05	0,034
	Hg			8,10E+01		1,22E+05	9,90E+06	0,912
	Ni			1,50E-01		1,52E+06	2,28E+05	0,021
	Zn			1,60E-02		4,52E+07	7,23E+05	0,067
Pesticides	Fungicides							
	Herbicides							
	Insecticides							
Air emissions	Cd			4,50E+00		1,80E+06	8,10E+06	0,746
	As			1,00E+02		1,54E+06	1,54E+08	14,183
	Cr(VI)			1,10E+00		1,08E+07	1,19E+07	1,094
	Hg			8,10E+01		1,04E+07	8,42E+08	77,583
	Ni			1,20E-01		9,47E+07	1,14E+07	1,047
	Pb			8,30E-02		1,60E+08	1,33E+07	1,223
	Se			4,40E-02		2,88E+05	1,27E+04	0,001
	Cu			4,00E-03		6,04E+07	2,42E+05	0,022
	Zn			1,30E-02		2,79E+08	3,63E+06	0,334
	Dioxin			1,40E+04		1,44E+02	2,02E+06	0,186

Appendix D: Distribution of impact potentials

The appendix is split up into three separate sections, presenting the distribution of the following impact potentials:

Appendix D1: Normalisation references for human toxicity via air for EU-15 and the individual Member States
Appendix D2: Normalisation references for human toxicity via water for Denmark, the Netherlands and EU-15
Appendix D3: Normalisation references for human toxicity via soil for Denmark, the Netherlands and EU-15

D.1 Normalisation references, air; distribution of impact potentials

Country	EU-15	A	D	DK	L	NL	UK	S	GR	I	P	E	F	Ir	B	Fi
Population	3,70E+08	8,00E+06	8,11E+07	5,20E+06	4,00E+05	1,53E+07	5,82E+07	8,75E+06	1,04E+07	5,70E+07	9,82E+06	3,96E+07	5,79E+07	3,54E+06	1,01E+07	5,08E+06
Total	2,25E+19	2,67E+17	3,73E+18	2,91E+17	3,68E+16	5,94E+17	3,69E+18	5,39E+17	8,74E+17	4,85E+18	4,50E+17	2,15E+18	3,46E+18	1,53E+17	8,65E+17	2,22E+17
Normalisation factor	6,09E+10	3,33E+10	4,60E+10	5,59E+10	9,21E+10	3,88E+10	6,34E+10	6,16E+10	8,40E+10	8,51E+10	4,58E+10	5,42E+10	5,98E+10	4,33E+10	8,57E+10	4,36E+10
SO2	0,07	0,03	0,10	0,07	0,05	0,03	0,10	0,02	0,08	0,04						
NOx	0,48	0,55	0,52	0,82	0,53	0,77	0,56	0,71	0,35	0,38						
N2O	0,01	0,01	0,01	0,01	0,00	0,02	0,01	0,01	0,00	0,01						
CO	0,17	0,37	0,15	0,20	0,33	0,13	0,13	0,20	0,12	0,16						
nmVOC	0,33	0,82	0,36	0,28	0,23	0,64	0,43	0,44	0,16	0,24						
nmVOC - transport	95,20	95,88	96,34	96,51	86,29	95,14	93,61	98,17	99,15	94,47	100,00	100,00	100,00	100,00	100,00	100,00
Cd	0,05	0,11	0,03	0,04	0,16	0,03	0,07	0,00	0,03	0,07						
As	0,01	0,01	0,01	0,00	0,09	0,00	0,03	0,00	0,00	0,01						
Cr(VI)	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00						
Hg	0,00	0,01	0,01	0,02	0,00	0,01	0,00	0,00	0,01	0,00						
Ni	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00						
Pb	3,14	0,91	1,68	1,36	11,91	2,69	4,76	0,29	0,08	4,49						
Se	0,00	0,00	0,00	0,00	0,03	0,00	0,00	0,00	0,00	0,00						
Cu	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00						
Zn	0,00	0,01	0,00	0,00	0,03	0,00	0,00	0,00	0,00	0,00						
PAH-eq. (benzo(a)pyren)	0,10	1,02	0,07	0,08	0,02	0,11	0,12	0,00	0,00	0,00						
Dioxin	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00						
PCP	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00						
Hexachlorobenzene (HCB)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00						
Tetrachloromethane (TCM)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00						
Trichloroethylene (TRI)	0,01	0,00	0,01	0,00	0,00	0,00	0,01	0,00	0,00	0,00						
Tetrachloroethylene (PER)	0,01	0,00	0,01	0,00	0,00	0,01	0,01	0,00	0,00	0,00						
Trichlorobenzene (TCB)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00						
Trichloroethane (TCE)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00						
Hexachlorocyclohexane (HCH)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00						
Chlorobenzenes	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00						
Vinylchloride	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00						
Particulate matter (PM10)	0,26	0,28	0,71	0,35	0,32	0,13	0,15	0,15	0,00	0,12						

D.2 Normalisation references, water; distribution of impact potentials

		EU-15	DK	NL
Total		1,93E+13	9,29E+11	1,31E+12
Population		3,70E+08	5,20E+06	1,53E+07
Normalisation factor		5,21E+04	1,79E+05	8,55E+04
Water emissions	Substance	%	%	%
Heavy metals	Hg	9,66	8,60	5,43
	Cd	0,64	0,27	0,39
	Cu	0,16	0,07	0,11
	Zn	1,05	0,28	0,79
	Pb	2,07	0,21	2,50
Aliphatic compounds				
Aromatics				
	Benzene (1)	0,04	0,02	0,03
	Benz(a)pyrene			
	Ethylbenzene (1)			
	Fluoranthene			
	Phthalates			
	Isopropylbenzene			
	PAH (6 comp.) (2)			
	PAH-eq. (Benzo(a)pyren)	0,08	0,03	0,05
	Toluene	0,00	0,00	0,00
	Xylenes	0,00	0,00	0,00
Halogenated org. Compounds				
Aliphatics				
	1,2-Dichloroethane	0,00	0,00	0,00
	Hexachlorbutadiene (1)			
	Hexachlorcyclohexane (1)			
	Tetrachlorethylene	0,00	0,00	0,00
	Tetrachlormethane	0,00	0,00	0,00
	1,1,1-Trichloroethane (1)	0,00	0,00	0,00
	Trichloroethene (1)	0,00	0,00	0,00
	Trichloromethane	0,00	0,00	0,00
	Vinylchloride	0,00	0,00	0,00
Aromatics				
	Chlorobenzene (1)	0,00	0,00	0,00
	DRINS			
	Hexachlorobenzene (1)	0,00	0,00	0,00
	PCB (1)			
	Pentachlorophenol (1)	0,00	0,00	0,00
	Thichlorobenzene (1)	0,00	0,00	0,00
Air emissions	Cd	0,30	0,07	0,08
	As	0,01	0,00	0,00
	Cr(VI)	0,01	0,00	0,00
	Hg	79,66	89,83	87,43
	Ni	0,00	0,00	0,00
	Pb	1,94	0,23	0,65
	Se	0,05	0,00	0,00
	Cu	0,01	0,00	0,02
	Zn	0,15	0,05	0,09
	Dioxin	4,16	0,33	2,42

D.3 Normalisation references, soil; distribution of impact potentials

		EU-15	DK	NL
Total		4,44E+10	8,04E+08	1,09E+09
Population		3,70E+08	5,20E+06	1,53E+07
Normalisation factor		1,20E+02	1,55E+02	7,10E+01
	Substance	%	%	%
Sludge	Acenaphthene			
	Fluorene			
	Phenanthrene			
	Fluoranthene			
	Pyrene			
	Benzofluoranthene			
	Benzo(a)pyrene			
	Benzo(ghi)perylene			
	Indeno(1,2,3-cd)pyrene			
	PAH-eq. (Benzo(a)pyren)	0,00	0,00	0,00
	PCB 28			
	PCB 52			
	PCB 101			
	PCB 118			
	PCB 138			
	PCB 153			
	PCB 180			
	Sum PCB			
	Butylbenzylphthalate			
	Chloroform	0,00	0,00	0,00
	Di(ethylhexyl)phthalate			
	Dichlorobenezene	0,00	0,00	0,00
	Di-n-butylphthalate			
	Di-n-octylphthalate			
	Nonylphenol + 1-2EO			
	Tetrachloroethylene	0,00	0,00	0,00
	Trichlorothylene	0,00	0,00	0,00
	LAS (2)			
	Toluene	0,00	0,00	0,00
	Dioxine (2,3,7,8-TCDD)	0,00	0,00	0,00
	As	3,98	7,76	2,26
	Cd	0,08	0,15	0,04
	Cr	0,41	0,80	0,23
	Cu	0,01	0,02	0,01
	Pb	0,06	0,12	0,03
	Hg	1,60	3,13	0,91
	Ni	0,04	0,07	0,02
	Zn	0,12	0,23	0,07
Pesticides	Fungicides			
	Herbicides			
	Insecticides			
Air emissions	Cd	1,05	0,66	0,75
	As	63,54	9,23	14,18
	Cr(VI)	1,40	0,48	1,09
	Hg	25,46	76,40	77,58
	Ni	0,57	0,33	1,05
	Pb	1,32	0,41	1,22
	Se	0,03	0,00	0,00
	Cu	0,01	0,01	0,02
	Zn	0,20	0,19	0,33
	Dioxin	0,11	0,02	0,19

10 Ecotoxicity

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10.1 Summary

This chapter summarises the presently available data on environmental releases of toxic organic and inorganic substances to the Danish and European environment. The estimated releases include:

Aquatic environment:

- Releases of organic pollutants with wastewater
- Releases of metals
- Emissions of oil from oil extraction and refineries
- Release of organotin compounds from antifouling paints
- Atmospheric deposition

Terrestrial environment:

- Pesticide use
- Agricultural use of sewage sludge
- Atmospheric deposition of metals and dioxins

The ecotoxicological impact is estimated from the released amounts of the individual chemicals and expressed as the volume of water and soil in 1994 (reference year) that was theoretically polluted to a level which corresponds to the no-effect concentration of the substances, assuming an even distribution of the pollution.

The main results are presented in **Table 10-1**.

Table 10-1
Summary of normalisation references for ecotoxicity for Denmark, EU-15 and Worldwide in 1994.

		Denmark	EU-15	World
ETWC	m^3 water/capita/year	$7.91*10^5$	$3.52*10^5$	$2.82*10^5$
ETWA	m^3 water/capita/year	$7.40*10^4$	$2.91*10^4$	$2.33*10^4$
ETSC	m^3 soil/capita/year	$6.56*10^5$	$9.64*10^5$	$7.71*10^5$

ETWC: Ecotoxicity Potential for chronic effects on aquatic organisms.
ETWA: Ecotoxicity Potential for acute effects on aquatic organisms.
ETSC: Ecotoxicity Potential for chronic effects on soil organisms.

The dominating release of toxicants originates from the use of pesticides in agriculture and the use of antifouling paints, containing tributyltin compounds, on ships. The uncertainties of these releases are high and probably over one order of magnitude. Consequently, the results presented above should be regarded as rough estimates with a high degree of uncertainty. In order to obtain more precise results it is recommended to improve the estimates of the emission from these sources.

10.2 Description of the impact category

The purpose has been to prepare a normalisation reference for ecotoxicological impacts based on data collected from European national environmental agencies as well as international data centres. The work is based on 1994 data and covers Denmark and the European Union. In addition a rough estimate of the ecotoxicity potential on a worldwide basis is presented.

The impact category ecotoxicity covers the possible effects of toxic substances released during the life cycle of a product to the environment. The sources of toxicants are quite different depending on the type of environment as well as the methods used in the assessment of the impact. Consequently, the impact on aquatic and terrestrial systems are usually considered separately.

In principle, the normalisation reference for ecotoxicology includes all toxic substances emitted to the environment due to human activities, and it requires extensive data on all types of emissions. In general, however, only few data on environmental releases of toxic substances are available, and the normalisation therefore relies on extrapolations from a relatively limited set of data.

The normalisation reference includes the following emission types:

Aquatic environment:

- Releases of organic pollutants with wastewater
- Releases of metals
- Emissions of oil from oil extraction and refineries
- Release of organotin compounds from antifouling paints
- Atmospheric deposition

Terrestrial environment:

- Pesticide use
- Agricultural use of sewage sludge
- Atmospheric deposition of metals and dioxins

10.3 Methodology

The presented estimates of the ecotoxicological impacts are based on estimated releases of toxicants to the aquatic and terrestrial environments on the basis of statistics on emitted volumes of wastewater, sludges, pesticides, etc. as well as concentrations measured in different environmental media. The data sources and the methods used for estimation of the releases from different types of sources are discussed together with an evaluation of the uncertainties involved in the sections below.

In order to obtain a quantitative and comparable value for the ecotoxicity potential (EP), the released amounts of individual substances are multiplied by a substance-specific factor, the equivalency factor (EQF), which corresponds to the potential environmental impact of the substance according to the principles described in Hauschild ***et al***. (1998). The EQF for the single substances are derived from the predicted no-effect concentration (PNEC) based on the toxicity to aquatic or soil organisms, the biodegradability, the bioaccumulation potential, and the calculated environmental distribution. The

EP is calculated for the individual emission types evaluated and for the following effect types:

- Acute aquatic toxicity
- Chronic aquatic toxicity
- Chronic terrestrial toxicity

In a few cases it was necessary to calculate new EQF values as not earlier included substances were found in emission surveys, i.e. if no EQF was available or if a revision of the existing EQF was required. In general, however, it was not possible, within the frame of the project, to revise or generate equivalency factors.

The toxicity to the microflora in wastewater treatment plants (WWTP) was included in the former Danish normalisation reference but it is excluded here for the following reasons:

1. It is not possible to estimate the potential impact on WWTP because of the lack of reliable data. Estimations of the effects on wastewater treatment plants require data for toxicity to microbiological treatment processes such as nitrification, respiration or similar relevant parameters. Such data are available only for a few organic and inorganic substances.

2. Effects on wastewater treatment plants have an environmental relevance but are an indirect measure for the environmental impact from treatment plants. There is no simple relationship between an impaired wastewater treatment and the environmental impact of the emitted wastewater.

3. The impact on a wastewater treatment facility depends on the toxicity of the emitted wastewater as well as the sensitivity of the facility. A modern treatment plant with N and P removal is normally regarded as more sensitive to toxic substances than more traditional treatment techniques. Consequently, the impact strongly depends on the wastewater technology used in different countries.

The results presented here are based on a high number of calculations and assumptions. Background data for the individual emission types and data for the different geographical regions are presented in Appendices A-E.

10.4 Normalisation reference – Aquatic environment

The normalisation reference for the aquatic environment includes those contained in the previous normalisation reference (Hauschild ***et al***. 1998), i.e. wastewater, emissions from oil extraction activities, and atmospheric depositions. In addition the release of toxicants from the use of tributyltin-based antifouling paints is included. The primary data references are shown in Table 10-2.

Table 10-2
Emission types and selected references used for the estimation of emissions to the aquatic environment.

Emission type	Data source
Municipal wastewater	Jepsen and Grüttner (1997) DEPA (1995) van der Auweraert *et al.* (1996) EUROSTAT (1998)
Industrial wastewater	van der Auweraert *et al.* (1996)
Oil extraction Oil emission from refineries	EUROSTAT (1998) ITOPF (1999)
Antifouling	Madsen *et al.* (1998)
Atmospheric deposition	Data from chapter 9 on human toxicity
Other data sources	Grüttner and Neergaard Jacobsen (1994), Grüttner *et al.* (1996), Lassen *et al.* (1996a), DEPA (1996), Lassen and Hansen (1996), Lassen *et al.* (1996b), Jensen and Markussen (1993) van der Auweraert *et al.* (1996) EEA (1998)

Because of the methodological differences and differences in the used data sources, heavy metals, organic substances, oil emissions, antifouling, and air deposition are separately discussed in the following sections.

10.4.1 Emission of heavy metals

10.4.1.1 Data sources

For 10 European countries the emission of heavy metals to the aquatic environment has been estimated in a recent report from the EUROSTAT (EUROSTAT, 1998). These estimates are based on data from the European Topic Centre on Marine Environment (ENEA), the Helsinki Commission (HELCOM), the Oslo and Paris Commission (OSPAR), the Barcelona Commission, and the Danube Commission. The emissions are based on data on riverine and direct input of heavy metals to the marine environment and include the marine and coastal areas from Gibraltar to the Gulf of Bothnia.

The OSPAR data used by EUROSTAT (1998) include high as well as low estimates of the emitted amounts of toxic heavy metals. The high estimates were based on measured concentrations, and in cases where the substances were not detectable the detection limits were used. The low estimates were based on zero values if the substances were not detected. At emissions less than 1 tonne/year, a value of zero is used in the present report. The data from OSPAR cover the period of 1990 – 1995, and the data from HELCOM refer to 1995.

As to the countries not included in EUROSTAT (1998), the emissions were estimated by linear extrapolation from emission data from the Netherlands (NL), reported by van der Auweraert ***et al.*** (1996) by use of the Gross Domestic Product (GDP).

The Danish emissions of metals were estimated from measured concentrations in discharged wastewater from municipal treatment plants and estimated releases from other sources based on mass balance studies of the individual metals (Grüttner & Neergaard Jakobsen 1994; Grüttner ***et al.*** 1996; DEPA 1995; Lassen ***et al.*** 1996a; DEPA 1996; Lassen & Hansen 1996; Lassen ***et al.*** 1996b; Jensen & Markussen 1993).

Lead from loss of fishing equipment and cable sheets is a significant source (Danish release: 150-575 tonnes/yr., Lassen and Hansen (1996)) but is not included in the present report because metallic lead is available to the biota only to a very limited extent.

Only emissions of mercury (Hg), cadmium (Cd), copper (Cu), zinc (Zn), and lead (Pb) are included in this report.

10.4.1.2 *Results*

The ecotoxicity potential (expressed as m^3/yr.) for the metals are calculated according to Hauschild ***et al***. (1998) by multiplying the total emission of the individual metals with an equivalency factor (EF) (**Table 10-3**).

Table 10-3
Estimates of the ecotoxicity potential for metals emitted to the aquatic environment. The estimates are based on the emission reported by EUROSTAT (1998).

Metal emission					Denmark		EU-15	
	EU-15	DK	EF		EP		EP	
	t/year	t/year	m^3/g etwc[1]	m^3/g etwa[2]	m^3/yr. etwc	m^3/yr. etwa	m^3/yr. etwc	m^3/yr. etwa
Hg	13	0.73	$4.00*10^{3}$	$2.00*10^{3}$	$2.90*10^{9}$	$1.45*10^{9}$	$5.17*10^{10}$	$2.59*10^{10}$
Cd	40	0.90	$1.20*10^{5}$	$1.20*10^{4}$	$1.08*10^{11}$	$1.08*10^{10}$	$4.80*10^{12}$	$4.80*10^{11}$
Cu	1855	41	$1.30*10^{4}$	$1.30*10^{3}$	$5.28*10^{11}$	$5.28*10^{10}$	$2.41*10^{13}$	$2.41*10^{12}$
Zn	9600	123	$1.00*10^{3}$	100	$1.23*10^{11}$	$1.23*10^{10}$	$9.60*10^{12}$	$9.60*10^{11}$
Pb	1538	7.4	$2.00E*10^{3}$	200	$1.49*10^{10}$	$1.49*10^{9}$	$3.08E*10^{12}$	$3.08*10^{11}$
Sum					$7.77*10^{11}$	$7.88*10^{10}$	$4.16*10^{13}$	$4.19*10^{12}$

1. etwc: ecotoxicity potential for chronic toxicity to aquatic biota
2. etwa: ecotoxicity potential for acute toxicity to aquatic biota

The background data for these estimates, including emission data for the individual European countries, are included in Appendix A.

10.4.1.3 *Discussion*

The precision of the EUROSTAT data is validated by comparing with the Danish and NL releases of heavy metals. This is done by comparing the Danish releases of metals presented above with estimated Danish releases based on an extrapolation by use of EUROSTAT data. The extrapolation is based on linear extrapolation by use of the Gross Domestic Product (GDP). Similarly metal releases for the Netherlands, reported by van der Auweraert ***et al.*** (1996), are compared with an estimate based on EUROSTAT-data. The data are compared in **Table 10-4**.

Table 10-4
Estimated emissions of selected metals to the aquatic environment.

Metal emission t/year	EU-15	EU-15	DK	DK	NL	NL
	Present report	Extra-polated from NL data 1996[1]	Extrapolated from EUROSTAT 1998[1]	Present report[3]	EURO-STAT 1998 data	NL data[4] 1996
Hg	13	14.4	0.3	0.7	6	0.646
Cd	40	41.1	0.9	0.9	13	1.84
Cu	1855	1840	38.9	41	555	82.2
Zn	9600	11100	213.3	123	3522	495
Pb	1538	2820	31.9	7.4[2]	702	126

1. Extrapolation based on the Gross Domestic Product (GDP). NL data by van der Auweraert *et al.* (1996)
2. The figure does not include loss of commercial fishing equipment, which is estimated to be approx. 100-275 tonnes/yr. (Lassen & Hansen 1996).
3. Estimates based on measured wastewater concentrations and releases from other sources.
4. Data by van der Auweraert *et al.* (1996).

