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TNO-report
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A CHLORINE BALANCE FOR THE NETHERLANDS

Part 1: Summary and Main Report

Final report

Commissioned by the Ministries of Housing, Spatial Planning and the Environment (VROM), Economic Affairs and Transport, Public Works and Water Management

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PREFACE

In March 1993 the then Minister of Housing, Spatial Planning and the Environment (VROM) promised the Standing parliamentary Committee on Environmental Management that a strategic survey of the closing of the chlorine chain would be carried out. TNO and the Centre of Environmental Science Leiden (CML) performed phase 1 of the survey, which focused on surveying and prioritising emissions.

The study charts around 99% of the flow of chlorine and chlorine compounds in the Netherlands. This result was made possible by the considerable efforts of people both inside and outside TNO and CML. We would like to thank:

- the dozens of people employed in various companies and trade associations for supplying statistics, which were often confidential;
- Mrs. Ali v.d. Plas for the excellent service at the Emission Records;
- staff at the National Notification Centre for Waste Substances (LMA);
- M. Evenblij for his help in compiling the summary for the public;
- the National Institute of Public Health and Environmental Protection (RIVM), for providing us with their earlier analysis on toxicity risks;
- the Supervisory Committee, Technical Working Group and Feedback Group, whose comments greatly helped the quality of this study.

A peer review was carried out on this study which is reproduced in full in an appendix. It refers to a version which was completed on 3 August 1995. It contains a number of valuable comments. This fully underlines the importance of a critical review by experts who have some distance from the intense process of implementing such a complex project. TNO and CML opted to deal with the main points of the commentary as follows in this final version of the report which was not further reviewed (see page 7 of the review).

a) No motivation was given for the choice of methodology (points 3 and 4)

The choice of methodology for assessing toxicity was discussed extensively by researchers, client and the Supervisory committee. Once it was decided for an (interim) assignment, no further motivation was actually given in the report itself. The report now contains a clear consideration of the LCA method, USES-like models and the report on "substances demanding special attention" of the RIVM. The commission cites important shortcomings in the toxicity assessment of the LCA, such as the abstraction from distribution and transformation of substances in the environment. We endorse this criticism. The study therefore evaluates all substances with a LCA-score, on the basis of the most recently established *actual* concentrations to which the environment was exposed, against the background of the risk policy agreed with parliament. Since the exposure statistics used are often

somewhat dated and as emissions seem to be decreasing, the toxicity risks given are more likely to be overestimated than underestimated. The lack of a direct modelled relationship between the surveyed emissions and the concentrations in the environment therefore seems to be less problematic. In our opinion, there is little added value to be gained from using models such as USES. It involves a major extra effort, while USES is not intended for location-specific risk assessment. Twelve substances which did not score according to the LCA-method were not assessed for exceedance of the risk norms.

b) The gaps in knowledge were insufficiently taken into account in the conclusions (point 5)

Fears that the gaps in knowledge will be trivialized emerge in various parts of the review. We endorse this cause of concern. Environmental pressure points which cannot be traced due to gaps in knowledge are, after all, not taken into account in the other phases of the investigation. We regard rectifying these gaps in knowledge as a different kind of priority than solving points which have already been *proven* to form an environmental problem. We continually deal with these kind of priorities in separate paragraphs. The text was revised to reduce as far as possible the chance that gaps in knowledge are trivialized.

c) The reports contains value judgements and unclear passages (point 7)

The commission came across a number of sensitive passages, unclear points and what were, in its view, irrelevant value judgements. These comments were accepted with only a few minor exceptions.

d) The report and the summary are not easily accessible for the wider public

TNO and CML opted for an extensive, scientific summary in the report. Meanwhile, a scientific journalist has produced a simple summary which formed an appendix to the press release.

As researchers, we realise that this report can not be the final word in the highly charged chlorine debate. Firstly, a number of emission figures have not been published; industry cooperated on condition that no figures from individual companies would be presented. The degree of completeness of the survey of emissions is therefore not always easy to assess for third parties. Secondly, there are still gaps in our knowledge. And thirdly, opinions could may differ strongly about how the data must be interpreted in the context of the efforts to achieve sustainable development, even if they base themselves on the same basic data. Reference is made to the clear illustration by the Advisory Council on Government Policy in its report:"Permanent risks: a constant fact" (Duurzame risico's - een blijvend gegeven), which also includes a case study on chlorine. Our intention was, however, to survey facts and uncertainties regarding the degree to which chlorine contributes to environmental problems. The uncertainties identified could

form the basis for specific research to reduce the margins of uncertainty. The facts presented can be used to further clarify the scope for interpretation that remains between the social groups. We feel this report can make a contribution to a structured social decision-making process about chlorine.

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SUMMARY

1 INTRODUCTION

Chlorine is a cheap raw material which is highly receptive to other substances. For this reason, it is a widely used building block in the chemical industry. Although chlorine (compounds) account for only a small percentage of the materials consumed in the economy, the areas of application are highly diverse. Around 60% of consumer products contain materials produced with chlorine (compounds). Examples include PVC, coatings, glues, modified starch, medicines, disinfectants and components of washing powders. Chlorine therefore plays a major role in the functioning of society today.

However, the production and use of some chlorine compounds cause a number of environmental effects. In this context, for some years now there has been a public debate surrounding the use of chlorine (compounds). A number of substances on the EU's black list contain chlorine. These substances are increasingly under the microscope in international negotiations. The Dutch government has followed up international agreements by formulating a stringent policy concerning certain substances containing chlorine. Examples are CFCs, PCBs and PCP. In this context, industry has already taken a large number of measures to reduce emissions and phase out applications.