The data for the EU-15, which are based on extrapolation from EUROSTAT data, correspond well with the results obtained by extrapolation from the Netherlands by use of the Gross Domestic Products (GDP). This apparent compliance covers, however, some methodological differences and uncertainties.

The data on releases of cadmium, copper, and zinc to the Danish aquatic environment correspond within a factor of 2 with the extrapolated EUROSTAT-data. However, the figures for emission of mercury and lead show more significant differences.

The EUROSTAT data for the NL are a factor 5 - 10 higher than the data reported by van der Auweraert ***et al.*** (1996). These data are based on measured concentrations in municipal and industrial discharges and can be regarded as highly reliable. The differences can be explained by the fact that the EUROSTAT data are based on riverine inputs to the North Sea, i.e. measurements of river water, including emissions from Germany and other countries upstream as well as diffuse and natural sources.

The composition of the wastewater and thus the emissions of organic micropollutants and heavy metals depend on the treatment processes applied. The well-developed treatment technologies used in some European countries reduce the pollutants in the wastewater more efficiently than less sophisticated techniques. This will, together with differences in the composition of the industrial sectors between countries, introduce an error when the Gross Domestic Product is used as a basis for extrapolation.

The most important uncertainties are:

- The estimates from EUROSTAT are based on riverine and direct inputs to the marine environment and thus include natural sources. The figures do not include emissions of metals, which are bound to sediments upstream in the river basins. Furthermore, the used figures represent minimum estimates because zero values are used in case the concentrations are below the detection limits. Comparison with Danish estimates based on measured concentrations in wastewater and estimated releases corresponds, however, well with the EUROSTAT data.

- For some countries the releases of metals are based on extrapolation from NL data. It should be stressed that differences in the industrial sources and the wastewater treatment methods applied in European countries are an important source to uncertainty of the estimated releases.
- Only some metals are included in the estimates. By focusing on the dominating toxicants this error is, however, minimised, but the results should be regarded as a minimum estimate of the ecotoxicity potential.

10.4.2 Emission of organic substances

10.4.2.1 Data sources

The emission of toxicants from industrial sources is difficult to estimate because of the differences in the composition of the wastewaters and the limited amount of data. The normalisation reference used by Hauschild ***et al***. (1998) was based on directly measured toxicities of Danish industrial wastewater emissions. These data are, however, not updated and probably not available from other countries.

In general, there are only few data on emissions of organic micropollutants to the aquatic environment in Europe. The most comprehensive data compilation is made by van der Auweraert ***et al.*** (1996), which covers emissions from over 700 industrial sources and municipal treatment facilities in NL and includes approximately 100 individual parameters. Furthermore, a few organic micropollutants are reported by DETR (1999). In Germany the industrial emissions are estimated for selected industrial sectors only, but no national emission reference has been found (UBA 1999).

In Denmark a few selected organic substances have been monitored in wastewater from municipal treatment plants, but information on the emission of individual organic substances from industrial sources does not exist. Some of the most reliable Danish data are estimates of the emissions of selected substances based on mass balances on national levels and statistical reports published by the Danish EPA on an annual basis (DEPA 1995). Moreover, the Danish EPA has published a collection of data on emission of 38 single substances including organic solvents and heavy metals (Holmegaard Hansen, 1995). None of these data sources provides a base of data as extensive as the NL data.

Consequently, the emissions of organic substances via Danish and European wastewater sources are, in the present report, based on NL data extrapolated by use of GDP. To some extent these estimates can be validated by comparison with available national data (see discussion).

10.4.2.2 Results

Data for the environmental release of organic pollutants in NL are presented in Table 10-5. Industrial direct outlets as well as municipal wastewater emissions are included in the figures.

Table 10-5
Emission of organic substances to the aquatic environment from industrial and municipal sources. The data from the Netherlands are based on detailed estimations and measurements from over 700 individual industries. The data are extrapolated to Denmark and EU-15 by use of GDP. The number of decimals does not reflect the precision of the data. The uncertainties are discussed below.

Emission of organic substances	NL	DK	EU-15
		tonnes/yr.	
Aliphatic compounds	5550.00	2466.01	124191.64
Benzene	165.00	73.31	3692.18
Benz(a)pyrene	3.34	1.48	74.74
Ethylbenzene	0.00	0.00	0.00
Fluoranthene	15.80	7.02	353.55
Phthalates	0.11	0.05	2.53
Isopropylbenzene	0.40	0.18	8.93
PAH[1] (6 comp.)	18.50	8.22	413.97
Toluene	413.00	183.51	9241.65
Xylenes	165.00	73.31	3692.18
Total aromates	1210.00	537.63	27076.01
Halogenated org. compounds	29.80	13.24	666.83
Chlorinated aliphates	28.50	12.66	637.74
1,2-Dichloroethane	0.42	0.19	9.33
Hexachlorbutadiene	0.00	0.00	0.00
Hexachlorcyclohexane	0.01	0.00	0.15
Tetrachlorethylene	0.08	0.04	1.83
Tetrachlormethane	0.35	0.15	7.74
1,1,1-Trichloroethane	0.06	0.03	1.31
Trichloroethene	0.16	0.07	3.49
Trichloromethane	0.24	0.10	5.28
Vinylchloride	0.00	0.00	0.04
Chlorinated aromates	1.24	0.55	27.75
Chlorobenzene	0.10	0.04	2.24
DRINS[2]	0.00	0.00	0.07
Hexachlorobenzene	0.01	0.01	0.32
PCB[3]	0.00	0.00	0.02
Pentachlorophenol	0.01	0.01	0.26
Trichlorobenzene	0.00	0.00	0.02

1. PAH: Polycyclic Aromatic Hydrocarbons. van der Auweraert *et al.* (1996) report emissions of PAH to water as the sum of 6 individual and non-specified compounds.
2. DRINS: Common name for the group of commonly used cyclodien insecticides: Aldrine, dieldrine and endrine.
3. PCB: Polychlorinated Biphenyl Compounds

The estimate covers only selected prioritised industrial pollutants. Moreover, the estimated ecotoxicity potential is based only on substances where equivalency factors (EF) are published by Hauschild ***et al.*** (1998). For a few additional organic substances, the Water Quality Standards issued by the Danish EPA were used for the estimation of the ecotoxicity potential; see Table 10-6.

Table 10-6
Estimated ecotoxicity potential (EP) for organic toxic substances emitted to the aquatic environment.

Country	EP etwc m^3/yr.	EP etwa m^3/yr.
Netherlands	$2.89*10^{11}$	$4.25*10^{10}$
Denmark	$3.75*10^{11}$	$2.30*10^{10}$
EU-15	$1.89*10^{13}$	$1.16*10^{12}$

1. The estimates are based on equivalency factors (EF) according to Hauschild *et al.* (1998), except for aliphatic substances where the ecotoxicity has been assumed to equal that of crude oil.

The background data are included in Appendix B.1.

10.4.2.3 Discussion

The estimated ecotoxicity potential includes only approximately half of the substances presented in Table 10-5 (see Appendices B.1 and B.2). Aliphatic substances account for the major part of the released compounds in Table 10-5. No EF is, however, available for this group of substances, but if the ecotoxicity is assumed to be equivalent to the toxicity of crude oil, the aliphatic compounds will contribute with 66% of the chronic toxicity potential and 18% of the acute toxicity potential. The chronic and acute ecotoxicity potentials for EU would in this case be $1.89*10^{13}$ m^3/yr. and $1.16*10^{12}$ m^3/yr., respectively. These figures are used in the calculation of the normalisation reference as they are assumed to provide a more consistent result.

The Danish emission data presented above can be compared with reported releases of benzene, toluene, and xylenes via wastewater (Hansen 1995). The reference covers only selected industrial sources and thus gives only a rough picture of the releases. The author reported releases of benzene <1 tonnes/yr., and releases of toluene and xylenes at 20 tonnes/yr. and >10 tonnes/yr., respectively. The low emission reported for benzene may be explained by the fact that fuel is not included in the estimates. As for toluene the reported emission is about 9 times lower than the figures for Denmark presented in Table 10-5.

The uncertainties of the estimated effect potentials can be validated by comparing with measured emission data. In **Table 10-7** values for the release of selected organic pollutants in the UK calculated by extrapolation from NL data are compared with measured riverine and direct inputs reported by the DETR (1999). The figures show considerable differences. The estimated emission of trichloroethane is 10 times higher than the highest values reported by the DETR. Also the estimated emissions of pentachlorophenol are a factor of 4-5 times higher than the measured riverine inputs.

The differences may partly be explained by the uncertainties introduced by extrapolation and partly by the fact that emission data based on measured riverine inputs underestimate the actual emissions, as biodegradation, evaporation, and adsorption will reduce the concentrations of many organic substances in the water phase between the point of emission and the monitored sampling point.

In addition to the organic substances discussed above measured releases of selected metals in the UK are compared with extrapolated values in Table 10-7. The values based on riverine inputs reported by the DETR are generally a factor of 3-10 higher than the estimated figures. It should be stressed that data on heavy metals based on riverine inputs include diffuse sources and natural background levels and therefore tend to overestimate the emissions from man-made sources. Moreover, unlike most organic substances, metals do not degrade or evaporate from aquatic environments.

From these data it is concluded that an extrapolation from NL data to other European countries seems to give uncertain but useful estimates of the emission to the aquatic environment.

Table 10-7
Data on emission to the aquatic environment of selected organic and inorganic substances. The values reported by DETR are based on inputs from point sources and riverine inputs (DETR 1999). The extrapolated values are based on data from the Netherlands (van der Auweraert et al. 1996) extrapolated by use of GDP.

Substance	T/year.		
	Extrapolated from NL data[1]	DETR low[1]	DETR high[1]
1,1,1-Trichloroethane	179	5.90	17.60
Pentachlorophenol	35	1.32	7.75
Arsenic	15	82	163
Chromium	82	301	347
Nickel	103	307	348

1. Low values: Concentrations below detection limits are set to zero. High values: Concentrations below detection limits are considered to equal the detection limits.

The presented ecotoxicity potential for organic pollutants to the aquatic environments is associated with a number of uncertainties:

- In general, there are very few data on emission of organic toxicants to the aquatic environment. The most extensive data compilation is from the Netherlands (van der Auweraert ***et al.***, 1996), which is used here. Of the parameters included in **Table 10-5**, EF are available for only about half of the substances. As discussed above the emission of aliphatic compounds may very well contribute with over half of the actual ecotoxicity potential released to the aquatic environment in Europe. Because of lack of information on the type of substances included in this group as well as missing effect factors, the aliphatic compounds are not included in the estimated ecotoxicity potential presented here. Consequently, the estimates should be regarded as minimum values of the release of toxicants to the aquatic environment.

- There are considerable differences in the composition of the industrial sector between countries. This is likely to bias the estimated ecotoxicity potential. As DK has relatively few chemical industries, the figures for DK are probably overestimated.

- There are differences in the wastewater treatment techniques applied in different European countries and thus the retention of organic pollutants in the treatment facilities. In countries like Germany, the Netherlands, Denmark, and Sweden two- or three-step wastewater treatment techniques are used, which retain organic and inorganic pollutants more efficiently than more simple techniques in the Mediterranean region. Consequently the estimated releases from these countries are probably underestimated.

10.4.3 Oil extraction and spills

10.4.3.1 Data sources

Oil extraction, refineries, and sea transport contribute significantly to the pollution of the marine environment. Data on emissions from refineries and production facilities in the North Sea are reported by EUROSTAT (1998). The data include emission from land and sea based on point sources including refineries, off shore oil extraction facilities, spills from handling of oil from terminals, etc. as well as legal spills from ships. The data do not include emissions from the point sources discussed above, i.e. wastewater emissions from industries and WWTP, as well as accidental spills from tankers, because accidental emissions in general are not included in the normalisation reference. Spills from tankers are registered by the International Tankers Organisation (ITOPF 1999) and may contribute on a yearly basis with quantities that are comparable in size or higher than all other sources together. Furthermore, data on emissions to the Mediterranean sea are not included.

10.4.3.2 Results

The data on releases of oil and crude oil etc. are presented in Table 10-8.

Table 10-8
Emissions of crude oil etc. from refineries, off-shore production facilities in the North Sea, and legal discharges from ships. Accidental spills are not included.

Source	Emission	EF (etwc)[1]	EF (etwa)[1]	EP (etwc)	EP (etwa)
	t/year[2]	m^3/g	m^3/g	m^3/yea.	m^3/year
Refineries	4200	100	1.67	$4.20*10^{11}$	$7.01*10^{9}$
Off-shore	25005			$2.50*10^{12}$	$4.18*10^{10}$
Oil terminals etc.	2000			$2.00*10^{11}$	$3.34*10^{9}$
Legal ship discharges	5100			$5.10*10^{11}$	$8.52*10^{9}$
Sum	29205			$3.63*10^{12}$	$6.06*10^{10}$

1. The estimates are based on calculated equivalency factors (EF) as defined in Hauschild *et al.* (1998). See discussion below.
2. EUROSTAT (1998).

EP Ecotoxicity potential

The ecotoxicity potential from oil is calculated on the basis of a Predicted No-Effect Concentration (PNEC) for acute toxicity to aquatic organisms corresponding to 0.6 mg/l and a PNEC for chronic toxicity of 0.01 mg/l based on data for crude oil (IUCLID, 1996). The values are thus based on more recent data than used by Hauschild ***et al***. (1998). The corresponding equivalency factors are: etwa = 1.67 m^3/g and etwc = 100 m^3/g. Crude oil is here regarded as slowly degradable in the marine environment although some fractions may degrade more rapidly or evaporate from the water phase. The resulting ecotoxicity potential is shown in Table 10-8.

10.4.3.3 Discussion

The estimated release of oil is associated with a number of uncertainties:

- The Mediterranean Sea is not included in the reported emissions.

- Accidental spills are a significant source, which according to the applied methodology is not included in the present evaluation. The reported yearly spills from the International Tankers Organisation (ITOPF, 1999) show average spills from 1987-1997 ranging 9,000 - 435,000 tonnes on a world basis with an average of 147,000 tonnes/yr. In 1994 the spills in

European seas were about 25,000 tonnes, i.e. a volume comparable with the non-accidental emissions in the North Sea.

10.4.4 Antifouling

10.4.4.1 Data sources

Antifouling paints released from ships are a significant source for toxic substances released to the marine environment. Antifouling agents for commercial ship transport are normally based on the highly toxic tributyltin-compounds (TBT). The emission of tin to the Danish marine environment is estimated to be 0.6-4.9 tonnes TBT/yr. (DEPA 1997b). It has not been possible to identify other data sources.

10.4.4.2 Results

The release of TBT to the Danish marine waters is extrapolated to a European level by comparing the size of the Danish water area (approx. 43,000 km^2) with the European water area (20% of the total area = 809,000 km^2). The figures should be regarded as a rough estimate of the release of organotin compounds from antifouling paints.

The Danish EPA has set a Water Quality Standard (WQS) at 0.001 mg/l of ***bis***-tributyltinoxide (TBTO) corresponding to 0.00097 mg TBT/l. The equivalency factor for tributyltin used here is based on the Danish WQS (Danish Ministry of Environment, 1996). **Table 10-9** shows the estimated equivalency factors based on these data.

Table 10-9
Ecotoxicity potential for organic tin-compounds (as tributyltinoxide, TBTO) released from antifouling paint to the Danish marine environment.

	Emission of org. tin comp. t/year [1]	EF		EP	
		(etwc) m^3/g [2]	(etwa) m^3/g [2]	(etwc) m^3/yr.	(etwc2) m^3/g
DK					
Low[1]	0.6	1.03*10^6	1.03*10^5	6.18*10^{11}	6.18*10^{10}
High[1]	4.9			5.05*10^{12}	5.05*10^{11}
Average				2.83*10^{12}	2.83*10^{11}
EU-15 [3]					
Low	11.4	1.03*10^6	1.03*10^5	1.17*10^{13}	1.17*10^{12}
High	93.1			9.59*10^{13}	9.59*10^{12}
Average				5.38*10^{13}	5.38*10^{12}

1. Emission estimates from DEPA (1997b). Low = low end of the estimated range. High = high end of the estimated range.
2. The chronic equivalency factor for organotin is based on the water quality standards according to the Danish statutory order 921/1996 (Danish Ministry of Environment, 1996). The acute equivalency factor is a factor of 10 lower than the chronic factor.
3. Estimates for EU-15 are based on the area of marine water: Marine area in DK = approx. 43,000 km^2, marine area in EU-15 is 20% of the total area (approx. 809,000 km^2).

EF Equivalency factor.
EP Ecotoxicity potential.

10.4.4.3 Discussion

The emission of organotin compounds from antifouling paints is based on a rough estimate of the marine releases in Denmark. This figure is extrapolated to a European level by use of the water area. The uncertainty of the estimate depends on the size of the traffic through the Danish marine areas compared to that of other European waters and the size of the area included in the estimates (in this report calculated as 20% of the total EU-15 area).

Because of the relatively large contribution of this source and the high uncertainty of the estimate, it is recommended to validate these figures further.

10.4.5 Atmospheric depositions

10.4.5.1 Data sources

The atmospheric deposition of toxicants to the aquatic environment is estimated according to the principles described in Hauschild ***et al***. (1998). A discussion of the available data and the methods used for the estimation of the normalisation reference is found elsewhere in this report.

10.4.5.2 Results

The estimated deposition to the aquatic environment is shown in Table 10-10. The background data are included in Appendix C.

Table 10-10
Estimated contribution of toxic substances from deposition.

Deposition	EP Aquatic chronic m^3/yr.
DK	$1.37*10^{11}$
EU-15	$1.24*10^{13}$

10.4.5.3 Discussion

The estimated ecotoxicity potential is primarily based on the deposition of metals and includes only the organic toxicants where effect factors are available. The estimate should therefore be regarded as a minimum level.

10.5 Normalisation reference - Terrestrial environment

The estimated releases of toxic substances to the terrestrial environment include the same types of sources as evaluated by Hauschild ***et al***. (1998): Pesticides, agricultural use of sewage sludge, and atmospheric depositions. The emission types and data references included are presented in Table 10-11.

Table 10-11
Emission types and selected references used for the estimation of emissions to the terrestrial environment.

Emission type	Data source
Use of pesticides	Use of pesticides in Denmark (DEPA 1997a) EEA, second assessment (EEA 1998) OECD Environmental Data (OECD 1997)
Sewage sludge used for agricultural purposes	Use of Waste Products in Agriculture (Tørsløv *et al.* 1997) OECD Environmental Data (OECD 1997)
Atmospheric depositions	Data from sub-activity on human toxicity (chapter **9**)

10.5.1 Use of pesticides

10.5.1.1 Data sources

The dominating source of toxicant emission to the terrestrial environment is the agricultural use of pesticides. Statistics on the use is available from EEA (EEA 1998), OECD (1997) and from the national EPA’s, e.g. DEPA (1997a). The toxicity pressure from pesticides depends on the toxicity of the individual active ingredient used and the number of applications recommended for different crop types. The large number of pesticides used makes such an estimate very complex.

For this reason the approach previously used by Hauschild ***et al***. (1998) has been applied in the present report with some modifications.

The Danish data on use of pesticides are relatively detailed and allow calculations of the number of applications used for each of the main categories of pesticides (as active ingredients): Herbicides, fungicides, and insecticides. It is possible for each of these types to calculate an application factor expressing the average number of applications per ha for the different types of pesticides. The toxicity pressure expressed as the number of applications multiplied by the size of the treated area can then be estimated from the use of pesticides in the different countries.

10.5.1.2 Results

The estimated toxicity potential applied with the use of pesticides is presented in Table 10-12. The background data are presented in Appendix D.

Table 10-12
Estimated ecotoxicity potential for use of pesticides.

Pesticide type	Use[1] t/year	EP (m^3/year)	Distribution %
DK			
Fungicides	892	$3.504*10^{11}$	10
Herbicides	2685	$2.848*10^{12}$	83
Insecticides	95	$2.147*10^{11}$	6
SUM		$3.413*10^{12}$	
EU-15			
Fungicides	199191	$7.825*10^{13}$	22
Herbicides	119843	$1.271*10^{14}$	36
Insecticides	67148	$1.518*10^{14}$	42
SUM		$3.571*10^{14}$	

1. Use of pesticides (active ingredients): Danish data for 1994 from DEPA (1997a). European data for 1995 from OECD (1997).

10.5.1.3 Discussion

The estimated ecotoxicity potential is associated with a number of uncertainties:

- The differences in toxicity of the pesticides are not considered, i.e. the equivalency factor is based on a very rough estimate of a common PNEC value for all pesticides.
- Differences in application rates and praxis, crop types, climatic conditions, and national regulations are not considered.

10.5.2 Sewage sludge used for agricultural purposes

10.5.2.1 Data sources

Large quantities of sewage sludge are applied as agricultural fertiliser in most European countries. The normalisation reference estimated by Hauschild ***et al***. (1998) was based on the content of heavy metals and tensides only. Since then extensive studies have made more comprehensive data available on the contents of organic pollutants in sewage sludge (Tørsløv ***et al.*** 1997).

These data are used in the present report for the estimation of the environmental release of toxicants via sewage. Data for use of sludge in agriculture in the European countries are derived from a study from 1994 by Hall and Dalimier (1994).