The Netherlands does not, however, have a specific policy on chlorine in general. However, the Dutch National Environmental Policy Plan (NMP) stated that: "In the future the chemical industry will be asked to study ways of reducing the use of chlorine as a basic material or making it fully manageable in order to reduce the risks to external safety". In this context, the Association of the Netherlands Chemical Industry (VNCI) and McKinsey conducted the study 'Integrated Substance Chain Management'. The purpose of this study was initially to study the entire chlorine chain. Because of the enormous number of applications of chlorine compounds it was decided, however, to limit the study to the development of a method of evaluation. The methodology focused on securing consensus among social groupings on the balancing of environmental safety and economic considerations of various environmental measures.

In March 1993 the Minister of Housing, Spatial Planning and the Environment (VROM) gave a commitment to the Standing Committee on Environmental Management of the Lower House of Parliament for a strategic study which would give an overall picture of the Dutch chlorine chain, the leaks in it and the (im)possibilities of closing them. The Ministry of VROM then prepared a memorandum which divided the exploratory study into 4 phases as described below:

- in phase 1, an inventory would be made of the leaks from the chlorine chain and these would be assessed and prioritised;

- in phase 2, potential measures to close these leaks would be evaluated;
- in phase 3, the need for and extent of measures to be taken or the implementation of alternatives would be investigated on the basis of the results of phases 1 and 2;
- in phase 4, a policy memorandum would be drawn up and presented to the Lower House on the basis of the earlier phases.

Phase 1 was commissioned to TNO and the Centre of Environmental Science Leiden (Centrum voor Milieukunde Leiden - CML), subject to review by the Ministries of VROM, Economic Affairs and Transport and Public Works and industry. The environmental movement declined to take part in the review as it felt the terms of reference for phase 1 were insufficiently focused on its own premise, i.e. the ending of the use of chlorine.

This is a summary of the main report which is in three parts. Part 1 describes the methodology and results. Part 2 discusses in detail the processes and figures for emissions and the use of chlorine compounds. Part 3 gives some methodological background. The summary covers methodology and working methods, a description of the chlorine chain and an assessment of emissions and conclusions in that order.

2 METHODOLOGY AND WORKING METHOD

The TNO/CML study in essence encompassed a substance flow analysis for chlorine and compounds containing chlorine in the Netherlands, linked to the impact assessment step of the Life Cycle Analysis (LCA). The task was to chart at least 95% of the chain and to compare the seriousness of the emissions from it with each other. The base year was 1990. When the study commenced, this was the latest year for which various emission records were complete. A complete chlorine balance sheet has been prepared for that year. Furthermore, the situation with regard to emissions after implementation of the policy adopted as of 1 January 1995 has been forecast on the basis of "concrete" policy proposals derived from regulation or bipartite agreement between industry and government. This refers to reductions to be achieved by the year 2000, except for the phasing out of HCFCs by 2015 and the phasing out of the last (closed) PCB applications by 2005. The analysis involved the following steps:

- a 'skeleton' chlorine chain, divided into 46 segments, was described on the basis of the literature and interviews with experts. Each segment consists of a related group of consumption or production processes (see the fold-out page at the end of this report).

- the flows were quantified, producing an overview of chlorine flows in the economy and from the economy to the environment at the level of detail of types of production process and consumption use. Except for 1990, the emission situation after implementation of the envisaged policy was also inventoried.

- data were entered in a computer program (SFINX) with which groups of segments from the chain were selected along different cross-sections.

- with the aid of the equivalence factors from the LCA methodology, which were also used in the VNCI/McKinsey study, current and future emissions were scored by cross-section/segment group for the environmental themes human toxicity, eco-toxicity, acidification, ozone depletion, global warming, smog formation, odour and the lanfill volume.

- the scores by cross- section/segment group on the 8 themes were weighted and expressed in a single figure so that segment groups could be prioritised. After comparing the priorities for the various cross-sections, a final list of environmental priorities *within* the chlorine chain was established. For the themes human toxicity and eco-toxicity, the LCA method was too crude for the purpose of this study. Substances which scored on these themes were therefore

re-assessed on the basis of the risk policy agreed with the Lower House of Parliament, taking the future situation as the premise for the priority setting.

An extra assessment step for emissions had to be inserted because an outflow expressed as a *quantity of chlorine* in fact says nothing about its seriousness. In view of the goal of the study, i.e. the mutual comparison of emissions that occur at a large number of locations, as with LCAs the assessment of emissions is primarily concerned with establishing their *potential* contributions to environmental themes. The method takes no account of local situations, and for the themes human toxicity and eco-toxicity takes no account of the fate of substances in the environment. For these themes, therefore, the method was used for screening purposes, to select substances for further assessment. The principal criterion adopted for priority setting in this further assessment was whether or not the Maximum Acceptable Risk level (MAR) and the Negligible Risk level (NR) were exceeded. This follows from the outcome of the discussions held with the Lower House of Parliament on policy regarding risks from environmentally hazardous substances.

The study has a number of limitations which are referred to in the terms of reference for the study or agreed with the supervisory committee. The most important of these are:

- external safety and occupational health risks were not studied;
- chains of inorganic chlorine compounds, such as salt, iron chloride and hydrochloric acid were omitted from the study. The discussion of environmental bottlenecks focused specifically on organic chlorine compounds. The study is therefore concentrated on the production of chlorine and the chains in which organic chlorine compounds are used or formed;
- no account has been taken of natural chlorine compounds. For example, we did not identify the relationship between the volume of emissions from the chlorine chain and the quantities and type of chlorine compounds formed naturally;
- to keep the study manageable, the chlorine chain was studied from the perspective of 'chlorine'; in phase 1, emissions or environmental impacts caused by compounds not containing chlorine were ignored;
- emissions were assessed using existing operational assessment methods. The development of specific methods of evaluation for this project fell outside the scope of the research.

Limitations with respect to the extensiveness of the inventory of emissions will be dealt with in the conclusions.

3 SUBSTANCE FLOWS AND EMISSIONS

3.1 Substance flows in the economy in 1990

The figure in the fold-out page gives an overview of the Dutch chlorine chain. The chain is here described in brief. For more detail, see the descriptions by segment in Part Two. All figures are expressed in kilotons of chlorine and apply for 1990 unless otherwise indicated. Segments marked with a * are substances or processes which since 1990 have been or are being phased out.

a. Five companies in the Netherlands produce chlorine, which is usually used at or close to the location. Consumption in 1990 was 486 ktons (segment 1).

b. 1,2-dichloroethane (EDC) is produced from chlorine (149 ktons in 1990) and ethane or hydrochloric acid and ethane. Part of it is cracked to produce vinyl chloride (VCM; segment 2), from which PVC, and to a small extent PVC-copolymers are produced (segments 3 and 4). PVC is largely used in long-life products which accumulate in the community. Short-life and discarded long-life PVC products are disposed of as waste (segment 5). Around 57 ktons were used as EDC in the production of ethylene amines (segment 6). Segment 7 includes the other, limited uses of EDC.

c. 131 ktons of chlorine were used in the production of epichlorohydrine (ECH) via allyl chloride (AC). The ECH is largely used on-site for the production of epoxy resin (segment 8). Some of the AC is sold externally. By-products of ECH production are tri- and dichloropropane (incinerated as waste), and dichloropropene (used as soil decontaminant in agriculture; segment 38). Polymers, flocculants and ECH derivatives are produced externally from ECH. The latter are used to improve for cellulose and paper (segment 10).

d. There were 63 ktons of chlorine used in the on-site production of phosgene, which is used directly in the production of polycarbonate or methylenediphenyldi-isocyanate (MDI; a raw material for polyurethane foam). All chlorine is converted into salt or hydrochloric acid in the process (segments 11 and 12).

e. Aramid fibre is produced via the intermediate product Terephthaloyldichloride (TDC). Chlorine is also released here in the form of chloride (segment 13).

f. Chlorine and acetic acid are raw materials for monochloroacetic acid (MCA; segment 14). From MCA or (imported) chloropropionic acid the pesticides MCPA and MCPP are prepared using chlorine (segment 15). MCA is also used to produce modified cellulose and starch; in this case all chlorine escapes as chloride (Segment 16). 32 ktons of chlorine were used.

g. In a number of mutually linked processes, chlorine (50 ktons in 1990), hydrochloric acid (5 ktons in 1990) and methanol are used to produce dichloromethane, chloroform and tetra (the so-called chloromethanes). Up to mid-1990 perchloroethane (PER) was also produced (segment 17). Chloroform is a raw material for HCFC-22 (segment 18), which is itself a raw material for teflon (segment 19). Tetra is a raw material for CFC-11 and 12 (segment 22*), PER for CFC 113 and 114. For this, 7.5 ktons were used in 1990 (segment 26*). These substances also have, together with imported 1,1,1-tri, tri and other (H)CFCs, other (open) consumption applications. Those of tetra, 1,1,1-tri and (H)CFCs will in fact be phased out in the future. Depending on the substance, these are (Segments 22-34):
   - degreasing, stripping and cleaning agents (e.g. dry cleaning);
   - solvents;
   - propellants;
   - cooling agents;
   - aerosol.

h. From imported 1,1,2 trichloroethane vinylidene chloride is produced, all of which is in turn exported. (Segment 35*).

i. Chlorobenzenes are entirely imported and used for the production of, among others, pesticides and medicines (segment 36) and in consumption applications (segment 37). Pesticides are for the most part imported and used in agriculture, etc.(Segment 38)

j. Segment 39 describes the other imports of organochlorine compounds. These include halon 1211 (phased out after 1994) and chloroethane.

k. Chlorine is also used to produce inorganic substances such as hydrochloric acid, iron chloride and tin chloride (Segment 43; 19 ktons), titanium oxide (Segment 42; 2 kton) and hypochlorite (Segments 40 and 41; 14 ktons).

l. Emissions occur during transport and transhipment (some of it in transit) which can not be easily allocated to any of the previously mentioned processes or consumption applications (Segment 44).

m. Wherever possible, emissions of dioxins and PCBs are allocated to the previously mentioned segments. Diffuse sources are described in segment 45.

n. Waste is released from the aforementioned segments. Waste that is processed internally by companies is included under the relevant production process. External processing of waste is covered in segment 46.

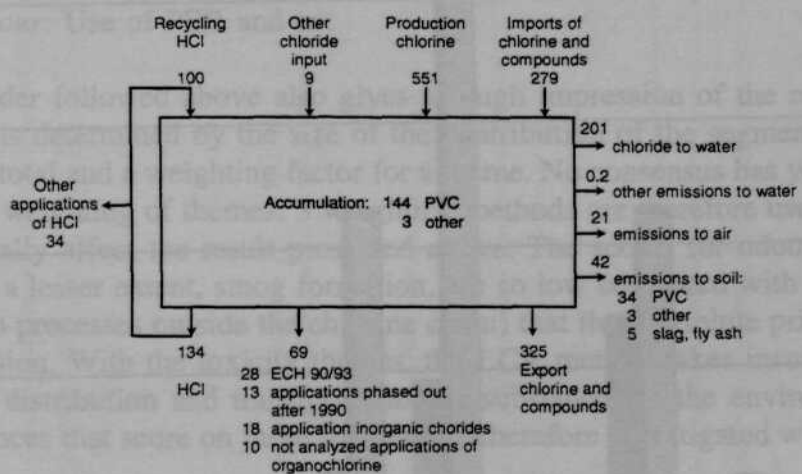
3.2 *Quantification of flows*

Figure 1 shows the total chlorine balance sheet for the Netherlands in 1990. No balance sheet was prepared for the future situation; we have merely quantified the emissions. The total inflow amounted to 939 ktons of chlorine, of which 551 ktons from production of chlorine, 279 ktons from imports and 100 ktons in secondary chlorine: HCl that is released as a by-product of a particular process and used again as a raw material. Furthermore, just over 9 ktons of chloride were introduced into the chlorine chain (especially during waste processing).