10.5.2.2 Results

The resulting EP from the use of sludge in agriculture is presented in Table 10-13. The background data are found in Appendices E.1 and E.2.

Table 10-13
Ecotoxicity potential from sewage sludge used in agriculture.

	Agricultural use[1]	EP soil[2]
	tonnes/yr.	etwc m^3/yr.
DK	$1.29*10^5$	$1.89*10^7$
EU-15	$3.66*10^6$	$5.35*10^8$

1. Sewage sludge used in agriculture. Data from DEPA (1998), OECD (1997), and Hall and Dalimier (1994).
2. Ecotoxicity potential calculated from the contents of toxicants in sludge (Tørsløv *et al.* 1997 and Hauschild *et al.* 1998). Additional equivalency factors derived from Jensen and Folker Hansen (1995).

10.5.2.3 Discussion

The ecotoxicity from the application of sewage sludges in agriculture is based on Danish data for contents of toxicants in sludge. These figures are in agreement with reported values for Swedish sludges but should be regarded as a low estimate of the contents of sludge from more heavily industrialised European regions. In addition the content of toxicants will depend on the design of the treatment facility, for example the hydraulic retention time and sludge age. Moreover, only a limited number of toxic substances are included in the estimate. By focusing on the dominating toxicants this error is minimised, but the estimate should be regarded as a realistic minimum of the ecotoxicity potential.

The overall contribution of sewage sludge is, however, small compared to other terrestrial sources.

10.5.3 Atmospheric depositions

10.5.3.1 Data sources

The atmospheric deposition of toxicants to the terrestrial environment is estimated according to Hauschild ***et al***. (1998). A discussion of the available data and the methods used for the estimation is found in the section on human toxicity.

10.5.3.2 Results

The estimated deposition to the terrestrial environment is shown in Table 10-14. The background data are presented in Appendix C.

Table 10-14
Estimated contribution of toxic substances to the terrestrial environment from deposition.

	Ecotoxicity potential terrestrial chronic estc m^3/yr.
DK	$5.90*10^7$
EU-15	$3.51*10^{10}$

10.5.3.3 Discussion

The atmospheric deposition contributes with about half of the ecotoxicity potential emitted to the soil environment in Europe. 96% of this contribution is caused by selenium. The deposition of selenium is twice the deposition of mercury and three times the deposition of cadmium, i.e. metals that are normally regarded as more serious pollutants. Nevertheless, the estimated toxicity potential for deposition of selenium on soil is 50 and 180 times higher than that for mercury and cadmium, respectively.

It is recommended to re-evaluate the equivalency factor of selenium.

10.6 Normalisation references

The data and estimates presented above are summarised in Table 10-15. In addition to the calculated ecotoxicity potential for DK and EU-15 an estimate of the ecotoxicity potential on a world basis is presented. The normalisation data for DK and EU-15 is discussed in the sections above.

Assuming correlation among acidification, GDP and ecotoxicity the worldwide normalisation reference is calculated by a simple extrapolation from the EU-15 data to a world basis by use of the Gross Domestic Products. Data for the emission of toxic substances to the environment was found for high-income countries only. Because of the lack of data for countries with lower per capita income it was not possible to differentiate between income groups in the extrapolation of releases of toxic substances. Thus the extrapolation presented here does not take the differences between countries with respect to degree of industrialisation, pesticide use etc. into consideration.

Table 10-15
Ecotoxicity potentials for emissions of toxic substances to the environment in Denmark and EU-15. A worldwide normalisation reference is calculated by extrapolation from EU-15 data by use of Gross Domestic Products.

	Substances	EP etwc (m3/yr)	%	EP etwa (m3/yr)	%	EP etsc (m3/yr)	%
DK							
Wastewater	Organic substances	3,75E+11	9	2,30E+10	6		
	Metals	7,77E+11	19	7,88E+10	20		
Pesticides	Fungicides					3,50E+11	10
	Herbicides					2,85E+12	83
	Insecticides					2,15E+11	6
Sludge	Organic substances+metals					1,89E+07	0,00
Deposition, water		1,37E+11	3				
Deposition, soil						5,90E+07	0,00
Antifouling	Organotin compounds	2,83E+12	69	2,83E+11	74		
DK		4,12E+12		3,85E+11		3,41E+12	
Person equivalent		7,91E+05		7,40E+04		6,56E+05	
EU15							
Wastewater	Organic substances	1,89E+13	14	1,16E+12	11		
	Metals	4,16E+13	32	4,19E+12	39		
Pesticides	Fungicides					7,83E+13	22
	Herbicides					1,27E+14	36
	Insecticides					1,52E+14	42
Sludge	Organic substances+metals					5,35E+08	0,0001
Oil emission		3,63E+12	3	6,06E+10	1		
Deposition, water		1,24E+13	10				
Deposition, soil						3,51E+10	0,010
Antifouling	Organotin compounds	5,38E+13	41	5,38E+12	50		
EU15		1,30E+14		1,08E+13		3,57E+14	
Person equivalent		3,52E+05		2,91E+04		9,64E+05	
World							
Person equivalent (extrapolated)		2.82E+05		2.33E+04		7.71E+05	

Table 10-15 shows the annual contribution of the individual emission types and types of substances to the overall ecotoxicity potential (EP) in m^3 released to the environment. By using the extrapolation method proposed in chapter 3, Development of normalisation references for different geographic areas, the worldwide normalisation reference for ecotoxicity can be estimated to 7.95*10^4 m^3/capita/year (etwc), 6.57*10^3 m^3/capita/year (etwa), and 2.78*10^5 m^3/capita/year (etsc). These normalisation references are slightly above the references estimated by extrapolation of the effect potential.

The contribution to the aquatic environment is dominated by the release of organotin compounds from antifouling paints that contributes with over 70% of the total aquatic emissions in Denmark, and about 50% of the aquatic emissions in Europe. The EP for organotin is based on an emission to the

Danish aquatic environment of organotin of 2.8 tonnes per year representing a range from 0.6-4.9 tonnes per year. If the lower end of this interval is used instead of an average value the contribution from organotin compounds is reduced to 37% of a total EP for chronic toxicity released to the Danish aquatic environment at $1{,}66 \cdot 10^{12}$ m^3/yr. In this case metal emitted from point sources will contribute with 47%. If the high end of the interval is used organotin will contribute with 83% of the emitted EP and metals with only 13%.

Emission of metals to the aquatic environment accounts for 40% of the emission in EU-15 and 20% of the Danish emissions. Copper contributes with 21% in EU-15 and with 14% in Denmark. Also zinc contributes significantly (9 and 3%, respectively).

The use of pesticides contributes with almost 100% of the EP to the Danish and EU-15 terrestrial environments. This holds true even if the contribution from the pesticide use is assumed to be 10 times lower than assumed in the estimates of the toxicity from this source. The second largest contribution to terrestrial toxicity is thus the atmospheric deposition, mainly caused by selenium. According to Hauschild ***et al.*** (1998) selenium has a very high equivalency factor for chronic toxicity in soil, when emitted to the air (106 m^3/g), compared to metals like cadmium (1.8 m^3/g) and mercury (5.3 m^3/g). This is caused by a combination of a relatively low partitioning coefficient for selenium in soil and a high toxicity.

10.7 Comparison with the previously used normalisation reference

In **Table 10-16** the estimated normalisation references are compared with the values for 1990-1992 calculated by Hauschild ***et al.*** (1998).

Table 10-16
The estimated total ecotoxicity normalisation reference for Denmark compared to the values for the years 1992-1994 in Hauschild et al. (1998).

		Denmark	EU-15	World
ETWC, 1990	m^3 water/capita/year	$4.7 \cdot 10^5$	-	-
1994		$7.91 \cdot 10^5$	$3.52 \cdot 10^5$	$2.82 \cdot 10^5$
ETWA, 1990	m^3 water/capita/year	$4.8 \cdot 10^4$	-	-
1994		$7.40 \cdot 10^4$	$2.91 \cdot 10^4$	$2.33 \cdot 10^4$
ETSC, 1990	m^3 soil/capita/year	$3.0 \cdot 10^4$	-	-
1994		$6.56 \cdot 10^5$	$9.64 \cdot 10^5$	$7.71 \cdot 10^5$

ETWC: Ecotoxicity Potential for chronic effects on aquatic organisms.
ETWA: Ecotoxicity Potential for acute effects on aquatic organisms.
ETSC: Ecotoxicity Potential for chronic effects on soil organisms.

The EP for the aquatic environment is about 1.5 times higher than estimated in 1990-1992. Considering the uncertainties involved, the estimates are, however, comparable in size. The main differences are the contribution from organotin compounds to the aquatic environment and the lower deposition of heavy metals in the present estimate compared to the earlier estimates.

The present estimate for the terrestrial environment is considerably higher than earlier reported. This is mainly caused by a higher estimated ecotoxicity potential for pesticides (a factor of 65 higher).

It should be stressed, however, that the observed differences are mainly caused by methodological differences rather than changes in the environmental releases.

10.8 Evaluation of uncertainties

The uncertainties discussed above are summarised in **Table 10-17**. The uncertainties are scored in three categories: “Low”, i.e. an uncertainty expected to be considerably lower than one order of magnitude, “medium”, i.e. an uncertainty expected to be up to one order of magnitude, and “high”, i.e. an uncertainty expected to be higher than one order of magnitude. The uncertainties are due to both the applied methodology and limitations of data. It should be stressed that these uncertainties are subjective and based on the author’s experiences obtained during the project. Within the frame of this project it was not possible to estimate the size of the uncertainties more precisely.

The overall uncertainty of the normalisation reference is expected to be high as the uncertainties of the dominating sources of toxicant releases in the aquatic as well as the terrestrial environments are high, i.e. the release of organic tin compounds from antifouling paints used on ships and from the use of pesticides in agriculture.

Table 10-17
Summary of the expected uncertainties of the presented ecotoxicity potentials of the individual sources of toxicants. It is stressed that the uncertainties are based on the author’s subjective impressions and do not represent a quantitative estimate.

Emission type	Main uncertainties	Contribution % (EU-15 data)	Uncertainty
Aquatic environment			
Heavy metals	Release data are only available for few substances	32-39	Medium
Organic substances	Release data and effect factors are only available for few substances	11-14	Medium
Oil extraction, etc.	The reported emissions do not include the Mediterranean sea	1-3	Medium
Antifouling	Very uncertain release data	41-50	High
Deposition, water	Limitations of data and available effect factors	10	Medium
Terrestrial environment			
Pesticide use	The applied method for estimation of the ecotoxicity potential introduces a high uncertainty. The release figures are reliable	100	High
Sewage sludge	The uncertainty of both data and the applied method is low	0	Low
Atmospheric deposition	Limitations of data and available effect factors	0	Medium

10.9 Recommendations

Most of the data sources used in the estimates are linked to international or national statistics, which are regularly updated. It should therefore be relatively simple to update the calculations. The two dominating sources of toxicant release: Pesticides and tributyltin compounds used in antifouling paints are, however, based on rather rough assumptions and non-validated data.

Statistics on the use of pesticides are available on a yearly basis, but the estimated ecotoxicity potentials are based on non-validated assumptions. Data on the release of tributyltin are not available, and the presented figures are based on rough estimates of the release to the Danish aquatic environment. It is recommended that the ecotoxicity potentials for these emission types are further validated.

The estimated ecotoxicological impact is based on relatively limited data on environmental releases of selected organic and inorganic substances and should in general be regarded as a minimum estimate because it was impossible to include all types of sources, and only some of the substances that are known to be emitted are included in the presented estimates.

It is recommended to validate the estimated ecotoxicity potential by comparison with chemical consumption data combined with release factors. This will probably represent a maximum estimate of the actual release levels. It was, however, not possible within the frame of the present project to perform this validation.

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Appendix A: Emissions to the aquatic enironment, metals

Austria

	Emission (1)	EF m3/g		EP m3/yr		EP m3/yr	
	g/yr	etwc	etva	etwc	%	etva	%
Hg	3,86E+05	4,00E+03	2,00E+03	1,54E+09	0	7,72E+08	1
Cd	1,10E+06	1,20E+05	1,20E+04	1,32E+11	11	1,32E+10	11
Cu	4,91E+07	1,30E+04	1,30E+03	6,39E+11	52	6,39E+10	52
Zn	2,96E+08	1,00E+03	1,00E+02	2,96E+11	24	2,96E+10	24
Pb	7,53E+07	2,00E+03	2,00E+02	1,51E+11	12	1,51E+10	12
EP for metals (m3/yr)				1,22E+12		1,23E+11	

References

1) Based on van der Auweraert *et al.* (1996)

Belgium

	Emission (1)	EF m3/g		EP m3/yr		EP m3/yr	
	g/yr	etwc	etva	etwc	%	etva	%
Hg	0,00E+00	4,00E+03	2,00E+03	0,00E+00	0	0,00E+00	0
Cd	0,00E+00	1,20E+05	1,20E+04	0,00E+00	0	0,00E+00	0
Cu	1,00E+06	1,30E+04	1,30E+03	1,30E+10	4	1,30E+09	4
Zn	2,52E+08	1,00E+03	1,00E+02	2,52E+11	79	2,52E+10	79
Pb	2,60E+07	2,00E+03	2,00E+02	5,20E+10	16	5,20E+09	16
EP for metals (m3/yr)				3,17E+11		3,17E+10	

References

1) Eurostat (1998)

Denmark

	Emission	EF m3/g		EP m3/yr		EP m3/yr	
	g/yr	etwc	etva	etwc	%	etva	%
Hg	7,26E+05	4,00E+03	2,00E+03	2,90E+09	0	1,45E+09	2
Cd	9,03E+05	1,20E+05	1,20E+04	1,08E+11	14	1,08E+10	14
Cu	4,06E+07	1,30E+04	1,30E+03	5,28E+11	68	5,28E+10	67
Zn	1,23E+08	1,00E+03	1,00E+02	1,23E+11	16	1,23E+10	16
Pb	7,43E+06	2,00E+03	2,00E+02	1,49E+10	2	1,49E+09	2
EP for metals (m3/yr)				7,77E+11		7,88E+10	

References

Danish Environmental Protection Agency 1995
Danish Environmental Protection Agency 1996
Grüttner and Neergaard Jakobsen 1994
Grüttner *et al.* 1996
Jensen and Markussen 1993
Lassen and Hansen 1996
Lassen *et al.* 1996a
Lassen *et al.* 1996b

Finland

	Emission	EF m3/g		EP m3/yr		EP m3/yr	
	g/yr	etwc	etva	etwc	%	etva	%
Hg	0,00E+00	4,00E+03	2,00E+03	0,00E+00	0	0,00E+00	0
Cd	2,00E+06	1,20E+05	1,20E+04	2,40E+11	53	2,40E+10	53
Cu	1,10E+07	1,30E+04	1,30E+03	1,43E+11	31	1,43E+10	31
Zn	6,80E+07	1,00E+03	1,00E+02	6,80E+10	15	6,80E+09	15
Pb	2,00E+06	2,00E+03	2,00E+02	4,00E+09	1	4,00E+08	1
EP for metals (m3/yr)				4,55E+11		4,55E+10	

References
1) Eurostat (1998)

France

	Emission	EF m3/g		EP m3/yr		EP m3/yr	
	g/yr	etwc	etva	etwc	%	etva	%
Hg	0,00E+00	4,00E+03	2,00E+03	0,00E+00	0	0,00E+00	0
Cd	1,00E+06	1,20E+05	1,20E+04	1,20E+11	14	1,20E+10	14
Cu	4,70E+07	1,30E+04	1,30E+03	6,11E+11	73	6,11E+10	73
Zn	2,20E+07	1,00E+03	1,00E+02	2,20E+10	3	2,20E+09	3
Pb	4,00E+07	2,00E+03	2,00E+02	8,00E+10	10	8,00E+09	10
EP for metals (m3/yr)				8,33E+11		8,33E+10	

References
1) Eurostat (1998)

Germany

	Emission	EF m3/g		EP m3/yr		EP m3/yr	
	g/yr	etwc	etva	etwc	%	etva	%
Hg	6,00E+06	4,00E+03	2,00E+03	2,40E+10	0	1,20E+10	2
Cd	8,00E+06	1,20E+05	1,20E+04	9,60E+11	14	9,60E+10	14
Cu	2,68E+08	1,30E+04	1,30E+03	3,48E+12	51	3,48E+11	50
Zn	1,90E+09	1,00E+03	1,00E+02	1,90E+12	28	1,90E+11	27
Pb	2,47E+08	2,00E+03	2,00E+02	4,94E+11	7	4,94E+10	7
EP for metals (m3/yr)				6,86E+12		6,96E+11	

References
1) Eurostat (1998)

Greece

	Emission	EF m3/g		EP m3/yr		EP m3/yr	
	g/yr	etwc	etva	etwc	%	etva	%
Hg	1,52E+05	4,00E+03	2,00E+03	6,06E+08	0	3,03E+08	1
Cd	4,32E+05	1,20E+05	1,20E+04	5,18E+10	11	5,18E+09	11
Cu	1,93E+07	1,30E+04	1,30E+03	2,51E+11	52	2,51E+10	52
Zn	1,16E+08	1,00E+03	1,00E+02	1,16E+11	24	1,16E+10	24
Pb	2,96E+07	2,00E+03	2,00E+02	5,91E+10	12	5,91E+09	12
EP for metals (m3/yr)				4,78E+11		4,81E+10	

References
1) Based on van der Auweraert *et al.* (1996)

Ireland

	Emission	EF m3/g		EP m3/yr		EP m3/yr	
	g/yr	etwc	etva	etwc	%	etva	%
Hg		4,00E+03	2,00E+03	0,00E+00	0	0,00E+00	0
Cd	0,00E+00	1,20E+05	1,20E+04	0,00E+00	0	0,00E+00	0
Cu	2,21E+08	1,30E+04	1,30E+03	2,87E+12	71	2,87E+11	71
Zn	1,04E+09	1,00E+03	1,00E+02	1,04E+12	26	1,04E+11	26
Pb	7,50E+07	2,00E+03	2,00E+02	1,50E+11	4	1,50E+10	4
EP for metals (m3/yr)				4,07E+12		4,07E+11	

References
1) Eurostat (1998)

Italy

	Emission	EF m3/g		EP m3/yr		EP m3/yr	
	g/yr	etwc	etva	etwc	%	etva	%
Hg	2,00E+06	4,00E+03	2,00E+03	7,99E+09	0	4,00E+09	1
Cd	5,69E+06	1,20E+05	1,20E+04	6,83E+11	11	6,83E+10	11
Cu	2,54E+08	1,30E+04	1,30E+03	3,31E+12	52	3,31E+11	52
Zn	1,53E+09	1,00E+03	1,00E+02	1,53E+12	24	1,53E+11	24
Pb	3,90E+08	2,00E+03	2,00E+02	7,79E+11	12	7,79E+10	12
EP for metals (m3/yr)				6,31E+12		6,34E+11	

References
1) Based on van der Auweraert *et al.* (1996)

Luxemburg

	Emission (1)	EF m3/g		EP m3/yr		EP m3/yr	
	g/yr	etwc	etva	etwc	%	etva	%
Hg	2,16E+04	4,00E+03	2,00E+03	8,66E+07	0	4,33E+07	1
Cd	6,17E+04	1,20E+05	1,20E+04	7,40E+09	11	7,40E+08	11
Cu	2,75E+06	1,30E+04	1,30E+03	3,58E+10	52	3,58E+09	52
Zn	1,66E+07	1,00E+03	1,00E+02	1,66E+10	24	1,66E+09	24
Pb	4,22E+06	2,00E+03	2,00E+02	8,44E+09	12	8,44E+08	12
EP for metals (m3/yr)				6,83E+10		6,87E+09	

References
1) Based on van der Auweraert *et al.* (1996)

Netherlands

	Emission (1)	EF m3/g		EP m3/yr		EP m3/yr	
	g/yr	etwc	etva	etwc	%	etva	%
Hg	6,46E+05	4,00E+03	2,00E+03	2,58E+09	0	1,29E+09	1
Cd	1,84E+06	1,20E+05	1,20E+04	2,21E+11	11	2,21E+10	11
Cu	8,22E+07	1,30E+04	1,30E+03	1,07E+12	52	1,07E+11	52
Zn	4,95E+08	1,00E+03	1,00E+02	4,95E+11	24	4,95E+10	24
Pb	1,26E+08	2,00E+03	2,00E+02	2,52E+11	12	2,52E+10	12
EP for metals (m3/yr)				2,04E+12		2,05E+11	

References
1) Based on van der Auweraert *et al.* (1996)

Portugal

	Emission g/yr	EF m3/g etwc	etva	EP m3/yr etwc	%	EP m3/yr etva	%
Hg	1,00E+06	4,00E+03	2,00E+03	4,00E+09	0	2,00E+09	1
Cd	4,00E+06	1,20E+05	1,20E+04	4,80E+11	22	4,80E+10	22
Cu	1,20E+08	1,30E+04	1,30E+03	1,56E+12	72	1,56E+11	71
Zn	1,10E+08	1,00E+03	1,00E+02	1,10E+11	5	1,10E+10	5
Pb	6,00E+06	2,00E+03	2,00E+02	1,20E+10	1	1,20E+09	1
EP for metals (m3/yr)				2,17E+12		2,18E+11	