One uncertainty in the (significant) PVC imports works its way through into the accumulation presented here (147 ktons), but does not influence any emission figures. The known outflow to the environment was 264 ktons (28% of the inflow), largely in the form of chloride (salt) into water (201 ktons; 21%). There was a further 42 ktons of (principally PVC) waste, emissions of 7 ktons of HCl and 14 ktons of organochlorine into the air and emissions of 0.2 ktons of organic chlorine into water.

The balance sheet has three accounting discrepancies. or AC/ECH, a production balance was only acquired for 1993. Around 28 kilotons more chlorine was used in 1990, which shows up as a difference in the overall balance sheet. Around 13 ktons was not followed because the chlorine application has since been phased out. Inorganic applications, which fell outside the scope of the study, account for 18 ktons. A number of smaller chains of organic applications were not followed further because of a lack of information. This involves around 10 ktons of chlorine. In other words, these are not emissions but flows which were not followed. *In short, the study follows the trajectory of practically 99% of the 939 ktons of inflowing chlorine.*

Figure 1: A chlorine balance for the Netherlands for 1990 (in ktons of chlorine)



3.3 *Evaluation of emissions in 1990 and following adoption of policy*

Introduction

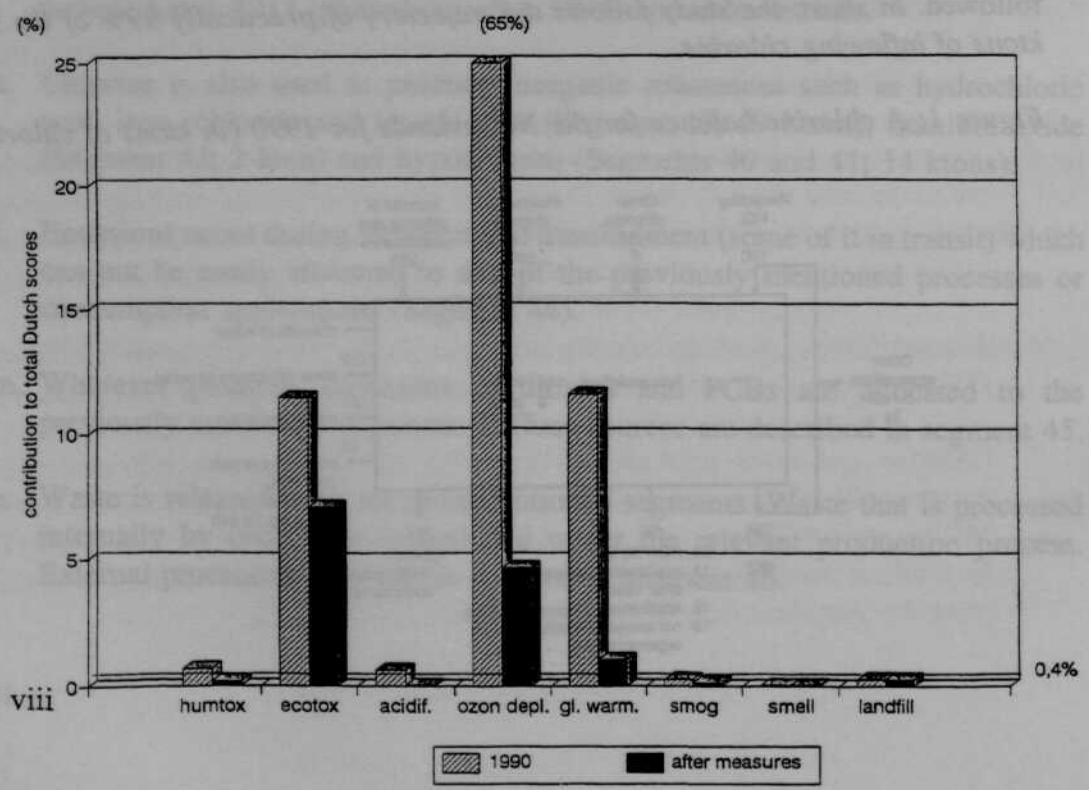
The current and future emissions from the segments of the chlorine chain have been aggregated in different ways for the purposes of assessing the emissions. The following cross-sections were selected:

- emissions by group of segments;
- emissions by substance, aggregated over all segments;
- emissions by life cycle stage: production, use and waste processing;
- emissions by sub-chain (branch) of production and use.

Relative importance of emissions of chlorine

Figure 2 shows the contribution by theme of the emissions from the chlorine chain to the total score for all emissions (including non-chlorine) from economic activities in the Netherlands. For certain themes the chlorine chain's score is low. This is partly explained by the fact that the number of processes in the chlorine chain is small compared with the total number of Dutch processes, and a chlorine chain study of a process excludes all emissions that do not contain chlorine. The figure therefore provides a tentative comparison with the 'average' environmental burden of social activities on the basis of material consumption. Material consumption in the chlorine chain represents around 0.4% of the total material consumption in the Netherlands (see Part III). Proportionally, therefore, the contribution of the chlorine chain to the total Dutch score for each environmental

Figure 2: Score of emissions (containing chlorine) from the chlorine chain on environmental themes as % of Dutch total in 1990



theme should be around 0.4%. The line in figure 2 represents the level for 1990. There are other conceivable bases for comparison, while the calculation is also a fairly rough one. Other assumptions may lead to figures deviating by factors. The 0.4% should therefore be taken as indicative. Even after implementation of the proposed policy, the chlorine chain scores well above average on eco-toxicity, ozone depletion and global warming. The score for toxicity is unreliable because of uncertainties in the total for the Netherlands and significant deficiencies in the scoring method for this theme.

Scores of segment groups in the chlorine chain

The 46 segments were clustered in 32 logically arranged groups. For instance, the use of different CFCs is represented in a single 'CFC' segment group. Figures 3 to 10 compare the scores of the segment groups by theme. The figures show that for almost every theme, the largest reductions were achieved by the highest scoring segment groups. Examples are the major reductions thanks to the phasing out of (H)CFCs and the lower score of waste processing for toxicity and acidification through improved flue gas scrubbing. The existing policy has therefore established the right priorities. According to figures 3 to 10, in the future situation the following segment groups will determine 85% or more of the score on a theme:

1. *Ozone depletion and global warming*: especially the emissions of CFC-11 from the foam accumulated in society and (H)CFCs in some production processes for essential applications;
2. *Eco-toxicity:* the use of pesticides and biocides;
3. *Landfill*: the use of PVC;
4. *Human toxicity*: other consumption applications (especially the use of EDC in pharmacy and diffuse emissions of dioxins and PCP from impregnated wood accumulated in society), the use of DCM and pesticides and the production of EDC/PVC, AC/ECH and chloromethanes;
5. *Smog formation*: the use of DCM and tri;
6. *Acidification*: the production of EDC/PVC and waste processing;
7. *Odour*: Use of PER and tri.

The order followed above also gives a rough impression of the relative priority, which is determined by the size of the contribution of the segment groups to the Dutch total and a weighting factor for a theme. No consensus has yet been reached on the weighting of themes; 3 weighting methods are therefore used. This did not essentially affect the result presented above. The scores for odour, acidification, and to a lesser extent, smog formation, are so low compared with the Dutch total (and so processes outside the chlorine chain) that their absolute priority is open to discussion. With the toxicity themes, the LCA method takes insufficient account of the distribution and transformation of substances in the environment. For all substances that score on these themes, we therefore investigated whether recently

Figure 3: Score on human toxicity caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990. Excl. decomposition in the environment.

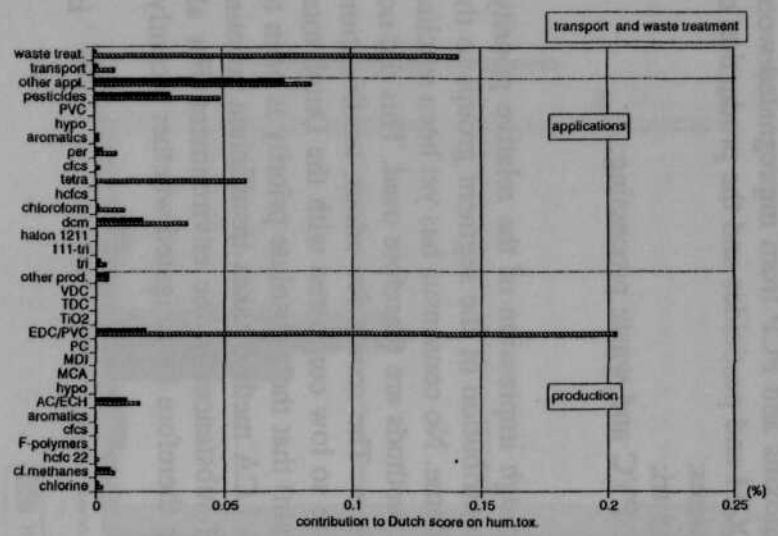


Figure 4: Score on aq. ecotoxicity caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990. Excl. decomposition the environment.

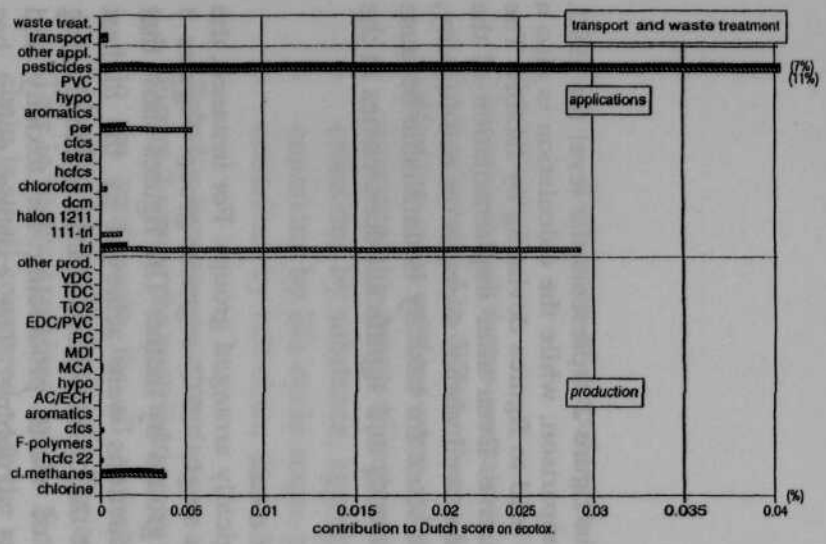


Figure 5: Score on acidification caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990.