References
1) Eurostat (1998)

Spain

	Emission g/yr	EF m3/g etwc	etva	EP m3/yr etwc	%	EP m3/yr etva	%
Hg		4,00E+03	2,00E+03	0,00E+00	0	0,00E+00	0
Cd		1,20E+05	1,20E+04	0,00E+00	0	0,00E+00	0
Cu	2,20E+07	1,30E+04	1,30E+03	2,86E+11	74	2,86E+10	74
Zn	9,70E+07	1,00E+03	1,00E+02	9,70E+10	25	9,70E+09	25
Pb	2,00E+06	2,00E+03	2,00E+02	4,00E+09	1	4,00E+08	1
EP for metals (m3/yr)				3,87E+11		3,87E+10	

References
1) Eurostat (1998)

Sweden

	Emission g/yr	EF m3/g etwc	etva	EP m3/yr etwc	%	EP m3/yr etva	%
Hg	0,00E+00	4,00E+03	2,00E+03	0,00E+00	0	0,00E+00	0
Cd	0,00E+00	1,20E+05	1,20E+04	0,00E+00	0	0,00E+00	0
Cu	3,90E+07	1,30E+04	1,30E+03	5,07E+11	71	5,07E+10	71
Zn	1,83E+08	1,00E+03	1,00E+02	1,83E+11	26	1,83E+10	26
Pb	1,10E+07	2,00E+03	2,00E+02	2,20E+10	3	2,20E+09	3
EP for metals (m3/yr)				7,12E+11		7,12E+10	

References
1) Eurostat (1998)

UK

	Emission g/yr	EF m3/g etwc	etva	EP m3/yr etwc	%	EP m3/yr etva	%
Hg	2,00E+06	4,00E+03	2,00E+03	8,00E+09	0	4,00E+09	0
Cd	1,50E+07	1,20E+05	1,20E+04	1,80E+12	12	1,80E+11	12
Cu	6,78E+08	1,30E+04	1,30E+03	8,81E+12	59	8,81E+11	59
Zn	3,35E+09	1,00E+03	1,00E+02	3,35E+12	22	3,35E+11	22
Pb	4,97E+08	2,00E+03	2,00E+02	9,94E+11	7	9,94E+10	7
EP for metals (m3/yr)				1,50E+13		1,50E+12	

References
1) Eurostat (1998)

EU-15

	Emission g/yr	EF m3/g etwc	etva	EP m3/yr etwc	%	EP m3/yr etva	%
Hg	1,29E+07	4,00E+03	2,00E+03	5,17E+10	0	2,59E+10	1
Cd	4,00E+07	1,20E+05	1,20E+04	4,80E+12	12	4,80E+11	11
Cu	1,86E+09	1,30E+04	1,30E+03	2,41E+13	58	2,41E+12	58
Zn	9,60E+09	1,00E+03	1,00E+02	9,60E+12	23	9,60E+11	23
Pb	1,54E+09	2,00E+03	2,00E+02	3,08E+12	7	3,08E+11	7
EP for metals (m3/yr)				4,16E+13		4,19E+12	

Appendix B.1 Emissions to the aquatic environment, organic substances - Denmark

Based on van der Auweraert ***et al***. (1996)

Substance		NL (4) Emission g/yr	DK Emission g/yr	EF chron. etwc m3/g	EF acute etwa m3/g	Ref. for EF	EP chron. etwc m3/yr	%	EP acute etwa m3/yr	%
Aliphatic compounds		5,55E+09	2,47E+09							
Aromatics		1,21E+09	5,38E+08							
	Benzene	1,65E+08	7,33E+07	20	50	2	1,47E+09	1	3,67E+09	19
	Benz(a)pyrene	3,34E+06	1,48E+06							
	Ethylbenzene	3,87E+00	1,72E+00	4	10	2	6,88E+00	0	1,72E+01	0
	Fluoranthene	1,58E+07	7,02E+06							
	Phthalates	1,13E+05	5,02E+04							
	Isopropylbenzene	3,99E+05	1,77E+05	2,9	7,1	1	5,14E+05	0	1,26E+06	0
	PAH (6 comp.)	1,85E+07	8,22E+06	15240	1524	3	1,25E+11	98	1,25E+10	66
	Toluene	4,13E+08	1,84E+08	4	10	1	7,34E+08	1	1,84E+09	10
	Xylenes	1,65E+08	7,33E+07	4	10	1	2,93E+08	0	7,33E+08	4
Halogenated org. Compounds		2,98E+07	1,32E+07							
Aliphatics		2,85E+07	1,27E+07							
	1,2-Dichloroethane	4,17E+05	1,85E+05	100	10	1	1,85E+07	0	1,85E+06	0
	Hexachlorbutadiene	0,00E+00	0,00E+00	2000	1000	2				
	Hexachlorcyclohexane	6,84E+03	3,04E+03	100000	10000	2	3,04E+08	0	3,04E+07	0
	Tetrachlorethylene	8,20E+04	3,64E+04	20	10	1	7,29E+05	0	3,64E+05	0
	Tetrachlormethane	3,46E+05	1,54E+05							
	1,1,1-Trichloroethane	5,85E+04	2,60E+04	2	1	2	5,20E+04	0	2,60E+04	0
	Trichloroethene	1,56E+05	6,93E+04	20	10	2	1,39E+06	0	6,93E+05	0
	Trichloromethane	2,36E+05	1,05E+05							
	Vinylchloride	1,91E+03	8,49E+02							
Aromatics		1,24E+06	5,51E+05							
	Chlorobenzene	1,00E+05	4,44E+04	200	100	2	8,89E+06	0	4,44E+06	0
	DRINS	3,00E+03	1,33E+03							
	Hexachlorobenzene	1,41E+04	6,26E+03	20000	10000	2	1,25E+08	0	6,26E+07	0
	PCB	8,22E+02	3,65E+02	100000	10000	2	3,65E+07	0	3,65E+06	0
	Pentachlorophenol	1,14E+04	5,07E+03	1000	100	2	5,07E+06	0	5,07E+05	0
	Thichlorobenzene	9,14E+02	4,06E+02	2000	1000	2	8,12E+05	0	4,06E+05	0
							1,28E+11		1,89E+10	

References
1. Hauschild *et al.* (1998)
2. Danish Ministry of Environment.1996: Statutory order No. 921.
3. van der Auweraert *et al.* (1996)

Appendix B.2: Emissions to the aquatic environment, organic substances - EU-15

Based on van der Auweraert ***et al.*** (1996)

Substance		NL Emission g/yr	EU-15 Emission g/yr	EF chron. etwc m3/g	EF acute etwa m3/g	Ref. for EF	EP chron. etwc m3/yr	%	EP acute etwa m3/yr	%
Aliphatic compounds		5,55E+09	1,24E+11							
Aromatics		1,21E+09	2,71E+10							
	Benzene	1,65E+08	3,69E+09	20	50	2	7,38E+10	1	1,85E+11	19
	Benz(a)pyrene	3,34E+06	7,47E+07							
	Ethylbenzene	3,87E+00	8,66E+01	4	10	2	3,46E+02	0	8,66E+02	0
	Fluoranthene	1,58E+07	3,54E+08							
	Phthalates	1,13E+05	2,53E+06							
	Isopropylbenzene	3,99E+05	8,93E+06	2,9	7,1	1	2,59E+07	0	6,34E+07	0
	PAH (6 comp.)	1,85E+07	4,14E+08	15240	1524	3	6,31E+12	98	6,31E+11	66
	Toluene	4,13E+08	9,24E+09	4	10	1	3,70E+10	1	9,24E+10	10
	Xylenes	1,65E+08	3,69E+09	4	10	1	1,48E+10	0	3,69E+10	4
Halogenated org. Compounds		2,98E+07	6,67E+08							
Aliphatics		2,85E+07	6,38E+08							
	1,2-Dichloroethane	4,17E+05	9,33E+06	100	10	1	9,33E+08	0	9,33E+07	0
	Hexachlorbutadiene	0,00E+00	0,00E+00	2000	1000	2				
	Hexachlorcyclohexane	6,84E+03	1,53E+05	100000	10000	2	1,53E+10	0	1,53E+09	0
	Tetrachlorethylene	8,20E+04	1,83E+06	20	10	1	3,67E+07	0	1,83E+07	0
	Tetrachlormethane	3,46E+05	7,74E+06							
	1,1,1-Trichloroethane	5,85E+04	1,31E+06	2	1	2	2,62E+06	0	1,31E+06	0
	Trichloroethene	1,56E+05	3,49E+06	20	10	2	6,98E+07	0	3,49E+07	0
	Trichloromethane	2,36E+05	5,28E+06							
	Vinylchloride	1,91E+03	4,27E+04							
Aromatics		1,24E+06	2,77E+07							
	Chlorobenzene	1,00E+05	2,24E+06	200	100	2	4,48E+08	0	2,24E+08	0
	DRINS	3,00E+03	6,71E+04							
	Hexachlorobenzene	1,41E+04	3,16E+05	20000	10000	2	6,31E+09	0	3,16E+09	0
	PCB	8,22E+02	1,84E+04	100000	10000	2	1,84E+09	0	1,84E+08	0
	Pentachlorophenol	1,14E+04	2,55E+05	1000	100	2	2,55E+08	0	2,55E+07	0
	Thichlorobenzene	9,14E+02	2,05E+04	2000	1000	2	4,09E+07	0	2,05E+07	0
							6,46E+12		9,50E+11	

Appendix C: Emissions to the aquatic environment, atmospheric deposition

		DK (80,20)		EU-15		DK(80, 20)		EU15	
		EP water m3/yr	%	EP water m3/yr	%	EP soil m3/yr	%	EP soil m3/yr	%
Substance	Approx.								
Cd		2,84E+10	21	2,50E+12	20	2,13E+06	4	1,87E+08	1
As		2,82E+08	0	1,07E+11	1	2,00E+05	0	7,62E+07	0
Cr(VI)		4,53E+08	0	7,35E+10	1	3,49E+04	0	5,66E+06	0
Hg		3,03E+10	22	5,58E+11	4	4,02E+07	68	7,40E+08	2
Ni		2,87E+09	2	2,72E+11	2	1,10E+06	2	1,05E+08	0
Pb		1,58E+10	12	2,83E+12	23	3,95E+05	1	7,07E+07	0
Se		5,28E+08	0	1,28E+12	10	1,40E+07	24	3,39E+10	96
Cu		2,64E+10	19	1,40E+12	11	2,11E+05	0	1,12E+07	0
Zn		2,37E+10	17	1,37E+12	11	5,91E+05	1	3,43E+07	0
Formaldehyde									
Benzene									
Phenol									
Styrene									
Toluene									
Xylenes									
PAH									
Fluoranthen	0,05								
Benzo(b)fluoranthen	0,05								
Benzo(k)fluoranthen	0,05								
Benzo(a)pyren	1								
Benzo(g,h,i)perylene	0,02								
Indino(1,2,3-c,d)pyren	0,1								
PAH-eq. (benzo(a)pyren)									
Dioxin		7,84E+09	6	2,04E+12	16	1,68E+05	0	4,38E+07	0
PCP									
Hexachlorbenzene (HCB)									
Tetrachloromethane (TCM)									
Trichloroethylene (TRI)									
Tetrachloroethylene (PER)									
Trichlorobenzene (TCB)									
Trichloroethane (TCE)									
Hexachlorohexane (HCH)									
Chlorbenzenes									
Vinylchloride									
		1,37E+11		1,24E+13		5,90E+07		3,51E+10	

Appendix D: Emissions to the terrestrial environment, pesticides

Equivalency factor based on the principles used in Hauschild ***et al***. (1998)

	A.i. (1,2)	Area (1,3)	Applikat. (1)	Exposure	Factor: P		EP (m3/yr)
	Tonnes	ha	times		(ha/tonsxapp.)		
Fung (F)	892	881580	0,53	0,15	78,57131166		
Herb (H)	2685	2966656	1,28	0,15	212,1407642		
Insek (I)	95	493616	0,58	0,15	452,0483368		
DK	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	892	79	70085,61	500	10000	3,504E+11	
Herbicides	2685	212	569597,952	500	10000	2,848E+12	
Insecticides	95	452	42944,592	500	10000	2,147E+11	
SUM							3,413E+12
AU	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	1410	79	110785,5494	500	10000	5,539E+11	
Herbicides	1607	212	340910,2081	500	10000	1,705E+12	
Insecticides	123	452	55601,94543	500	10000	2,780E+11	
SUM							2,536E+12
BE	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	2659	79	208921,1177	500	10000	1,045E+12	
Herbicides	6240	212	1323758,369	500	10000	6,619E+12	
Insecticides	1140	452	515335,104	500	10000	2,577E+12	
SUM							1,024E+13
FI	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	114	79	8957,129529	500	10000	4,479E+10	
Herbicides	791	212	167803,3445	500	10000	8,390E+11	
Insecticides	57	452	25766,7552	500	10000	1,288E+11	
SUM							1,013E+12
F	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	45578	79	3581123,243	500	10000	1,791E+13	
Herbicides	27416	212	5816051,193	500	10000	2,908E+13	
Insecticides	8346	452	3772795,419	500	10000	1,886E+13	
SUM							6,585E+13
GE	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	9652	79	758370,3001	500	10000	3,792E+12	
Herbicides	16065	212	3408041,378	500	10000	1,704E+13	
Insecticides	5090	452	2300926,035	500	10000	1,150E+13	
SUM							3,234E+13
GR	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	3072	79	241371,0694	500	10000	1,207E+12	
Herbicides	2131	212	452071,9686	500	10000	2,260E+12	
Insecticides	2529	452	1143230,244	500	10000	5,716E+12	
SUM							9,183E+12
IE	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	850	79	66785,61491	500	10000	3,339E+11	
Herbicides	1426	212	302512,7298	500	10000	1,513E+12	
Insecticides	89	452	40232,30198	500	10000	2,012E+11	

	A.i. (1,2)	Area (1,3)	Applikat. (1)	Exposure	Factor: P		EP (m3/yr)
	Tonnes	ha	times		(ha/tonsxapp.)		
SUM							2,048E+12
I	Tonnes	P	ha x app	m3/ha	PNEC fak	EP (m3/yr)	
Fungicides	106121	79	8338066,165	500	10000	4,169E+13	
Herbicides	26671	212	5658006,323	500	10000	2,829E+13	
Insecticides	34619	452	15649461,37	500	10000	7,825E+13	
SUM							1,482E+14
LX (3)	Tonnes	P	ha x app	m3/ha	PNEC fak	EP (m3/yr)	
Fungicides	113	79	8878,558217	500	10000	4,439E+10	
Herbicides	121	212	25669,03247	500	10000	1,283E+11	
Insecticides	10	452	4520,483368	500	10000	2,260E+10	
SUM							1,953E+11
NL	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	3990	79	313499,5335	500	10000	1,567E+12	
Herbicides	3070	212	651272,1462	500	10000	3,256E+12	
Insecticides	2871	452	1297830,775	500	10000	6,489E+12	
SUM							1,131E+13
PT	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	9078	79	713270,3672	500	10000	3,566E+12	
Herbicides	1660	212	352153,6686	500	10000	1,761E+12	
Insecticides	667	452	301516,2407	500	10000	1,508E+12	
SUM							6,835E+12
ES	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	9021	79	708791,8025	500	10000	3,544E+12	
Herbicides	6326	212	1342002,475	500	10000	6,710E+12	
Insecticides	9538	452	4311637,037	500	10000	2,156E+13	
SUM							3,181E+13
SE	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	200	79	15714,26233	500	10000	7,857E+10	
Herbicides	975	212	206837,2451	500	10000	1,034E+12	
Insecticides	17	452	7684,821726	500	10000	3,842E+10	
SUM							1,151E+12
UK	Tonnes	P	ha x app	m3/ha	PNEC fac	EP (m3/yr)	
Fungicides	6441	79	506077,8184	500	10000	2,530E+12	
Herbicides	22659	212	4806897,577	500	10000	2,403E+13	
Insecticides	1957	452	884658,5952	500	10000	4,423E+12	
SUM							3,099E+13
EU15							
Fungicides	199191	79	15650698,14	500	10000	7,825E+13	
Herbicides	119843	212	25423585,61	500	10000	1,271E+14	
Insecticides	67148	452	30354141,72	500	10000	1,518E+14	
SUM						3,571E+14	
Sum						3,287E+14	3,57142E+14

References
1. DEPA (1997a)
2. EEA (1998)
3. OECD (1997)

Appendix E.1: Emissions to the terrestrial environment, sewage sludge applied in agriculture - Denmark

Production in 1994 (3)	On soil	On soil
Ton dry weight /yr	%	Tonnes/yr
231000	56	129360

Substance	Concentration mg/kg dw	Emission g/yr	EF (1) etsc m3/g	EP etsc m3/yr	EP%
Acenaphthene	0,0364	4709		0	0
Fluorene	0,0707	9146		0	0
Phenanthrene	0,3066	39662		0	0
Fluoranthene	0,32289	41769		0	0
Pyrene	0,3095	40037		0	0
Benzofluoranthene	0,298	38549		0	0
Benzo(a)pyrene	0,15239	19713		0	0
Benzo(ghi)perylene	0,1177	15226		0	0
Indeno(1,2,3-cd)pyrene	0,067	8667		0	0
Sum PAH (2)	1,68118	217477	1,0	217477	1
PCB 28	0,0044	569		0	0
PCB 52	0,00901	1166		0	0
PCB 101	0,00768	993		0	0
PCB 118	0,00575	744		0	0
PCB 138	0,00708	916		0	0
PCB 153	0,00864	1118		0	0
PCB 180	0,00577	746		0	0
Sum PCB	0,04833	6252	100,0	625197	3
Butylbenzylphthalate	0,1751	22651		0	0
Chloroform	0,00081	105	25,0	2620	0
Di(ethyhexyl)phthalate	37,86	4897570		0	0
Dichlorobenezene	0,01091	1411	0,5	692	0
Di-n-butylphthalate	3,8832	502331		0	0
Di-n-octylphthalate	0,60785	78631		0	0
Nonylphenol + 1-2EO	15,176	1963167		0	0
tetrachloroethylene	0,01759	2275	1,1	2503	0
Trichlorothylene	0,0029	375		0	0
LAS (2)	2667	345003120	0,04	13800125	73
Toluene	0,02069	2676	1,0	2596	0
Dioxine (2,3,7,8-TCDD)	1,00E-05	1	15000,0	19404	0
As	3,71	479926	0,3	158375	1
Cd	1,67	216031	2,2	475269	3
Cr	35,42	4581931	0,01	45819	0
Cu	287,34	37170302	0,02	743406	4
Pb	72,8	9417408	0,01	94174	0
Hg	2,4	310464	5,3	1645459	9
Ni	29,78	3852341	0,1	269664	1
Zn	887,37	114790183	0,01	803531	4
Sum				1,89E+07	

References
1. Hauschild & Wenzel (1998).
2. DEPA (1995).
3. DEPA (1998).

Appendix E.2: Emissions to the terrestrial environment, sewage sludge applied in agriculture - EU-15

Production in 1994 (3,4)	On soil	On soil
Ton dry weight /yr	%	Tonnes/yr
12497276	29	3661415

Substance	Concentration mg/kg dw	Emission g/yr	EF (1) etsc m3/g	EP etsc m3/yr	EP%
Acenaphthene	0,0364	133276		0	0
Fluorene	0,0707	258862		0	0
Phenanthrene	0,3066	1122590		0	0
Fluoranthene	0,32289	1182234		0	0
Pyrene	0,3095	1133208		0	0
Benzofluoranthene	0,298	1091102		0	0
Benzo(a)pyrene	0,15239	557963		0	0
Benzo(ghi)perylene	0,1177	430949		0	0
Indeno(1,2,3-cd)pyrene	0,067	245315		0	0
Sum PAH (2)	1,68118	6155498	1,0	6155498	1
PCB 28	0,0044	16110		0	0
PCB 52	0,00901	32989		0	0
PCB 101	0,00768	28120		0	0
PCB 118	0,00575	21053		0	0
PCB 138	0,00708	25923		0	0
PCB 153	0,00864	31635		0	0
PCB 180	0,00577	21126		0	0
Sum PCB	0,04833	176956	100,0	17695619	3
Butylbenzylphthalate	0,1751	641114		0	0
Chloroform	0,00081	2966	25,0	74144	0
Di(ethyhexyl)phthalate	37,86	138621176		0	0
Dichlorobenezene	0,01091	39946	0,5	19574	0
Di-n-butylphthalate	3,8832	14218007		0	0
Di-n-octylphthalate	0,60785	2225591		0	0
Nonylphenol + 1-2EO	15,176	55565636		0	0
tetrachloroethylene	0,01759	64404	1,1	70845	0
Trichlorothylene	0,0029	10618		0	0
LAS (2)	2667	9764994125	0,04	390599765	73
Toluene	0,02069	75755	1,0	73482	0
Dioxine (2,3,7,8-TCDD)	1,00E-05	37	15000,0	549212	0
As	3,71	13583850	0,3	4482671	1
Cd	1,67	6114563	2,2	13452039	3
Cr	35,42	129687324	0,01	1296873	0
Cu	287,34	1052071021	0,02	21041420	4
Pb	72,8	266551021	0,01	2665510	0
Hg	2,4	8787396	5,3	46573200	9
Ni	29,78	109036942	0,1	7632586	1
Zn	887,37	3249029935	0,01	22743210	4
SUM				5,35E+08	

References
1. Hauschild *et al.* (1998)
2. DEPA (1995).
3. DEPA (1998).