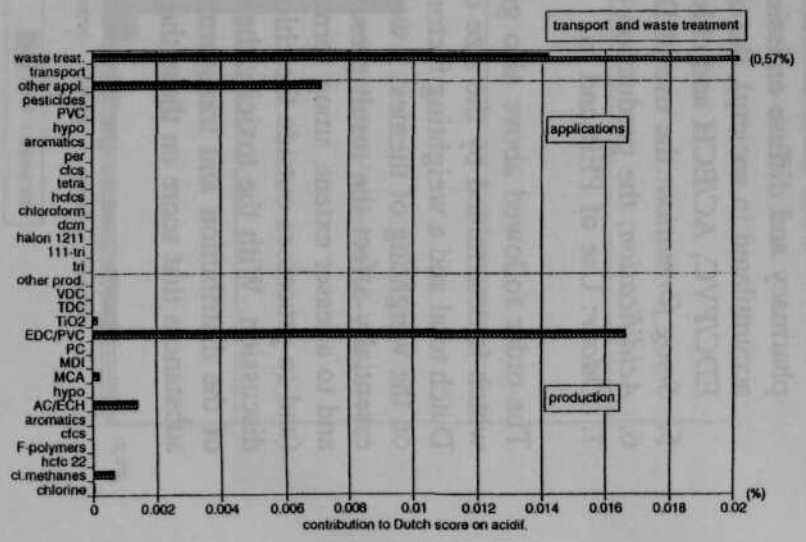
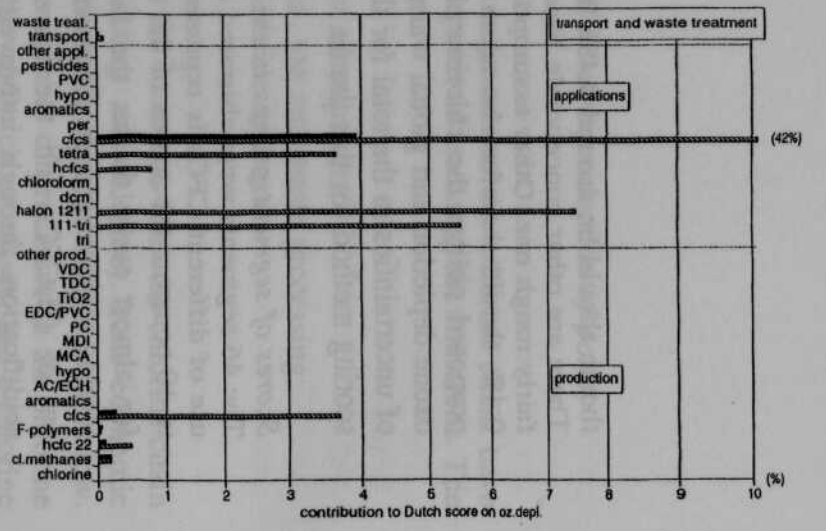


Figure 6: Score on ozone depletion caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990.



1990 after policy

Figure 7: Score on odour caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990.

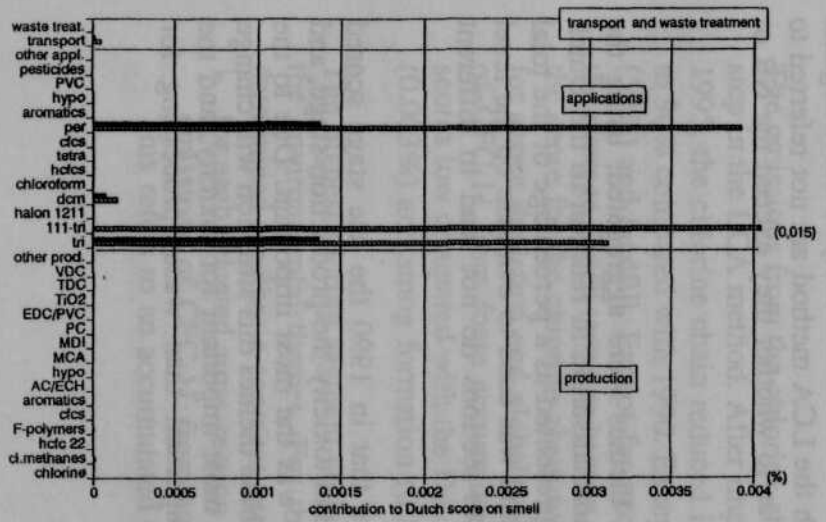


Figure 8: Score on global warming caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990.

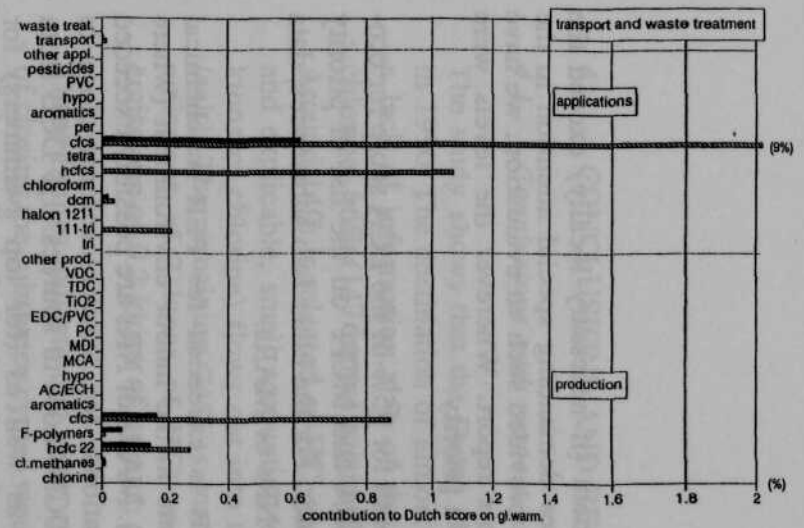


Figure 9: Score on smog formation caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990.

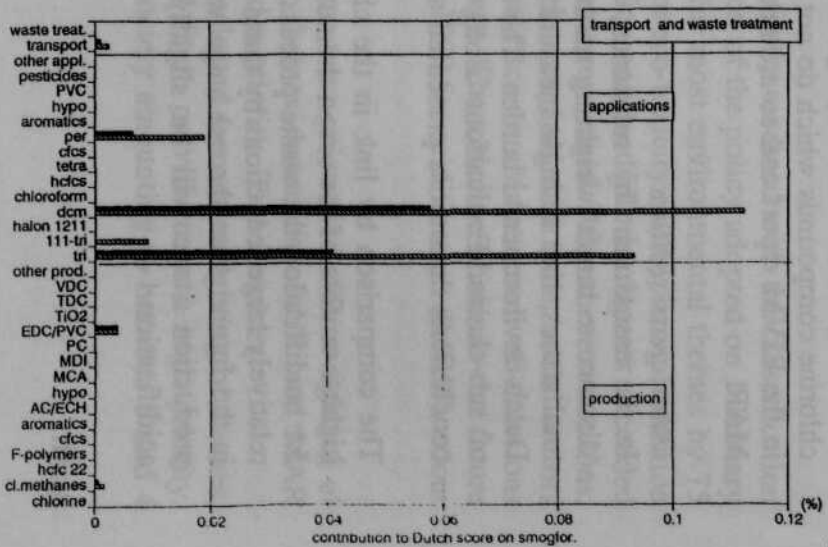
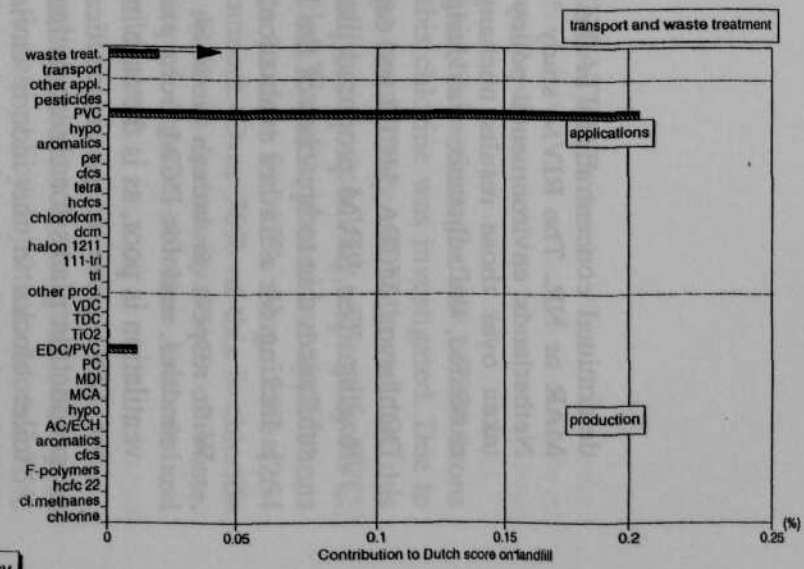
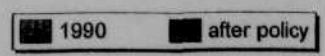


Figure 10: Score on landfilling caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990. Amount calculated in kg chlorine.





determined concentrations *in* the environment (if necessary locally) exceed the MAR or NR. The RIVM study "Substances demanding special attention in the Netherlands' environmental policy" already provided such an evaluation; we have taken over those results unchanged in this report. Wherever the levels were exceeded, the substance was designated as a priority.

Dichlorvos, MCPA, MCPP and captan account for 95% of the LCA score for eco-toxicity. The RIVM proposed placing MCPA and MCPP on the list of priority substances due to breaches of the NR in water. For the other two substances, data is lacking for a further evaluation, such as NRs or MARs.

With respect to human toxicity, the MAR is exceeded for PER in chemical laundries, and for DCM from paint strippers in the indoor environment (where ventilation is poor, as is the case in practice). MARs or NRs are possibly exceeded for EDC close to pharmaceutical applications, for tetra/chloroform close to production plants for chloromethanes, for DCM close to sources. 1,4 DCB from toilet blocks in the indoor environment, as well as (for top swimmers) for chloroform in swimming pools due to the use of hypochlorite. Reaching the target for soil quality will require further reductions in emissions of tri. The risk assessment of dioxins in mother's milk requires further research. For the production of AC/ECH and EDC/PVC exposure data are dated so it is unclear to what extent AC, ECH and EDC still exceed the NR locally, and the effect that the envisaged reduction of emissions of EDC by 90% will have. These segments still score slightly higher in the future with the LCA method than the emissions of dioxins and PCP in the impregnated wood accumulated in society. Twelve organic chlorine compounds which do not score with the LCA method are not referred to in the RIVM report and so are not assessed as to whether they exceed the NR or MAR.

Other cross-sections
In the assessment by substance, scores on themes were aggregated, using the 'distance to target' weighting method after normalisation in relation to the Dutch total scores, into a single measure and then presented as a percentage of the total Dutch environmental burden. The same method was used to evaluate on the level of sub-chains. Evaluations along these cross-sections do not lead to different conclusions than those presented above.

The comparison by link in the chain shows that in 1990 the use stage scored highest on five of the seven themes. For human toxicity the production stage, and for acidification the waste processing stage, was the most important. Due to the relatively large reductions by these links for these themes this situation will change in the future; then the use stage will be the most important for toxicity, and the production stage will be slightly more important than waste processing for acidification.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions with respect to substance flows

The study shows that the Dutch chlorine chain had a through-flow of 939 ktons in 1990. The destination of almost 99% of this chlorine was investigated. Due to a lack of information, 1% of the chain was consciously not followed. Of this chlorine, 16% (147 ktons) accumulates annually in the economy, especially PVC. Around 14% is released as HCl and is recycled. Exports, phased out applications and explicable, small accounting differences account for 41%. Some 28% (264 ktons of chlorine) flows out into the environment. Over 76% of this is chloride (salt). The remaining 24% is made up of 42 ktons (primarily PVC) of waste, emissions of 7 ktons of HCl and 14 ktons of organic chlorine into air and emissions of 0.2 ktons of organic chlorine into water.