11 Calculation of weighting factors

Niels Juul Busch, Rambøll

11.1 Summary

The aim of this chapter has been to calculate new weighting factors for a broad range of impact categories for Denmark, European and global level. The method applied for calculating the weighting factors is based on the environmental regulation of substances, impact categories etc. Hence, it is the same methodology as the one used in the EDIP study (Hauschild & Wenzel, 1998).

However, weighting factors based on regulation that will lead to full phase out of the substances within the target period will tend to result in very high numbers or infinite. This is in particular the case for Ozone Depletion. In these cases the weighting factors are indicated by the sign for infinity (∝).

Table 11-1 summarises the calculated new weighting factors for the period 1994-2004 and the similar weighting factors calculated in the EDIP study for the period 1990-2000.

Table 11-1
Summary of calculated weighted factors (WF) and comparison with EDIP factors. WFs at global scale have only been calculated for Global Warming, Ozone depletion and Photochemical Ozone, due to the fact that regulation of the other effect categories have not been implemented at global level.

Impact category	New weighting factors 1994 - 2004	EDIP weighting factors, 1990 – 2000
Global Warming, Denmark	1.12	1.3
Global Warming, EU	1.05	-
Global Warming, World, Industrialised countries	1.11	-
Ozone Depletion, Denmark	∞	23
Ozone Depletion, EU	2.46	-
Ozone Depletion, World, Industrialised Countries	63	-
Ozone Depletion, World, Develop. Countries	4.4	-
Photochemical Ozone, Denmark	1.26	1.2
Photochemical Ozone, EU	1.33	-
Photochemical Ozone, World	1.00	-
Acidification, Denmark	1.34	1.3
Acidification, EU	1.27	-
Nutrient enrichment, Denmark	1.31	1.2
Nutrient enrichment, EU	1.22	-
Ecotoxicity, Denmark, Aquatic chronic	1.67	2.6
Ecotoxicity, Denmark, Aquatic acute	1.73	2.6
Ecotoxicity, Denmark, Terrestrial	1.56	1.9
Ecotoxicity, EU, Aquatic chronic	1.18	-
Ecotoxicity, EU, Aquatic acute	1.11	-
Ecotoxicity, EU, Terrestrial	1.00	-
Human toxicity, Denmark, Air	1.11	1.1
Human toxicity, Denmark, Water	1.02	2.9
Human toxicity, Denmark, Soil	1.00	2.7
Human toxicity, EU, Air	1.06	-
Human toxicity, EU, Water	1.30	-
Human toxicity, EU, Soil	1.23	-

It should be emphasised that there is not much regulation on global level of the impact categories addressed in EDIP, except for global warming, ozone depletion and to a limited extent - photochemical ozone. Calculation of a weighting factor thus requires a close examination of reduction targets in all regions of the World - a task that is outside the scope of the present study. Accordingly, global weighting factors have only been calculated for the impact categories that are global in their scale.

Furthermore, it should be mentioned that EU-regulation of substances that contribute to, in particular the ecotoxicity and human toxicity impact categories, is very rudimentary. The reason for this is that EU regulation can be seen as supplementary to national regulations. A precise weighting factor for EU thus requires that all national regulations and reduction targets are examined in sufficient detail. It has been tried to obtain this information from the national ministries of environment, but only very scattered information was found. The EU weighting factors for human toxicity and ecotoxicity are therefore most probably underestimated and should be used with some reservations.

11.2 Definition of "weighting" procedures

According to the ISO standard, ISO 14042 on Life Cycle Impact Assessment (LCIA) "weighting" is defined in the following way (ISO 2000):

"Weighting is conversion of indicator results or normalised results by using numerical factors. Weighting is an optional element with two possible procedures:

- To convert the indicator results or normalised results with selected factors
- To possible aggregate these converted indicator results or normalised result across impact categories, i.e. scoring.

The application and use of weighting methods shall be consistent with the goal and scope of the LCA study and be fully transparent. Different people, organisations and societies may have different values; therefore it is possible that different parties will reach different weighting results based on the same indicator results. In the LCA study it may be desirable to use different weighting methods and to conduct sensitivity analysis to assess the consequences on the life cycle impact assessment results of different value-choices and weighting methods.

All weighting methods and operations used shall be documented to provide transparency. Data and Life Cycle Impact Assessment results reached prior to weighting should be made available together with the weighting results. This ensures that:

- Trade-offs and other information remain available to decision makers and others, and
- Users can appreciate the full extent and ramification of the results."

11.3 Scope of weighting procedure

Before choosing a weighting method and procedure to be applied for a certain LCA, it is important to take a number of different aspects into consideration:

- Does the method comply with the objectives of the LCA?
- Is the method developed to a stage, which makes it applicable to the LCA?
- Will sufficient and reliable data be available for calculating the weighting factors?

11.4 Different weighting methods

A number of different methods have been discussed at national and international level, e.g.:

- Expert based/quality based weighting systems.
- Weighting systems based on an eco-scarcity/carrying capacity approach.
- Weighting system based on political priorities within different impact categories.

These methods have been developed to different levels and have different advantages and disadvantages.

In this project - as in the Original EDIP97 - it has been decided to apply a weighting method based on “political targets and goals” established for the selected impact categories. This is due to the relatively advanced state of the method and the availability of sufficient and reliable data and information for most impact categories.

For all impact categories, regardless of their geographical scale, the weighting factors are based on politically determined reduction targets in Denmark, the EU or at the global level. These reduction targets are taken as an expression of the importance assigned to the impact category in those parts of the world. If important stakeholders for a study come from different parts of the world and it can be expected that they will have environmental priorities that differ significantly from the priorities expressed through these reduction targets, it may be relevant to derive weighting factors more in line with these priorities e.g. by basing them on political reduction targets in the important stakeholders’ part of the world.

11.4.1 Weighting procedure based on political goals

The procedure for applying and using weighting in this project consist of the following steps:

- Determination of actual emission in reference year
- Determination of targeted emissions in target year
- Calculation of weighting factor.

In this project 1994 has been chosen as “reference year” and 2004 as “target year”. The impact potential is either regulated directly by the political priorities through legislation, actions plans etc. or indirectly through regulation of the emission of the substances that determines the impact category.

For each impact category x, the weighting factor (WF) is thus defined as follows:

$$\mathrm{WF}(x) = \frac{\text{Actual impact potential for x in reference year (1994)}}{\text{Target impact potential for x in target year (2004)}}$$

As the actual political targets for reducing certain pollutants in the different countries seldom are related to the target year selected for this project, it has been necessary to interpolate or extrapolate the data, so that the weighting factors for all impact categories relate to year 2004.

11.4.2 Environmental impact categories

Weighting factors have been calculated for the following impact categories, corresponding to those categories for which normalisation references have been calculated in the previous chapters:

- Global warming
- Stratospheric ozone depletion
- Photochemical ozone formation
- Acidification
- Nutrient enrichment
- Ecotoxicity

- Human toxicity.

11.4.3 Geographic scope

In this project it has been decided to establish weighting factors for the following geographical areas:

- Denmark
- European Union (EU-15)
- The World

For Denmark the calculation of weighting factors will be an update of the existing weighting factors developed through the EDIP project (Hauschild & Wenzel, 1998). Calculation of weighting factors for EU is a natural extension of the weighting factors for Denmark, which make the method valid for a larger market, e.g. Europe. It should be mentioned that weighting factors have not been calculated for each of the individual EU member states for the following reasons:

- The environmental regulation differs from country to country.
- The environmental legislation of the 15 member states is being harmonised, and should in the long run refer to the same standards.

This means that the weighting factors developed for EU only represent a part of the environmental targets valid for the individual countries, namely that part for which common EU goals have been adopted. It has been suggested to make this method applicable at worldwide level. However, this is only possible for few impact categories, as worldwide regulation only exist for global warming, ozone depleting substances, and substances contributing to formation of photochemical ozone.

11.4.4 Calculation of weighting factors

In the following the weighting factors for the individual impact categories have been calculated, together with brief explanation of the data on which the weighting factors are based.

11.5 Global warming

At the global level the greenhouse gasses are regulated according to the ***Kyoto Protocol*** (UN 1997), except for those greenhouse gasses that are regulated through other international agreements.

In principle the ***Kyoto Protocol*** regulates the following greenhouse gasses:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFC’s)
- Perfluorocarbons (PFC’s)
- Sulphur hexafluoride (SF_6)

Ozone Depleting Substances (ODS) are global warming gasses as well, but as they are regulated according to the ***Montreal Protocol*** (UNEP 1987), they are not regulated by ***The Kyoto Protocol***. However, as the ODS are contributing to the global warming the consumption of the substances – which is considered corresponding to the emission and thereby the impact on the global warming the equivalent data of the consumption is included where appropriate. Detailed information on the regulation of ODS's according to the Montreal Protocol is dealt with in section 11.6

At the regional level the greenhouse gasses are regulated according to different agreements. Some of the gasses, VOC's and CO, are regulated according to the ***Convention on Long Range Transboundary Air Pollution*** (UN-ECE 1979), while others are regulated according to EU resolutions.

At the national level in Denmark the greenhouse gasses were earlier regulated according to various ministerial executive regulations and the governmental action plan, Energy 21 (Energistyrelsen 1996), but now (May 2002) as the Kyoto Protocol has been ratified by countries accounting in total for nearly 55% of the total carbon dioxide emissions for 1990, which is the criteria for implementation of the Protocol, this will be the guiding regulation for Denmark as well.

11.5.1 Weighting factors for global warming at global level

According to the ***Kyoto Protocol*** (UN 1997) the Annex-1 parties (industrialised countries) shall reduce their anthropogenic carbon dioxide equivalent emissions with at least 5% below 1990 level in the period 2008 to 2012. It is further stated that each of the Annex-1 parties shall have made demonstrable progress in achieving its commitments under the Protocol by 2005.

For most of the Annex-1 parties, including EU as a whole, the demand is to reduce the emission by 8%. Some individual countries have targeted a reduction by up to 28%, others have to reduce emission by 6-7%, and some countries will even be allowed to increase their emission of greenhouse gasses up to a level of 10% more than the baseline level in 1990.

According to the reporting by the parties to the ***Kyoto Protocol*** the "aggregated CO_2 equivalent emissions, including CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 emissions" from the Annex-1 parties in 1994 is reported to be 16.837 billion tonnes CO_2-eq (UN/FCCC 2003, (On-line searchable database of GHG inventory data). With a reduction target for 2008-2012 (2010) on 5% (or 2.5% for the present reference period) the interpolated emission for 2004 should be 16.416 billion tonnes CO_2-eq.

Although USA and the Russian Federation have yet not ratified the Kyoto Protocol, their emissions of global warming gases are included in these calculations.

The total emission of global warming gases (excluding ODS) for both Article 1- and Non Article 1 countries in 1994 has been estimated to 19.548 billion tonnes CO2-eq (UN/FCCC 2003).

It should be noticed that the ***Kyoto Protocol*** until now only regulates the greenhouse gas emissions from industrialised countries and that there are different reduction targets for the individual industrialised countries at both regional and national level.

The ozone depleting substances are divided into different chemical groups (CFC's, Halons, Methyl chloroform and HCFC's) that have different impact on the ozone layer as well as on the global warming. The regulation of the substances differs for the different groups of substances and for the two different categories of countries ("Article 5 countries", being the developing countries and the "Non Article 5 countries" being the industrialised countries, including countries under economic transition). In Table 11-2 below the background data for calculating the CO_2-eq of the ozone depleting substances have been summarised.

Table 11-2
Calculated CO_2-eq for ozone depleting substances, global level.

Article 5 parties, 1994	Consumption, metric tonnes 1994	GWP 100	Tonnes CO2-eq, 1994	Reduction target, 1996-2005	Emission 2004, Tonnes CO2-eq
A I CFC-11	67,382	4600	309,957,200	50%	154,978,600
A I CFC-12	97,726	10600	1,035,895,600	50%	517,947,800
A I CFC-113	9,828	6000	58,968,000	50%	29,484,000
A I CFC-114	528	9800	5,174,400	50%	2,587,200
A I CFC-115	919	7200	6,616,800	50%	3,308,400
A II HALON-1211	8,054	6900	55,572,600	50%	27,786,300
A II HALON-1301	865	1300	1,124,500	50%	562,250
A II HALON-2402	6	6900	41,400	50%	20,700
B II Carbon Tetrachloride	145,514	1800			
B III Methyl Chloroform	35,655	140	4,991,700	30%	3,494,190
C I HCFC-21	13	?			
C I HCFC-22	77,134	1700	131,127,800	0%	
C I HCFC-123	460	120	55,200	0%	
C I HCFC-124	746	620	462,520	0%	
C I HCFC-141	4,281	700	2,996,700	0%	
C I HCFC-142	242	2400	580,800	0%	
C I HCFC-225	527	400	210,800	0%	
E I Methyl Bromide	13,121	5	65,605	20%	52,484
Total			1,613,841,625		740,221,924
Non-article 5 parties, 1994	Consumtion, metric tonnes 1994	GWP 100	Tonnes CO2-eq, 1994	Reduction target, 1996-2005	Emission 2004, Tonnes CO2-eq
A I: CFC-11	47,479	4600	218,403,400	100%	0
A I: CFC-12	117,948	10600	1,250,248,800	100%	0
A I: CFC-113	76,752	6000	460,512,000	100%	0
A I: CFC-114	30,032	9800	294,313,600	100%	0
A I: CFC-115	7,415	7200	53,388,000	100%	0
A II: HALON-1211	145	6900	1,000,500	100%	0
A II: HALON-1301	25	1300	32,500	100%	0
A II: HALON-2402	225	6900	1,552,500	100%	0
B II: Carbon Tetrachloride	319,309	1800			
B III: Methyl Chloroform	246,884	140	34,563,760	100%	0
C I: HCFC-21	322	?		35%	
C I: HCFC-22	291,804	1700	496,066,800	35%	322,443,420
C I: HCFC-123	1,824	120	218,880	35%	142,272
C I: HCFC-124	2,025	620	1,255,500	35%	816,075
C I: HCFC-141	67,940	700	47,558,000	35%	30,912,700
C I: HCFC-142	45,208	2400	108,499,200	35%	70,524,480
C I: HCFC-225	0	400	0	35%	0
E I: Methyl Bromide	28,306	5	141,530	100%	0
Total			2,967,754,970		424,838,947

Carbon tetrachloride is not included in the calculations as it is primarily used as feedstock for other ODS substances.

Table 11-3 below summarises the calculations of global warming gases, ODS as well as non-ODS, divided on the Article 1 and Non Article 1 countries.

Table 11-3
Summary of calculation of emissions of global warming gases

	1994 emissions, tonnes CO_2-eq	2004 emissions
Article 1 countries, GWG	16,836,999,000	16,416,074,025
Article 1 countries, ODS	2,967,754,970	424,838,947
Non Article 1 countries, GWG	2,711,370,000	2,711,370,000
Non Article 1 countries, ODS	1,613,841,625	740,221,924
Total Global	22,516,123,970	20,292,504,896

Based on the combined figures for CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 and the ozone depleting substances accounted for in Table 11-2 the weighting factor for global warming at global level will be:

$$WF_{\text{GWP, World}} = \frac{22.516 \text{ billion tonnes } CO_2 \text{ - eq}}{20.292 \text{ billion tonnes } CO_2 \text{ - eq}} = \text{approx.} 1.11$$

11.5.2 Weighting factors for global warming at EU level

During the negotiations of the ***Kyoto Protocol*** the EU proposed more drastic reductions of the greenhouse gasses within its own geographical area than was finally agreed upon for the Annex-1 parties in general. Hence, in its implementation of the regulation of the greenhouse gasses the Environment Ministers Council of EU has agreed upon the following reduction targets for the individual EU countries (EU 1998):

Luxembourg	28%
Germany	21%
Denmark	21%
Austria	13%
UK	12.5%
Belgium	7.5%
Italy	6.5%
Netherlands	6%
France	0%
Finland	0%
Portugal	-27%
Greece	-25%
Spain	-15%
Ireland	-13%
Sweden	-4%

As it appears from the table the five last mentioned countries are allowed to increase their CO_2-eq emission. For the EU as a whole the reduction target will be 8% in 2010 based on the 1990 emission level.

According to the reporting to the ***Kyoto Protocol*** the “aggregated CO_2 equivalent emissions” in 1994 the emission is reported to 3.972 billion tonnes CO_2-eq (UN/FCCC 2003). With a reduction target for 2008-2012 (2010) on

8% (4% for the reference period) the interpolated emission for 2004 should be about 3.813 billion tonnes CO_2-eq.

Among the ozone depleting substances only HCFC and methyl chloroform is relevant for EU. The remaining groups of ozone depleting substances are supposed to be phased out so quickly that they are not included in the calculation. In Table 11-4 below the background data for calculating the CO_2-eq of the global warming and the ozone depleting substances have been summarised.

Table 11-4
Calculated CO_2-eq for ozone depleting substances as well as other green house gases (GHG) for EU.

	Methyl chloroform	HCFC	GHG	Total
EU Consumption, 1994, tonnes	46 000	73 000		
Emission 1994, in million CO_2-eq	5	73	3972	4050
Reduction target, base & target year	-100% 1996	-35% 1991 / 2005	4%	
Emission 2004, in million CO_2-eq	0	28	3813	3841

Based on these figures the weighting factor for GWP at EU level will be:

$$\mathrm{WF}_{\mathrm{GWP,EU}} = \frac{4.050 \text{ billion tonnes } CO_2 \text{ - eq}}{3.841 \text{ billion tonnes } CO_2 \text{ - eq}} = \text{approx. } 1.05.$$

This is a general weighting factor for EU as whole, but as it appears from the table above different targets have been set for the individual countries.

11.5.3 Weighting factors for global warming for Denmark

As mentioned earlier, the EDIP97 weighting factors for all impact categories are based on political reduction targets for Denmark or Europe regardless the geographical scale of the impact. The Danish regulation of greenhouse gasses is based on the EU regulation.

According to the Kyoto Protocol and the internal EU agreement the aggregated CO_2 emission should be reduced with 21% by 2010, based on 1990 emission level.

According to the reporting to the ***Kyoto Protocol*** the “aggregated CO_2 equivalent emissions” in 1994 the emission is reported to 80.152 million tonnes CO_2-eq (UN/FCCC 1998). With a reduction target for 2008-2012 (2010) on 21% the interpolated emission for 2004 should be about 71.736 million tonnes CO_2-eq.

According to the Danish rules for ODS phase out all the ODS should be fully phased out before 2004. There are special rules for the HFCs, which are supposed to be phased out by 2007.

The calculation of the global warming potential of the ODS and HFCs appear from Table 2-1 below.

Table 11-5.
Calculated CO_2-eq for ozone depleting substances for Denmark.

DK	GWP 100	Emission 1994, 1000 tonnes	GWP, 1994 tonnes CO_2-eq	Reduction targets, %	2004 emission
CFC-11	4600	0.055	253	100	0
CFC-12	10600	0.24	2544	100	0
CFC-113	6000	0.065	390	100	0
CFC-115	9800	0.025	245	100	0
HCFC-22	7200	0.75	5400	100	0
HCFC-141b	700	0.51	357	100	0
HCFC-142b	2400	0.145	348	100	0
HFC-134a	1300	0.52	676	77	155.48
HFC-152a	120	0.05	6	77	1.38
Halon 1301	6900	0.005	34.5	100	
Halon 1211	1300	0	0	100	0
CH3CCl3	140	0,57	79.8	100	0
CH3Br	5	0.012	0.06	100	0
Total		2.947	10333.36		156.86

Based on these figures the weighting factor for global warming for Denmark will be:

$$WF_{GWP,\,DK} = \frac{80.162 \text{ tonnes } CO_2 \text{ - eq}}{71.636 \text{ tonnes } CO_2 \text{ - eq}} = \text{approx.} 1.12$$

It should be emphasised that ozone depleting substances should have been included in the above calculation, just like for the other geographical areas. However, as the ozone depleting substances have been phased out in Denmark during the target period, it would add an infinitive value to the above weighting factor, totally overruling the result of the phasing out of green house gases. Hence, it has not been included in these calculations.

11.5.4 Comparison of existing and new weighting factors

Table 11-6 summarises the calculated weighting factors for the different groups of GWP, divided on three geographical areas. The table also includes the general GWP weighting factors for Denmark, developed through the EDIP project.

Table 11-6
Weighting factors for Global Warming (GW).

Geographical scope	WF (GW)
Denmark	1.12
EU (including ODS)	1.05
World, Industrialised countries (including ODS)	1.11
Denmark (including ODS 1990-2000) (Hauschild & Wenzel 1996a)	1,3
Denmark (including ODS, 1990-2000) (Hauschild & Wenzel 1998b)	1,2

As it appears the weighting factors for Global Warming are relatively low, indicating a long-term phase down of the emissions of green house gases. The relatively lower WF for Denmark in the period 1994-2004, compared to the one calculated for 1990-2000, is due to the fact that ODS are not included in the new WF which was the case in the earlier calculations (EDIP, 1990-2000).

This impact category includes relatively few substances, and the calculation of the emission of the dominating substances is well documented. Furthermore, the impact is relatively well researched. Hence, the uncertainty of the calculated weighting factors must be considered as limited compared to some of the other weighting factors.

11.6 Stratospheric ozone depletion

The depletion of the stratospheric ozone layer is regulated through reducing the production and consumption of the ozone depleting substances (ODS).

This means that the regulation works indirectly in relation to the actual effect. For many of the applications of ODS there will be a considerable time span between the "production/consumption" of the substances, the emission of the substances to the atmosphere as well as between the emission and the actual impact on the ozone layer. A time span on 10-20 years between consumption and impact is not unusual.

However, it is not possible to regulate the ozone depletion directly, so this indirect regulation is the only practical option.

Almost all countries in the world have become parties of the ***Montreal Protocol*** (UNEP 1987), which is the international agreement to protect the stratospheric ozone layer. Those countries which have not become parties to the ***Montreal Protocol*** are few and represent only a very limited consumption of ODS.

This means that the regulation prescribed by the ***Montreal Protocol*** represent the basic regulation to phase out ODS in most countries. The regulation in the ***Montreal Protocol*** is divided on two different categories of countries:

- Article 5 countries: Any Party that is a developing country and whose annual calculated level of consumption of the controlled substances in Annex A is less than 0.3 kilograms per capita
- Non-Article 5 countries: All parties to the ***Montreal Protocol***, except those which have got special exceptions (see below). The Non-Article 5 countries include the industrialised countries.

Apart from the overall regulation based on ***The Montreal Protocol*** a number of countries have adopted their own regulations, which are stricter than the ***Montreal Protocol***. Especially the industrialised countries have adopted stricter regulation, while the east and central European as well as most developing countries have adopted a regulation close to the one prescribed in the ***Montreal Protocol***.

In the EU a general regulation has been adopted which has to be followed by the 15 members states, although these countries can adopt their own stricter regulation.

11.6.1 Weighting factors for Ozone Depletion for Denmark

Denmark has adopted its own regulation, which is stricter than the EU regulation. The Danish regulation consists of the following steps (Miljøstyrelsen 1999):

- Phase out of CFC’s by 1995
- Phase out of halons by 1993
- Phase out of methyl bromide by 1998
- Phase out of HCFC’s by 2002
- Phase out of carbon tetrachloride by 1992
- Phase out of 1,1,1-trichloroethane by 1996

As it appears from the above list most of the ODS should have been phased out by now, and this is also more or less the case. Some substances are still in use, and recycling is allowed under certain conditions. The use of HCFC’s is allowed until 2002, and hence by 2004, they have to be fully phased out.

This means that by 2004 all substances controlled according to the ***Montreal Protocol*** have to be phased out in Denmark. Hence, the weighting factors for the ozone depleting substances, calculated strictly in line with the formula, will be infinite:

$$WF_{ODS,DK} = \infty.$$

An infinite weighting factor will obviously also cause the weighted result to become infinite. This is a strong signal that the product system being investigated contributes to an environmental impact where Danish regulation actually aims at giving no contribution and that some kind of action is strongly requested. The global weighting factor, which is generally recommended for ozone depletion, may give a more realistic view of the importance with the current situation for phasing-out of ozone depleting substances. The difference, however, underlines the importance of using more than one weighting factor in a sensitivity analysis.

11.6.2 Weighting factors for Ozone Depletion at EU level

The overall regulation of ODS in EU is formulated in the Council Regulation (EC) No 3093/94 of 15 December 1994 on substances that deplete the ozone layer (Hansen, 1997). The phase out schedule for the various controlled substances can be summarised as follows:

- Phase out of CFC’s by 1 January 1995
- Phase out of halons by 1 January 1994
- Reduce 1991 methyl bromide consumption with 25% by 1 January 1999
- Reduce 1991 consumption of HCFC’s with 35% by 1 January 2005
- Phase out of carbon tetrachloride by 1 January 1995
- Phase out of 1,1,1-trichlorethan by 1 January 1996

On 21 December 1998 the Environment Ministers Council of EU reached political agreement on a proposal forwarded by the Commission to tighten the phase out schedule for some of the ODS’s (EU 1994):

- Phase out of methyl bromide by 2001, with exemption for critical uses
- Phase out of almost all HCFC’s by 1 January 2003

If the proposed amendment of the EU regulation on ODS is finally adopted almost all ODS will be phased out before 2004, and the weighting factor will be infinite (∞).

However, if the previously mentioned phase out plan is applied, the WF can be calculated as follows.

The ozone depleting potential for emitted HCFCs in EU 15 in 1991 can be estimated to 2,850 tonnes ODP, based on emission data for 1989 (1,900 tonnes ODP) and 1992 (3,330 tonnes ODP). The emission in 1994 is reported to be 5,577 tonnes ODP (UNEP, 1999). For 1995 the emission is reported to 7,631 tonnes ODP. A 35%'s reduction in the 1991 consumption would lead to a maximum emission in 2005 of 1,853 tonnes ODP. By interpolating the emission in 2004 should not exceed 2,264 tonnes ODP.

Based on these figures the weighting factor for ODS for EU will be:

$$\mathrm{WF}_{\mathrm{ODS,\,EU}} = \frac{5{,}577 \text{ tonnes ODP}}{2{,}264 \text{ tonnes ODP}} = \text{approx. } 2.46$$

11.6.3 Weighting factors for Ozone Depletion at global level for industrialised countries

As mentioned above, the ***Montreal Protocol*** represents the regulation of ODS at global level. The regulation is divided into two categories of countries, industrialised countries (called Non-Article 5 countries in the following) and developing countries (called Article 5 countries in the following).

The regulation for Non-Article 5 countries can be summarised as follows (UNEP 1987):

- Phase out of CFC's by 1 January 1996
- Phase out of halons by 1 January 1994
- Phase out of methyl bromide by 1 January 1996
- Reduce 1989 HCFC consumption with 35% by 1 January 2004, full phase out by 2020 (except 0.5%)
- Phase out of carbon tetrachloride by 1 January 1996
- Phase out of 1,1,1-trichlorethane (methyl chloroform) by 1 January 1996

As it appears from the above list all the controlled ODS's, except HCFC's, will be phased out before 2004. This is similar to the regulation at Danish and EU level.

11.6.3.1 Weighting factor based on ODSs

The calculation of the weighting factor for ozone depletion is based on the actual consumption of all ODS's in 1994 and the allowed consumption in 2004 that according to the regulation should not exceed 65% of the 1989 consumption of HCFC.

The 1989 consumption of HCFC is reported to 11,978 ODP tonnes, and the 1994 consumption of all ODS for the whole world is estimated to 490,099 ODP tonnes of (UNEP, 2002). According to the Montreal Protocol the HCFC consumption should in 2004 not exceed 7,786 ODP tonnes. Based on these figures the weighting factor for ozone depletion for Non-Article 5 countries will be:

$$\mathrm{WF}_{\mathrm{ODP.Art.5}} = \frac{490{,}099 \text{ ODP tonnes}}{7{,}786\text{ODP tonnes}} = \text{approx. } 63$$

11.6.4 Weighting factors for Ozone Depletion at global level for non-industrialised countries

The phase out scheme for Article 5 countries can be summarised as follows (UNEP 1987):

- Reduce 1995-97 CFC consumption with 50% by 1 January 2005, full phase out by 2010
- Reduce 1995-97 halons consumption with 50% by 1 January 2005
- Reduce 1995-98 methyl bromide consumption with 20% by 1 January 2005, full phase out by 1 January 2015
- Freeze 2015 HCFC consumption by 1 January 2016, full phase out by 2040
- Reduce 1998-2000 carbon tetrachloride consumption with 85% by 1 January 2005, full phase out by 2010
- Reduce 1998-2000 methyl chloroform consumption with 30% by 1 January 2005, full phase out by 2015

As it appears from the above none of the ODS's will be fully phased out in the Article 5 countries by 2004. Some reduction targets have been established for most of the substances for this or the following year.

The base line year for the first three mentioned groups of substances is set to 1996, for which data is available. There are no data available for the baseline year for the other substances. However, these substances are not that relevant, except HCFC's, as the consumption of them is limited.

In the following the data for each of the ODS groups are presented, and in the end of the section these data are summarised and weighting factors are calculated.

11.6.4.1 CFC's

The 1996 consumption of CFC's for Article 5 countries is estimated to 149,401 ODP tonnes (UNEP, 2002). The 2005 consumption should according to the Montreal Protocol be reduced to 74,700 ODP tonnes.

11.6.4.2 Halons

Similarly, the 1996 consumption of halons is estimated to 43,410 ODP tonnes (UNEP, 2002). The 2005 consumption should according to the Montreal Protocol be reduced to 21,705 ODP tonnes.

11.6.4.3 Methyl bromide

The 1995 and 1998 consumption of methyl bromide for Article 5 countries is estimated to 8,578 ODP tonnes, respectively 10,564 ODP tonnes (UNEP, 2002). The 2005 consumption should according to the Montreal Protocol be reduced to 7,657 ODP tonnes.

11.6.4.4 HCFC's

The reduction target for HCFC's in the Article 5 countries need to be measured in relation to the full phase out year 2040, as no earlier target can be determined. This means that a possible HCFC consumption for 2004 has to be interpolated based on the 1994 consumption and the full phase out in 2040.

According to the UNEP statistics (UNEP, 2002) the 1994 HCFC's consumption was 4,348 ODP tonnes. It should be mentioned that this statistics is based on reporting from the parties to the Montreal Protocol, and that for 1994 obviously there is a considerable lack of data. It is furthermore obvious that the HCFC consumption will increase in the following years. However, if the presented figures are taken for granted the 2004 consumption will be around 3,391 ODP tonnes.

11.6.4.5 Carbon tetrachloride

The reduction target for carbon tetrachloride in the Article 5 countries is measured for 2005, for which the intermediate target is to reduce the 1999 consumption with 85%.

According to the UNEP statistics (UNEP, 2002) the 1999 carbon tetrachloride consumption was 22,099 ODP tonnes. The target consumption in 2004 will thus be 3,315 ODP tonnes

11.6.4.6 1,1,1-trichloroethane

The reduction target for 1,1,1-trichloroethane in the Article 5 countries is measured in relation to the intermediate target, i.e. a 30% reduction in 2005 in relation to the 1999 consumption.

The 1994 and 1999 consumption was 3,510 and 1,951 ODP tonnes, respectively (UNEP, 2002), and accordingly the target consumption for 2002/2005 is calculated to 1,366 ODP tonnes.

Table 11-7
Summary of targeted (2004) consumption of Ozone Depletion Substances at global level for developing countries (Article 5 countries).

Group of ODS	Targeted consumption in 2004, tonnes ODP
CFCs	47,700
Halons	21,705
Methyl bromide	7,657
HCFCs	3,391
Carbon tetrachloride	3,315
Methyl chloroform	1,366
Total	112,133

Based on the above figures, the weighting factor for ozone depletion for Article 5 countries can be calculated as:

$$WF_{ODP.Art.5} = \frac{490{,}099\ \text{ODP tonnes}}{112{,}133\ \text{ODP tonnes}} = \text{approx.}\ 4.4$$

11.6.5 Comparison of existing and new weighting factors

Table 11-8 below summarises the calculated weighting factors for ozone depletion, divided into four geographical areas. The table also includes the ODP weighting factors for Denmark developed through the EDIP project.

Table 11-8
Weighting factors for ozone depleting substances.

	Total ODS
Denmark	∞
EU	2.46
World, Industrialised countries	63
World, developing countries	4.4
Denmark/World (WF for all ODS's, 1990-2000) (Hauschild & Wenzel 1996e)	23
Denmark/World (WF for all ODS's, 1990-2000) (Hauschild & Wenzel 1998e)	23

As it can be seen the weighting factors for ODS are in general high as was the case in the earlier studies.

The WF for Denmark is now estimated to be infinite, because all ODS have to be phased out within the period 1994-2004. The WF for EU 15 is moderate, because most of the ODS already are phased out in 1994, and EU will still be allowed to emit some ODS by 2004. The WF for industrialised countries is relatively high because they in total still had a high emission of ODS in 1994, while being supposed to phase out most of the emission before 2004. The WF for developing countries is low because they have been allowed to phase out the ODS over a longer period.

The differences in ODP weighting factors for different regions will often be reflected in the final results in an LCA if a sensitivity analysis is applied. As it is not possible in the current EDIP methodology to use different and region-specific weighting factors in the same calculations, such a sensitivity analysis can show the weight that are put on emissions of ozone depleting substances in specific regions, allowing a better interpretation. Identification of ozone depleting substances in any LCA should, however, always be followed by considerations on how they can be avoided.

The data on consumption of ODS is relatively well documented (based on reporting from the individual countries and cross examined with total production figures), and the uncertainty connected with the weighting factors for this impact category must be considered as limited.

11.7 Photochemical ozone creation (POC)

The principal precursors of tropospheric ozone are:

- CH_4
- nmVOC (non methane VOC)
- CO

VOC are regulated at regional level, according to the ***Convention on Long Range Transboundary Air Pollution*** (UN-ECE 1979). In some countries these substances are also regulated at national level.

CH_4 is regulated as greenhouse gas at both global and regional (EU) level, but not yet at national level in Denmark (1999). CO is regulated at point sources, but it is not regulated as POCP-gas. Hence, there are no limits for total emission of CO at neither national, nor regional and global level.

11.7.1 Weighting factors for Photochemical Ozone Creation at global level

The only POC gas that is regulated at global level is CH_4. According to the Kyoto Protocol the emission of green house gases should be reduced by 5% in 2008-2012, based on the 1990 emission level. Reduction levels for the different gases are not specified further, so in the following calculation it is assumed that CH_4 has to follow the general rule.

The emission of CH_4 in 1990 is estimated to 351 million tonnes. For 1994 the emission is reported to 375 million tonnes, equal to 2.625 million tonnes C_2H_4-equivalents. According to the regulation the emission in 2010 should not exceed 333 million tonnes. By interpolating the emission in 2004 should not exceed 349 million tonnes, equal to 2.443 million tonnes C_2H_4-equivalents.

According to the technical report (Stranddorf, 2003), the World-wide emissions of gases with a photochemical ozone creating potential (POCP) equalled 76.8 million tonnes C_2H_4-equivalents in 1994. Except for the reduction in emissions of CH_4 outlined above, the emissions are assumed to be the same in 2004.

Based on these figures the weighting factor for POCP at global level will be:

$$WF_{POCP,\ World} = \frac{76.8 \text{ million tonnes } C_2H_4 \text{ - eq}}{76.618 \text{ million tonnes } C_2H_4 \text{ - eq}} = \text{approx.}\ 1.002$$

11.7.2 Weighting factors for POCP at regional level

At the regional level the principal POCP substances are regulated according to the protocols under the ***Convention on Long Range Transboundary Air Pollution*** (UN-ECE 1979).

Emission of nmVOC is regulated according to the ***Geneva Protocol*** (UN-ECE, 1991) that was adopted in 1991. According to the Protocol the emission of VOCs should be reduced with 30% in 1999, with a year between 1984 and 1990 as a base.

As mentioned earlier, CH_4 is regulated according to the Kyoto Protocol with 5% over the period 1990-2010. CO is neither regulated at national nor regional level.

The data on which the calculation of the WF for POCP is based appears from Table 11-9 below.

Table 11-9.
Data for calculation of WF for POCP for EU-15.

Substance	Impact potential 1994 (kt C_2H_4/year)	Reduction target, %	Reduction period	Targeted level in 2004 (kt C_2H_4/year)
nmVOC	7,769	30	1987-1999	5,438
CO	1,381	0		1,381
CH_4	158	5	1990-2010	153
Total	9,307			6,972

Based on these figures the weighting factor for photochemical ozone formation for EU-15 will be:

$$WF_{POCP,\,EU} = \frac{9{,}307 \text{ million tonnes } H_2C_4 \text{ - eq}}{6{,}972 \text{ million tonnes } H_2C_4 \text{ - eq}} = \text{approx.}1.33$$

11.7.3 Weighting factors for POCP for Denmark

The Danish regulation concerning photochemical ozone formation is following the regional regulation. This means that nmVOC is following the ***Geneva Protocol*** and CH_4 the ***Kyoto Protocol***. The emission of CO is not regulated at national level. The weighting factor for POCP at national Danish level can then be calculated as follows shown in Table 11-10.

Table 11-10
Data for calculation of WF for POCP for Denmark.

Substance	Impact potential 1994 (kt C_2H_4/year)	Reduction target, %	Reduction period	Targeted level in 2004 (kt C_2H_4/year)
nmVOC	72.1	30	1987-1999	50.47
CO	28.6	0		28.6
CH_4	3.0	5	1990-2010	2.925
Total	103.7			81.995

Based on these figures the weighting factor for photochemical ozone formation for Denmark will be:

$$WF_{POCP.DK} = \frac{103.7 \text{ tons } C_2H_4 \text{ - eq.}}{81.995 \text{ tons } C_2H_4 \text{ - eq.}} = \text{approx } 1.26$$

11.7.4 Comparison of existing and new weighting factors

Table 11-11 summarises the weighting factors calculated for photochemical ozone formation for the three geographical areas, and compares them to the previously developed weighting factors in the EDIP project.

Table 11-11
Weighting factors for photochemical ozone formation (POCP).

Area	This project	EDIP (Hauschild & Wenzel 1996c)	EDIP (Hauschild & Wenzel 1998d)
Global	1.002		
EU	1.33	-	-
Denmark	1.26		1.2

As it appears from the table, the weighting factor for POCP for Denmark is somewhat higher than it was in the EDIP project. This is due to the fact that the reduction targets for CH_4 according to the Kyoto Protocol is included in these calculation, which was not the case for the original EDIP. The regulation of the POPC at global level is only determined by the regulation of CH_4 through the Kyoto Protocol, and this regulation is not so strict as the other regulation.

The uncertainty connected with the calculation of the weighting factors for POCP may be higher than that of Global Warming and Ozone Depletion. The reason for this is that the regulation of the involved substances refers to different international agreements and that it is difficult to estimate the emission data precisely.

11.8 Acidification

Acidification is primarily a regional environmental problem that is regulated both at local, national and regional level. The overall reduction of substances that lead to acidification is based on the ***Convention on Long Range Transboundary Air Pollution*** (LRTAP) (UN-ECE 1979), which is ratified by most of the countries in Europe and North America.

The regulation of acidification is focusing on two groups of substances, sulphur dioxide (SO_2) and nitrogen oxides (NO_x) each regulated according to their own protocols. NH_3 is not regulated as an air pollutant but as a water pollutant.

11.8.1 Weighting factors for acidification at global level

There is no binding regulation at global level, but as the primary industrial nations have adopted the LRTAP Convention, a weighting factor based on this can to a certain degree be applied as global weighting factor. However, this will require a closer investigation of how the LRTAP convention is implemented in the various regions, and that is not done in this study.

11.8.2 Weighting factors for acidification at EU level

SO_2 was one of the first substances to be regulated at international level. This was done through the LRTAP Convention which later on was replaced by the so-called the ***Helsinki Protocol*** (Helsinki Commission 1974) regulating the emission of SO_2 until 1993.

The ***Helsinki Protocol*** was replaced in 1994 by the ***Oslo Protocol***, or the ***Second Sulphur Protocol*** (UN-ECE 1994). According to this protocol the parties have agreed to reduce their sulphur emissions in accordance with the plan shown in Table 11-12. The baseline year is 1980.

Table 11-12
SO_2 emission reductions according to Oslo Protocol (UN-ECE 1994).

Parties	Emission level, 1980, kt SO_2	Reduction commitment according to Oslo Protocol Target year		
		2000	2005	2010
Austria	397	80		
Belgium	828	70	72	74
Denmark	451	80		
Finland	584	80		
France	3348	74	77	78
Germany	7494	83	87	
Greece	400	-49	-45	-43
Ireland	222	30		
Italy	3800	65	73	
Luxembourg	24	58		
Netherlands	466	77		
Portugal	266	0	3	
Spain	3319	35		
Sweden	507	80		
UK	4898	50	70	80

The following calculation of weighting factor is based on the reduction targets for 2005. For those countries, which only have set targets for 2000, these reduction figures are used instead. Where emission figures are missing for the reference year (1994), figures for a year earlier are used instead.

Based on the figures from the UN-ECE reports (UN-ECE 1994) the total 1994 emission of SO_2 in the countries is 12,105 kilotonnes SO_2. The calculated emission for 2004 should according to the reduction targets be 8,04 kilotonnes SO_2

The earlier regulation of NO_x, the ***Sofia Protocol*** (UN-ECE 1988a), will not effect the weighting factor for this project, as the targets have been reached several years ago. However, the ***Sofia Protocol*** was in 1988 supplemented by a declaration (UN-ECE 1988b) adopted by 12 European countries (Austria, Belgium, Denmark, Germany, Finland, France, Italy, Liechtenstein, Netherlands, Norway, Sweden and Switzerland).

The reduction target of the declaration is formulated as follows “the signatories will implement a reduction of national annual nitrogen oxide emission in the order of 30% as soon as possible and at the latest by 1998, using the level of any year between 1980 and 1986 as a basis”.

For the EU countries the declaration will result in reductions shown in Table 11-13. In the calculation 1983 has been used as basis for the calculations for all the countries.

Table 11-13
Reduction of NO_x according to the UN-ECE Declaration of 1988 (UN-ECE 1988b.).

Parties	Emission 1983, kt NO_x	Emission 1994 kt NO_x	Commitment according to UN-ECE NO_x Declaration	
			Target 1998, -30%	Target 2004,-30%
Austria	241	177		
Belgium	442	345		
Denmark	261	272		
Finland	261	282		
France	1645	1682		
Germany	3158	2210		
Italy	1568	1997		
Netherlands	555	542		
Sweden	401	372		
Total	8532	7879	5972	5972
SO_2-eq, total	5972	5515	4181	4181

The above data diverts a bit from those used for the calculations in the normalisation chapters. However, as the above data are those used in relation to the negotiation of the regulation, they are kept here for the calculation of the weighting factor.

For the remaining six countries that is not regulated with respect to NO_x the following total emission for the reference year and the target year are applied (derived from the calculation of the normalisation references): 1380 kt SO_2-eq.

The emission of NOx for EU-15 in 1994 is thus calculated to 6895 kt SO2-eq and for 2004 5561 kt SO2-eq.

There exist no regional regulation of the third acidifying component, ammonia (NH_3), so the emission figure remain the same in the reference year as in the target year: 6640 kt SO2-eq.

The figures for acidification for EU-15 are summarised in Table 11-14 below.

Table 11-14
Total Acidification in kt SO2-eq

Substance	1994	2004
SO_2	12105	8040
NOx	6895	5561
NH_3	6640	6640
Total	25640	20241

Based on these figures the weighting factor for acidification for EU-15 will be:

$$WF_{Acid,\,EU} = \frac{25{,}640\ \text{kt}\ SO_2\text{ - eq}}{20{,}241\ \text{kt}\ SO_2\text{ - eq}} = \text{approx.}1.27$$

A new regulation, integrating all the primary acidifying substances, is under way but no specific targets have been established so far.

11.8.3 Weighting factors for acidification for Denmark

With regard to acidification Denmark is following the Protocols under the ***Convention on Long Range Transboundary Air Pollution***.

According to the ***Oslo Protocol*** (UN-ECE 1994) Denmark has to reduce the SO_2 emission with 80% in 2000 relative to the 1980 emission.

The 1980 and the 1994 SO_2 emissions were 451,000 tonnes and 158,000 tonnes. The 2000 emission thus has to be 90,200 tonnes SO_2. As there have not been established new targets, the level in 2004 is considered to be equal to the one in 2000.

According to a UN-ECE Declaration on NO_x, adopted under the ***Sofia Protocol***, the Danish emission of NO_x has to be reduced with 30% in 1998 relative to the 1983 emission (or rather a year between 1980-1986).

The 1983 and the 1994 NO_x emissions has been registered to 261,000 tonnes and 276,000 tonnes. The 1998 emission thus has to be 182,700 tonnes NO_x. As there have not been established new targets, the level in 2004 is considered to be equal to the one in 1998. Converted into SO_2 equivalents the NO_x emission in 1994 and 2004 will be 193,200, respectively 127,900 tonnes SO_2-eq.

Airborne ammonia (NH3), which primarily originates in the agricultural sector, contributes to the acidification as well. It not regulated, but its contribution to acidification has to be included in the calculations. It is estimated that the annual emission amounts to about 93 600 tonnes of nitrogen (Andersen, et al 1999). Converted into SO_2-eq the emission will be 176 000 tonnes per year (equivalency factor is 1.88 (EDIP 97)).

The figures for acidification for Denmark is summarised in Table 11-15 below.

Table 11-15
Total Acidification for Denmark in kt SO2-eq

	1994	2004
SO2	158	90,2
NOx	193,2	127,89
NH3	175,968	175,968
Total	527,168	394,058

Based on these figures the weighting factor for acidification will be:

$$WF_{\mathrm{Acid,DK}} = \frac{527{,}168 \text{ tonnes } SO_2 \text{ - eq}}{394{,}058 \text{ tonnes } SO_2 \text{ - eq}} = \text{approx.} 1.34$$

11.8.4 Comparison of existing and new weighting factors

Table 11-16 summarises the weighting factors calculated for acidification for the three geographical areas, and compares them to the previously developed weighting factors in the EDIP project.

Table 11-16
Weighting factors for acidification.

Area	This project	EDIP (Hauschild & Wenzel 1996b)	EDIP (Hauschild & Wenzel 1998a)
EU	1.27	-	-
Denmark	1.34		1.3

As it appears the WF for Denmark in this study is more or less the same as the one calculated in the EDIP study, while the WF for EU is somewhat lower. It should be emphasised, however, that the target year differs between the various countries within EU.

The uncertainty connected with the calculation of the weighting factors for acidification is judged to be at the same level as that of Global Warming and Ozone Depletion. The reason for this is that the regulation of the involved substances is relative clear and that the emission data is relatively well documented. It is however also mentioned here that the target year for reduction for some countries is 2000 instead of 2004, adding a minor uncertainty to the weighting factor.

11.9 Nutrient enrichment

There exist both regional (EU) and national regulation of some of the substances that result in nutrient enrichment, primarily N containing substances.

The calculation of the weighting factors is based on reduction targets for the consumption and use of the two plant nutrients, N and P. EDIP 97 includes calculations of WFs for both N and P as well as an aggregated WF for N and P. However, as there is no current regulation of P in Denmark anymore and there have never been for EU, no new WF including P has been calculated in this study.

11.9.1 Weighting factors for nutrient enrichment for Denmark

The Danish emission of N and P to the water environment has primarily been regulated through the Water Environment Action Plans. The first plan, which established reduction targets for three sectors, covers in principle all emissions to the water environment, except precipitation from the air.

As the goals of the ***first Water Environment Action plan*** were not met, a second ***Action Plan*** (Miljøstyrelsen, 1998) was adopted in 1998 extending the period for reaching the goals. The reduction targets are based on the data from the NPO Study, which contains the baseline data for the emission of N and P. The new target year is 2003. In Table 11-17 the reduction targets established through the Action Plans are summarised.

Table 11-17
Reduction targets for N and P in Denmark.

Sector	Baseline emission, 1985 1000 tonnes	Reduction target, 2003 1000 tonnes or %	Target met
Nitrogen			
Agriculture	260	100 tonnes	No
Waste water treatment plants	25	15%	Yes
Industry	5	3%	Yes
Phosphorous			
Agriculture	4.4	n.a.	No
Waste water treatment plants	7.2	n.a.	Yes
Industry	3.4	n.a.	Yes

The only target, which is still relevant, is the reduction of the emission of N from the agriculture. The target on reduction of the emission of P from the agriculture has not been achieved, and the target has now been given up.

So far, there has been no reduction target for the emission of NH_3 but such a target is under way.

As the reduction target for N from the agriculture was not achieved during the first action plan the emission level is considered to be the same in 1994, 260,000 tonnes N. In 2004 the emission has to be reduced to 160,000 tonnes N, as this is target already for 2003.

The reduction targets for airborne NO_x is, as mentioned under Acidification, section 11.8, 30% in 1998, based on the emission level in 1983. As there have not been established new reduction targets for airborne NO_x, the 30% will also be valid for 2004. This means that the NO_x emissions in the reference and targets years are 261,000 tonnes NO_x (1994) and 182,700 tonnes NO_x (2004).

Airborne ammonia (NH_3), contributes to the nutrient enrichment as well, and has to be included in the calculations. It is assumed that the emission is more or less constant and that the annual emission amounts to about 93,000 tonnes of nitrogen (Andersen, et al 1999).

The emission of P is assumed to be the same in both reference and the target year, and amounts to a total of 15,000 tonnes P per year. Converted into NO_3-eq the amount will be 480,450 tonnes NO_3-eq.

The above data and conversion of them into NO_3^--eq is shown in Table 11-18 below (conversion factors as in EDIP).

Table 11-18
Summary of N- and P-contribution to nutrient enrichment (tonnes)

	Year	N contribution	NO_x contribution	NH_3 contribution	P contribution	Total
Specific substance	1994	260000	261000	93000	15000	
Specific substance	2004	160000	182799	93000	15000	
Characterisation factor		4.43	1.35	3.64	32.03	
NO_3^--eq	1994	1151800	352350	338520	480450	2 323 120
NO_3^--eq	2004	708800	246779	338520	480450	1 774 549

Based on the above figures the weighting factor for nutrient enrichment with N-containing substances for Denmark will be:

$$WF_{\mathrm{EutroN,\,DK}} = \frac{1\,842\,670 \text{ tonnes NO3 - eq}}{1\,294\,099 \text{ tonnes NO3 - eq}} = \text{approx.} 1.42$$

The weighting factor for nutrient enrichment with P-containing substances for Denmark can be estimated to:

$$WF_{\mathrm{EutroP,\,DK}} = \frac{480\,450 \text{ tonnes NO3 - eq}}{480\,450 \text{ tonnes NO3 - eq}} = 1.0$$

The aggregated weighting factor for nutrient enrichment for Denmark will be:

$$WF_{\mathrm{EutroN/P,\,DK}} = \frac{2\,323\,120 \text{ NO3 - eq}}{1\,774\,549 \text{ NO3 - eq}} = \text{approx.} 1.31$$

11.9.2 Weighting factors for nutrient enrichment at EU level

Within EU nutrient enrichment is regulated mainly through three directives:

- Urban Waste Water Treatment Directive (1991) (EU 1991a)
- The Nitrate Directive (1991) (EU 1991b)
- The IPPC directive (Integrated Pollution Prevention and Control Directive) (1996) (EU 1996)

According to the Urban Waste Water Treatment Directive (EU 1991a) the discharge of P via urban waste water treatment plants to “sensitive areas” shall be reduced by minimum 80% or concentration of Total P should be kept within 2 mg/l for 10 000 - 100 000 p.e. (person equivalents) plants and within 1 mg/l for plants over 100 000 p.e. Similarly, Total N has to be reduced with minimum 70-80%, or concentrations of 15 mg/l for 10 000 – 100 000 p.e. plants and 10 mg/l for plants over 100 000 p.e.

There are no exact reduction targets for discharge of treated wastewater to normal and less sensitive areas. The discharge of wastewater is divided on the three categories of recipients, see Table 11-19.

Table 11-19
Discharge of waste water to different areas according to EU regulation

Recipient waters	Discharge of waste water million PE
Sensitive areas	158 (37%)
Normal areas	229 (54%)
Less sensitive areas	37 (9%)
Total	424

The Urban Waste Water Treatment Directive was originally adopted in 1991, and has at a later stage been revised to the above mentioned version. Unfortunately, it has not been possible to provide baseline data, which the targets can be related to, so it has not been possible to include emission from urban areas in the calculation of weighting factors.

According to the Nitrates Directive (EU 1991b), adopted in 1991, the distribution of nitrogen containing manure on agricultural land should be reduced within certain time limits. In 1998 up to 210 kg N can be distributed per hectare, and in 2002 the limit is 170 kg N per hectare.

The Directive does not include further reduction of the distribution of nitrogen. Hence, it is stipulated that the limit on 170 kg N per hectare for 2002 is also valid for 2004. There are no limits for phosphorous. The IPPC Directive (EU 1996) set up procedures for regulating the emission and effluents from industries, but does not include specific values for emission of N and P to waterways.

Through extrapolation the reference amount of N in 1994 is 237 kg N per hectare. Based on these assumptions the weighting factor for N will be:

$$WF_{EutroN, EU} = \frac{237 \text{ kg N/hectare}}{170 \text{ kg N/hectare}} = \text{approx.} 1.39$$

It should be emphasised that this weighting factor is based on only one basic factor in the creation of nutrient enrichment. Hence, the scope of the estimation of the weighting factor is relatively narrow in relation to the biological mechanism of nutrient enrichment.

Due to the fact that phosphorous is not regulated at EU-level the weighting factor for P is one:

$$WF_{EutroP, EU} = 1.0$$

If it is assumed that the emission of the nutrient enrichment substances is linear to the use of the N and P as well as the air emissions an aggregated weighting factor can be calculated as follows.

In connection with the calculation of the normalisation references the following emissions for 1994 have been estimated as it appears from Table 11-20 below.

Table 11-20.
EU-15 emissions of nutrients in the form of nitrogen and phosphorus compounds to air and water. The unit is kt/year. Emissions to air from Ritter (1997). Waterborne emissions from EEA (1998a).

Substance	Impact potential 1994		Emissions in reference year	Emissions in target year
	kt N-eq./ year	kt P-eq./ year	1994	2004
Airborne emissions				
Nitrogen oxides	3763	0	3763	3763
Ammonia	2898	0	2898	2898
Waterborne emissions				
Total P	0.0	150	150	150
Total N	2342	0.0	2342	662
Total	9004	150	9155	7474

Based on these assumptions the aggregated weighting factor for nutrient enrichment with N and P will be:

$$WF_{EutroN,\, EU} = \frac{9155\ \mathrm{kt\ \ N\text{-}eq}}{7475\ \mathrm{kt\ N\text{-}eq}} = \mathrm{approx.}\,1.22$$

11.9.3 Weighting factors for nutrient enrichment at global level

There are no initiatives to establish reduction targets for nutrient enrichment substances at global level. Hence, it has not been tried to develop weighting factors for nutrient enrichment at this level.

11.9.4 Comparison of existing and new weighting factors

Table 11-21 summarises the weighting factors calculated for nutrient enrichment for the two geographical areas, and compares them to the previously developed weighting factors in the EDIP project.

Table 11-21
Weighting factors for nutrient enrichment.

Area	This project	EDIP (Hauschild & Wenzel 1998c)
EU, N	1.39	-
Denmark, N	1.42	1.3
EU, P	1.0	-
Denmark, P	1.0	1.0
EU, aggregated	1.22	-
Denmark, aggregated	1.31	1.2

The uncertainty connected with the calculation of the weighting factors for nutrient enrichment is judged to be at a higher level than that of Global Warming and Ozone Depletion. The reason for this is that the regulation of the involved substances only covers part of the impact category and that the impact mechanism and the emission data is less well documented.

11.10 Ecotoxicity

The overall impact category ecotoxicity is a relatively complex impact category, including a broad range of substances and recipients. In this project it has been decided to focus on the substances that have been identified as the most important for three specific “sub”-impact categories, as mentioned in the section Normalisation References for the Impact Category Ecotoxicity. The groups of substances and the “sub”-impact categories are summarised in Table 11-22.

Table 11-22
Groups of substances and “sub”-impact categories for Ecotoxicity

	Group of substances	Ecotox potential, water, acute	Ecotox potential, water, chronic	Ecotox potential, soil, chronic
Waste water	Organic substances	X	X	
Waste water	Metals	X	X	
Pesticides	Fungicides			X
Pesticides	Herbicides			X
Pesticides	Insecticides			X
Sludge	Organic substances + metals			X
Oil emission		X	X	
Deposition, water		X		
Deposition, soil				X
Antifouling	Organotin compounds	X	X	

The substances mentioned in Table 11-22 is applied for both Denmark and EU, except “Oil emission”, which is assumed relevant only at EU level.

11.10.1 Weighting factors for ecotoxicity for Denmark

11.10.1.1 Organic substances and metals to water

The emission of organic substances and metals to water, which in this context means marine areas, is primarily regulated through two international conventions, the ***Convention on the Protection of the Marine Environment of the Baltic Sea*** (The ***Helsinki Convention***) (Helsinki Commission 1974) and the ***OSPAR Convention for the North Atlantic Oceans*** (OSPAR Commission 1992), including the North Sea. The ***OSPAR Convention*** replaces the earlier adopted Oslo and the Paris conventions.

According to the ***OSPAR Convention*** the emission of hazardous substances to the oceans should be reduced with 50% in relation to the emissions in 1985. The list of substances includes those, which are mentioned under the previous sections on Normalisation References for Ecotoxicity, e.g. metals, organics, pesticides and organotin compounds. The target year was earlier 1995, but has now been prolonged to 2000.

Initiatives have been taken to formulate a full stop for emission of selected substances before 2020. However, this initiative is still under consideration, so no specific target can be established by now.

Therefore, the target for 2004 in this context is considered as being 50% of the 1985 emissions, which corresponds to a reduction of about 20% from 1994 to 2004.

11.10.1.2 Pesticides to soil

The outlet of pesticides to the soil is primarily regulated through the Action Plan for Reduction of the Consumption of Pesticides, 1986 (Miljøstyrelsen 1986). According to this action plan the consumption should be reduced with 25% in relation to the average annual consumption in the years 1981-85. Later on it has been decided to reduce the consumption with 25% more by 1997.

A further reduction, or even a full phase out of the use of pesticides, is under consideration in the Committee for Evaluation of Phasing Out the Use of Pesticides. The recommendation of this Committee has not been discussed by the political institutions, so it is too early to take it for granted that there will be a full or almost full phase out of pesticides. However, it seems evident that a decision on further reduction will take place within the coming years.

Therefore, the calculation of the reduction targets for pesticides will be based on the assumption that the current trend in the phasing out will continue anyway until 2004. This means that the consumption of pesticides should be reduced with 75% in 2004 in relation to the consumption in 1983, which correspond to an average annual reduction of about 3.57% in the period, or 36% in the period from 1994 to 2004.

11.10.1.3 Organic substances and metals in sludge

The outlet of organic substances and metals to the soil, via sludge from wastewater treatment plants, is regulated according to the executive regulation for the Application of Waste Products for Agricultural Purposes, issued 1996 (Miljø- og Energiministeriet 1996).

According to this executive regulation the content of one heavy metal and some organic substances (detergents) has to be reduced within a given period, see Table 11-23 below.

Table 11-23
Reduction targets for metals and organic substances in sludge.

Regulated substance	Reference date I: 1/10/1996	Reference date II: 16/7/1997	Target date I: 1/7/2000
Cadmium in mg per kg dry matt.	0.8		0.4
Cadmium in mg per kg Tot-P	200		100
LAS in mg per kg dry matter		2600	1300
PAH in mg per kg dry matter		6	3
NPE in mg per kg dry matter		50	10
DEHP in mg per kg dry matter		100	50

As it appears from Table 11-23 the threshold limit value for cadmium has to be reduced with 50% within four years. As there are no new initiatives under way these values will for the time being also be relevant for 2004.

For the organic substances the content has to be reduced also with 50% within the period from 1997 to 2000, except for NPE (nonylphenol ethoxylates), which will be reduced with 80% over the same period.

The threshold limit values for other regulated heavy metals (mercury, lead and nickel) are not reduced.

Emission of oil and products based on mineral oil is regulated also through the Helsinki and the OSPAR conventions. According to these conventions the emissions has to be reduced with 50%.

11.10.1.4 Air to water and soil

Deposition from air to water and soil involves, according to the section on Human Toxicity in chapter on Normalisation references , the following substances:

- Lead (Pb)
- Mercury (Hg)
- Arsenic (As)
- Cadmium (Cd)
- Chromium (Cr)
- Polycyclic aromatic hydrocarbons (PAH)
- Particulate matter
- Dioxins

The dominating source of airborne lead has been organic lead compounds in petrol. However, as leaded petrol has been phased out a number of years ago, it is not relevant for this project.

The source of airborne mercury originates primarily from power generation, waste incineration, sludge and land filling. The emission of mercury is indirectly regulated through the use of mercury for various purposes. According to an executive regulation on marketing and export of mercury and mercury containing products (Miljø- og Energiministeriet 1998), the use of mercury thermometers for certain applications is prohibited from 30 June 2004 and other thermometers from 31 December 1999. For a long range of other applications the use of mercury will still be allowed.

It is estimated that the regulated applications accounts for about 20% of the total use, whereas the regulation corresponds to a reduction of the present use with about 20% by 2004.

Arsenic, cadmium and chromium do not become airborne to the same extent as mercury, so the regulation of these substances can not be considered as relevant for the deposition of the substances. Hence, it is not possible to establish reduction targets for these substances.

The PAH originates from a long range of different sources, both stationary and mobile, but typically combustion processes. PAH is regulated as threshold limit values from some of the sources, but there are no overall national reduction targets.

This is the same for particulate matter.

Dioxin primarily originates from combustion, and especially solid waste incineration. Denmark had earlier its own reduction target for solid waste incineration, but it has now been replaced by a general EU reduction target on 90% of the emission by 2005, based on the 1985 emission level (EU 1992). This target corresponds to a reduction on 45% from 1994 to 2004.

Based on the figures for ecotoxicity potentials presented in the sections on Ecotoxicity, the weighted reduction target for the substances will be 10% from 1994 to 2004. It should be emphasised that only the reduction target for mercury contributes to this weighted reduction target.

11.10.1.5 Anti-fouling to water

The outlet of anti-fouling substances to the water environment is not yet regulated as such (as of March 1999), but the Minister of Environment and Energy has proposed a executive regulation prohibiting the use of pesticide containing anti-fouling paint for leisure boats by 2003.

According to a survey of the consumption of anti-fouling substances (tributyltin, TBT, trade name Diuren) in Denmark, conducted by the Danish EPA, the annual consumption of anti-fouling substances (active substance) is 850-1700 tonnes (1997). There is no exact figure for the consumption of these substances for large ships, which move much abroad and therefore release their anti-fouling treatment abroad. However, if it is assumed that half of the anti-fouling paint is used for leisure boats this means a reduction target on 50% by 2003 and also by 2004, in case there will not be established reduction targets for other ships. Based on the above assumptions the reduction from 1994 to 2004 will be 50%.

11.10.1.6 Weighting factors

Based on the above assumptions the following weighting factors can be calculated for ecotoxicity for Denmark, see Table 11-24 below.

Table 11-24
Calculation of weighting factor for chronic aquatic ecotoxicity, Denmark.

Activity / Substances	Scaled reduction target, 1994-2004 %	Ecotox Potential, etwc (m^3/yr) 1994	Ecotox Potential, etwc (m^3/yr) 2004	Weighting factor
Waste water / Organic substances	20	3,75E+11	3,00E+11	
Waste water / Metals	20	7,77E+11	6,22E+11	
Pesticides	36			
Sludge / Metals	50			
Sludge / Organic substances	50			
Oil to water	50			
Deposition to water	10	1,37E+11	1,23E+11	
Deposition to soil	10			
Antifouling / Metals	50	2,83E+12	1,42E+12	
Total		4,12E+12	2,46E+12	1.67

Table 11-25
Calculation of weighting factor for acute aquatic ecotoxicity, Denmark.

Activity / Substances	Scaled reduction target, 1994-2004 %	Ecotox Potential, etwa (m^3/yr) 1994	Ecotox Potential, etwa (m^3/yr) 2004	Weighting factor
Waste water / Organic substances	20	2,30E+10	1,84E+10	
Waste water / Metals	20	7,88E+10	6,30E+10	
Pesticides	36			
Sludge / Metals	50			
Sludge / Organic substances	50			
Oil to water	50			
Deposition to water	10			
Deposition to soil	10			
Antifouling / Metals	50	2,83E+11	1,42E+11	
Total		3,85E+11	2,23E+11	1.73

Table 11-26
Calculation of weighting factor for chronic terrestrial ecotoxicity, Denmark.

Activity / Substances	Scaled reduction target, 1994-2004 %	Ecotox Potential, etsc (m^3/yr) 1994	Ecotox Potential, etsc (m^3/yr) 2004	Weighting factor
Waste water / Organic substances	20			
Waste water / Metals	20			
Pesticides, fungicides	36	3,50E+11	2,24E+11	
Pesticides, Herbicides	36	2,85E+12	1,82E+12	
Pesticides, Insecticides	36	2,15E+11	1,38E+11	
Sludge / Metals	50	1,89E+07	9,45E+06	
Sludge / Organic substances	50			
Oil to water	50			
Deposition to water	10			
Deposition to soil	10	5,90E+07	5,31E+07	
Antifouling / Metals	50			
Total		3,42E+12	2,19E+12	1.56

11.10.2 Weighting factors for ecotoxicity at EU level

This section has been organised in the same way as the above section for Denmark.

11.10.2.1 Organic substances and metals to water

For EU as a whole the emission of organic substances and metals to water, which in this context means marine areas, are primarily regulated through the ***Helsinki Convention*** and ***The OSPAR Convention***, as most of the EU coastline is linked to the North Atlantic and Baltic oceans. No regulation covering the relevant substances for the Mediterranean Sea has been identified. Hence, the above regulation has been applied for this sea as well.

According to these conventions the discharge of hazardous substances to the oceans should be reduced with 50% in relation to the emissions in 1985. The list of substances includes those, which are mentioned under sections on Normalisation References for Ecotoxicity, e.g. metals, organics, pesticides and organotin compounds. The target year was earlier 1995, but has now been prolonged to 2000.

Therefore, the target for 2004 in this context is considered as being 50% of the 1985 emissions which corresponds to a reduction of about 20% from 1994 to 2004.

11.10.2.2 Pesticides to soil

There are no regulations of the amounts of pesticides at EU level.

11.10.2.3 Organic substances and metals in sludge

The outlet of organic substances and metals to the soil, via sludge from wastewater treatment plants, is regulated through the Council Resolution 86/278/EEC. However, this regulation does not provide a basis for establishing an overall reduction target for these substances at EU level.

11.10.2.4 Oil to water

Emission of oil and products based on mineral oil is regulated also through the Helsinki and the OSPAR conventions. According to these conventions the emissions has to be reduced with 50%.

11.10.2.5 Air to water and soil

There is no regulation at EU level that lead to reduction targets for heavy metals and organic substances above, except dioxins.

According to the EU regulation the reduction target is to reduce the emission with 90% of the 1985 emission by 2005 (EU 1992). This target corresponds to a reduction on 45% from 1994 to 2004.

11.10.2.6 Anti-fouling to water

There are no regulations of anti-fouling substances at EU level.

11.10.2.7 Weighting factors

Based on the above assumptions the following weighting factors for EU can be calculated for ecotoxicity, see Table 11-27-Table 11-29 below.

Table 11-27
Calculation of weighting factor for chronic aquatic ecotoxicity, EU.

Activity / Substances	Scaled reduction target, 1994-2004	Ecotox Potential, etwc (m^3/yr)	Ecotox Potential, etwc (m^3/yr)	Weighting factor
	%	1994	2004	
Waste water / Organic substances	20	1,89E+13	1,51E+13	
Waste water / Metals	20	4,16E+13	3,33E+13	
Pesticides	0			
Sludge / Metals	0			
Sludge / Organic substances	0			
Oil to water	50	3,63E+12	1,82E+12	
Deposition to water	45	1,24E+13	6,82E+12	
Deposition to soil	45			
Anti-fouling / Metals	0	5,38E+13	5,38E+13	
Total		1,30E+14	1,11E+14	1.18

Table 11-28
Calculation of weighting factor for acute aquatic ecotoxicity, EU.

Activity / Substances	Scaled reduction target, 1994-2004	Ecotox Potential, etwa (m^3/yr)	Ecotox Potential, etwa (m^3/yr)	Weighting factor
	%	1994	2004	
Waste water / Organic substances	20	1,16E+12	9,28E+11	
Waste water / Metals	20	4,19E+12	3,35E+12	
Pesticides	0			
Sludge / Metals	0			
Sludge / Organic substances	0			
Oil to water	50	6,06E+10	3,03E+10	
Deposition to water	45			
Deposition to soil	45			
Anti-fouling / Metals	0	5,38E+12	5,38E+12	
Total		1,08E+13	9,69E+12	1.11

Table 11-29
Calculation of weighting factor for terrestrial ecotoxicity, EU.

Activity / Substances	Scaled reduction target, 1994-2004	Ecotox Potential, etsc (m^3/yr)	Ecotox Potential, etsc (m^3/yr)	Weighting factor
	%	1994	2004	
Waste water / Organic substances	20			
Waste water / Metals	20			
Pesticides, fungicides	0	7,83E+13	7,83E+13	
Pesticides, Herbicides	0	1,27E+14	1,27E+14	
Pesticides, Insecticides	0	1,52E+14	1,52E+14	
Sludge / Metals	0	5,35E+08	5,35E+08	
Sludge / Organic substances	0			
Oil to water	50			
Deposition to water	45			
Deposition to soil	45	3,51E+10	1,93E+10	
Anti-fouling / Metals	0			
Total		3,57E+14	3,57E+14	1.00

11.10.3 Weighting factors for ecotoxicity at global level

There is no basis for establishing weighting factors for ecotoxicity at global level, as there are no overall global reduction targets for the substances involved in the calculation of normalisation references for ecotoxicity.

11.10.4 Comparison of existing and new weighting factors

Table 11-30 summarises the weighting factors calculated for ecotoxicity for the two geographical areas, and compares them to the previously developed weighting factors in the EDIP project.

Table 11-30
Weighting factors for ecotoxicity.

Category and area	This project	EDIP (Hauschild *et al.* 1998b)
Chronic aquatic ecotoxicity, Denmark	1.67	2.6
Acute aquatic ecotocxicity, Denmark	1.73	2.6
Terrestrial ecotoxicity, Denmark	1.56	1.9
Chronic aquatic ecotoxicity, EU	1.18	n.a.
Acute aquatic ecotocxicity, EU	1.11	n.a.
Territial ecotoxicity, EU	1.0	n.a.

The uncertainty connected with the calculation of the weighting factors for ecotoxicity is much higher than that of Global Warming and Ozone Depletion. The reason for this is:

- The impact mechanisms are very complicated
- The regulation only covers few of the involved substances
- A lot of the basic data are lacking and inaccurate

11.11 Human toxicity

11.11.1 Weighting factors for human toxicity for Denmark

According to the section on normalisation references for human toxicity in the previous chapter, the main substances contributing to the normalisation reference are those indicated in the table 1.27 below. All the other substances will be neglected in the further calculation of weighting factor for this impact category, because their contributions are so limited.

The political reduction targets for the substances contributing to the normalisation references have been mentioned in the earlier sections. For lead, cadmium, PAH, particles and benzene the reduction targets appear from the section on Ecotoxicity above. The political targets for SO_2 and NO_x appear from the section on Acidification and the targets for nmVOC and CO appear from the section on Photochemical Ozone.

The calculated Targeted Impact Potentials for the various substances in Table 11-31 below is based on the Impact Potentials for 1994, transferred from the Normalisation chapter.

Table 11-31
Human toxicity for air, Denmark.

Substance/Activity	Scaled reduction target in %, 1994-2004	Impact potential, 1994	Targeted impact potential, 2004
NmVOC – transport	30	2.80E+17	1.96E+17
Lead (Pb)	0	3.95E+15	3.95E+15
NO_x	33	2.37E+15	1.59E+15
Particles	0	1.02E+15	1.02E+15
NMVOC	30	8.03E+14	5.62E+14
Benzene	0	7.33E+14	7.33E+14
CO	0	5.94E+14	5.94E+14
PAH	0	2.19E+14	2.19E+14
SO_2	40	2.05E+14	1.23E+14
Cadmium	0	1.30E+14	1.30E+14
Total		2.88E+17	2.03E+17

Based on these assumptions and data the weighting factor for human toxicity for air in Denmark will be:

$$WF_{\text{HumtoxAir, DK}} = \frac{2.88E+17}{2.03E+17} = \text{approx.} 1.42$$

According to the section on normalisation references for human toxicity, the only substance contributing with more than 1% to the normalisation reference concerning human toxicity for water in Denmark is mercury, divided into 90% from air deposition and 9% from wastewater emission. As there are no political reduction targets for mercury deposition from air, the only relevant reduction in this respect is the one concerning emission to the waterways. This issue is regulated by the OSPAR convention, which prescribes a 50% reduction. This leads to the result as shown in Table 11-32.

Table 11-32
Human toxicity for water, Denmark.

Substance/ Activity	Scaled reduction target in %, 1994-2004	Impact potential 1994	Impact potential 2004
Mercury (Hg) water emission	20	7,98E+10	6,38E+10
Mercury (Hg) air emissions	0	8,34E+11	8,34E+11
Total		9,14E+11	8,98E+11

Based on these assumptions and data the weighting factor for human toxicity for Denmark will be:

$$WF_{\text{HumtoxWater.DK}} = \frac{9.14E+10}{8.98E+10} = \text{approx.} 1.02$$

According to the section on normalisation references for human toxicity, the only substances contributing with more than 1% to the normalisation reference concerning soil in Denmark is mercury and arsenic deposited from air, arsenic, mercury and tetrachloroethylene from sludge. Threshold limit values have been established for various substances in sludge when used for agricultural purposes and for heavy metals in air, but there are no national targets for reducing the total load of the substances to soil. Hence, the weighting factors for human toxicity for soil will be one:

$$WF_{HumtoxSoil.DK} = \frac{x}{x} = 1.0$$

11.11.2 Weighting factors for human toxicity at EU level

This section is organised in the same way as under the section on Human toxicity for Denmark. Concerning the legal basis for the reduction targets reference is made to the previous sections.

For human toxicity for air at EU level the only regulated substances are those regulated as regional air pollutants, e.g. NO_x, SO_2 and nmVOC. The reduction targets are thus defined according to the OSPAR convention. The data on which the calculation of the weighting factor is based on appears from Table 11-33 below

Table 11-33
Human toxicity for air, EU.

Substance	Scaled reduction target in %, 1994-2004	Impact potential, 1994	Impact potential, 2004
NmVOC – transport	30	2.15E+19	1.51E+19
Lead (Pb)	0	7.07E+17	7.07E+17
NO_x	33	1.08E+17	7.24E+16
NMVOC	30	7.42E+16	5.19E+16
Particles	0	5.78E+16	5.78E+16
CO	0	3.74E+16	3.74E+16
Benzene	0	3.69E+16	3.69E+16
PAH	0	2.24E+16	2.24E+16
SO_2	40	1.57E+16	9.42E+15
Cadmium	0	1.14E+16	1.14E+16
Total		2.25E+19	1.60E+19

Based on these assumptions and data the weighting factor for human toxicity for EU will be:

$$WF_{HumtoxAir.EU} = \frac{2.25E+19}{1.60E+19} = \text{approx.}1.40$$

According to the chapter on normalisation reference for human toxicity the substances that contribute with more than 1% for water are: mercury from air deposition, mercury from water emission, dioxin from air deposition, lead from water emission, lead from air deposition and zinc from water emission.

However, the only substances for which there have been established reduction targets are: metals from air deposition (20%) and metal from water emission (45%).

Table 11-34
Human toxicity for water at EU level.

Substance/ Activity	Scaled reduction target in %, 1994-2004	Impact potential 1994	Impact potential 2004
Mercury, water emissions	45	1,86E+12	1,02E+12
Zink, water emissions	45	2,02E+11	1,11E+11
Lead, water emissions	45	4,00E+11	2,20E+11
Mercury, air emissions	20	1,54E+13	1,23E+13
Lead, air emissions	20	3,75E+11	3,00E+11
Dioxin, air emissions	20	8,02E+11	6,42E+11
Total		1,90E+13	1,46E+13

Based on these assumptions and data the weighting factor for human toxicity for water at EU level will be:

$$\mathrm{WF}_{\mathrm{HumtoxWater.EU}} = \frac{1.9\mathrm{E}+13}{1.46\mathrm{E}+13} = \mathrm{approx.}1.30$$

According to the chapter on normalisation reference for human toxicity the substances contributing with more than 1% for soil are: arsenic from air deposition, mercury from air deposition, arsenic from sludge, mercury from sludge, chromium from air deposition, lead from air deposition and cadmium from air deposition.

However, the only substances for which reduction targets have been established are: metals from air deposition (20%) and metal from water emission (45%).

Table 11-35
Human toxicity for soil at EU level.

Substance/Activity	Scaled reduction target in %, 1994-2004	Impact potential 1994	Impact potential 2004
Arsenic from air	20	2,82E+10	2,26E+10
Mercury, air	20	1,13E+10	9,04E+09
Chromium, air	20	6,22E+08	4,98E+08
Lead from air	20	5,87E+08	4,70E+08
Cadmium, air	20	4,68E+08	3,74E+08
Arsenic, sludge	0	1,77E+09	1,77E+09
Mercury, sludge	0	7,12E+08	7,12E+08
Total		4,37E+10	3,54E+10

Based on these assumptions and data the weighting factor for human toxicity for EU will be:

$$\mathrm{WF}_{\mathrm{HumtoxSoil.EU}} = \frac{4.37\mathrm{E}+10}{3.54\mathrm{E}+10} = \mathrm{approx}\,1.23$$

11.11.3 Weighting factors for human toxicity at the Global level

There is no basis for establishing weighting factors for human toxicity at global level, as there are no overall global reduction targets for the substances involved in the calculation of normalisation references for human toxicity.

11.11.4 Comparison of existing and new weighting factors

Table 11-36 summarises the weighting factors calculated for human toxicity for the two geographical areas, and compares them to the previously developed weighting factors in the EDIP project.

Table 11-36
Weighting factors for human toxicity.

Category and area	This project	EDIP (Hauschlid *et al.* 1998a)
Human toxicity, Air, Denmark	1.42	1.1
Human toxicity, Water, Denmark	1.02	2.9
Human toxicity, soil Denmark	1.00	2.7
Human tocxicity, Air, EU	1.40	n.a.
Human tocxicity, Water, EU	1.30	n.a.
Human toxicity, Soil, EU	1.23	n.a.

The uncertainty connected with the calculation of the weighting factors for human toxicity is much higher than that of Global Warming and Ozone Depletion. The reason for this is:

- The impact mechanisms are very complicated
- The regulation only covers few of the involved substances
- A lot of the basic data are lacking or inaccurate

11.12 Comparison of existing and new weighting factors

The existing and new weighting factors are summarised in Table 11-37.

Table 11-37
Summary of calculated weighted factors (WF) and comparison with EDIP factors. WFs at global scale have only been calculated for Global Warming, Ozone depletion and Photochemical Ozone, due to the fact that regulation of the other effect categories have not been implemented at global level..

Impact category	New weighting factors 1994 - 2004	EDIP weighting factors, 1990 – 2000
Global Warming, Denmark	1.12	1.3
Global Warming, EU	1.05	-
Global Warming, World, Industrialised countries	1.11	-
Ozone Depletion, Denmark	∞	23
Ozone Depletion, EU	2.46	-
Ozone Depletion, World, Industrialised Countries	63	-
Ozone Depletion, World, Develop. Countries	4.4	-
Photochemical Ozone, Denmark	1.26	1.2
Photochemical Ozone, EU	1.33	-
Photochemical Ozone, World	1.00	-
Acidification, Denmark	1.34	1.3
Acidification, EU	1.27	-
Nutrient enrichment, Denmark	1.31	1.2
Nutrient enrichment, EU	1.22	-
Ecotoxicity, Denmark, Aquatic chronic	1.67	2.6
Ecotoxicity, Denmark, Aquatic acute	1.73	2.6
Ecotoxicity, Denmark, Terrestrial	1.56	1.9
Ecotoxicity, EU, Aquatic chronic	1.18	-
Ecotoxicity, EU, Aquatic acute	1.11	-
Ecotoxicity, EU, Terrestrial	1.00	-
Human toxicity, Denmark, Air	1.42	1.1
Human toxicity, Denmark, Water	1.02	2.9
Human toxicity, Denmark, Soil	1.00	2.7
Human toxicity, EU, Air	1.40	-
Human toxicity, EU, Water	1.30	-
Human toxicity, EU, Soil	1.23	-

11.13 Methodological concerns

11.13.1 Difference between impact category and emission targets

One of the major methodological concerns in connection with establishment of weighting factors is the difference between the scope of the impact category and the regulation and the political targets on which the calculation of the weighting factors are based. Especially for the two impact categories, ecotoxicity and human toxicity there seem to be large differences in the scope of the regulation and the impact mechanisms. In the following some of the aspects connected to this issue is discussed.

11.13.2 Impact category versus substances

In the case of the impact category, Global Warming, Denmark contributes to the global warming with CO_2, CH_4, N_2O, CFCs etc., but the regulation is only directed towards the emission of CO_2. This means that in principle it is only possible to establish a weighting factor for CO_2, but it has to cover the whole impact category.

Weighting factors for CH_4 and CFCs can be established through the regulation of these substances according to other impact categories, i.e. photo oxidant formation and the ozone layer protection. However, there is no regulation of N_2O on which the calculation of weighting factors can be based. This may be a problem, if the LCA of a product has a major component of e.g. N_2O.

11.13.3 Quick phase out

For some substances, e.g. CFCs, a relatively quick phase out has been decided, and obviously it also seems to take place. In such cases the weighting factors will be very high or even infinite. This is the case if the weighting factor is established through dividing the actual emission in 1994 with the supposed consumption of the substances in 2004, where it is supposed to be eliminated.

This will give an infinite weighting factor for one impact category, which will overrule all other impact categories, unless the weighting factor is modified.

11.13.4 Application of weighting factors for different countries

When a product is imported to another country it may have impacts in both countries. The question is which weighting factors should be applied to the product to give a fair assessment in relation to other product that may be imported from a third country with another weighting factor for the same impact category.

The choice will in general depend on the purpose of the weighting. The general recommendation to use EU normalisation references and weighting factors reflects the political prioritisation in Europe, which is relevant if the decision makers or important stakeholders are located in Europe. If the stakeholders are located outside of Europe, e.g. in Asia or the United States, this approach may be less relevant, and the World-wide normalisation references and weighting factors could be used. If should however be observed that these figures are crude estimates, and that the optimal solution would be to derive country-specific weighting factors.

11.14 Recommendation for future updating

For some of the above mentioned impact categories the political targets and regulations are relatively clear and fits very well to the impact mechanisms. In these cases there are usually well-established reporting systems providing reliable data, and it is relatively simple to update weighting factors.

However, in cases where the regulation and the political target setting do not fit the impact category, it requires considerable resources to provide the necessary data. Also in cases where many different substances are involved, it requires considerable resources to collect the necessary data and to adopt them to the established methodology.

It should be considered to simplify the methodology and the calculation procedure in cases where there are larger differences between the impact category and regulation on which the weighting factors are based.

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