These figures indicate that chain management of chlorine in the traditional sense of closing the substance cycles would be a pointless policy objective. Around 76% of the outflow from the chain is salt, usually released into brackish water. This represents a net movement of salt from geological reservoirs to the sea. Given the non-scarcity of salt as a raw material, reversing this flow has no relevance. As stated in the terms of reference for the strategic survey, this applies only for the other outflows: emissions and waste.

4.2 Priority emissions after implementation of the adopted policy

The emissions from the chlorine chain were firstly assessed with the classification step in the LCA method. After implementation of the policy adopted on 1 January 1995, the chlorine chain reduced its scores for most environmental themes by 75 to 90% compared with 1990. Exceptions were eco-toxicity (40%), smog formation (50%) and landfill. Except for ozone depletion and landfill, the figures exceeded the average Dutch target reduction for the theme concerned. After these reductions, the score for the chlorine chain was still high compared with other social sectors for ozone depletion and global warming. These scores are the result of emissions of CFC-11 from foam accumulated in society. The chlorine chain in the future scores low compared with the Dutch total in 1990 for acidification (0.03%), odour (0.003%) and smog formation (0.1%).

The highest scoring segment groups per theme were prioritised after weighting of the environmental themes. For the toxicity themes, breaches of NR and MAR determined whether a segment group formed a priority. This involves:

1. for each selected cross-section and each selected form of weighting of themes, emissions of CFC-11 from accumulated foam proved to be a high priority. This refers to an accumulated stock in society amounting to between 3 and 4

times the score of CFC emissions in 1990 for ozone depletion and global warming. This stock will be released over the next 50 years. This legacy largely overshadows the second priority, i.e. a number of process emissions of (H)CFCs. CFC-11 is already recovered from the limited quantities of foam in discarded refrigerators. This does not yet happen with other foam.

2. the use of the pesticides Dichlorvos, MCPA, MCPP and captan score highly on eco-toxicity, according to the LCA classification step. The RIVM has proposed placing MCPA and MCPP on the list of priority substances due to breaches of the NR in water. For the other two substances there is insufficient information, such as NRs. For pesticides there is a specific framework for assessment, i.e. the approval policy. All approved pesticides have already been assessed for their toxicity risk.

3. the use of PVC scores highly due to the volume of landfill. No account has been taken of a decline resulting from the recycling policy adopted or to an increase due to the extra amounts released of PVC accumulated in society.

4. the contribution of the chlorine chain to acidification (the EDC/VCM production and waste processing), smog formation (use of DCM and tri) and odour (PER use) is low compared to other social sectors. A normative choice determines the level of priority. Reductions may only be sought in sectors which contribute a lot to the overall Netherlands score, but one may also opt to seek further reductions in all sectors, including the chlorine chain, regardless of their absolute contribution. The chlorine chain in fact already achieves reductions on the themes equal to or higher than are required by the general objectives.

5. with respect to toxicity, the MAR is exceeded for PER in chemical laundries and for DCM from paint removers in the indoor environment (in the event, as happens in practice, of poor ventilation). MARs and NRs are possibly exceeded for EDC close to pharmaceutical applications, tetra/chloroform close to production plants for chloromethanes, DCM close to sources, 1,4 DCB indoors, as well as (for top swimmers) for chloroform in swimming pools formed by the use of hypochlorite. The risk assessment of dioxins in mothers' milk requires further research. Emissions need to be reduced further to achieve the target value for tri in soil. In the production of AC/ECH and EDC/PVC the exposure data are out of date and it is therefore not clear whether AC/ECH and EDC exceed the NR locally, and what influence the agreed reduction of emissions of 90% for EDC will have.

In future, for some themes the direct emissions from the chain will be almost as important as historical legacies: emissions of CFC-11 from accumulated foam and emissions of dioxins and PCP from impregnated wood accumulated in society.

This study expresses no opinion about whether products can be produced better with or without the use of chlorine (compounds). Environmental product analyses will have to determine whether their use leads to an increase, or in fact a decrease, in the environmental burden caused by the production of a particular product.

4.3 Gaps in knowledge and recommendations for research

The study has a number of limitations due to gaps in knowledge. TNO and CML make the following recommendations for dealing with these.

Slag and fly ash from incineration plants are contaminated with around 1 kg TEQ of dioxins. It is unclear where, and if so how, these dioxins reach the environment. They are therefore not given a score in this study. Hypochlorite is the subject of debate about whether its use leads to the formation of hazardous organochlorine compounds. Emission figures are only available for aggregate parameters, such as AOX, and not for individual substances, so hypochlorite barely scores on the themes. Given this information, it is conceivable that waste incineration and the use of hypochlorite will be selected for study in phase 2 although no scores have been determined on the themes.

There are a number of (possible) gaps in our knowledge about the occurrence of emissions. A survey of these fell outside the scope of the study. They are:

- the survey of *imports of chlorine compounds in products* is limited to the 8 most important product groups: paint strippers, paint, aerosols, foam, refrigerators, pesticides and products containing PVC.
- the study omits emissions from a limited number of production and consumption chains which were not followed. These use around 1% of the Dutch chlorine flow; 3 ktons of polymer and 7 ktons of other substances, including chloroparaffins.
- in certain cases products appear unintentionally to contain contaminants, which may lead to emissions when they are used. The study has ignored them, with the exception of dioxins and PCBs.
- the survey of emissions for the production stage focused, in accordance with the terms of the study, on dioxins, PCBs and substances included in the Emissions Records of the Ministry of VROM (ER-I), the WIER registration system of the Directorate General for Public Works and Water Management (Rijkswaterstaat), corporate internal environmental plans and a number of LCA databases. The study omits process emissions if they are not covered by these (extensive) databases (chlorinated micropollutants). It is impossible to say anything about whether, and if so to what extent, this leads to gaps in our knowledge about chlorinated micropollutants and whether they include persistent, bio-accumulating and toxic substances (pbt's) with a more than negligible environmental impact.

The gaps in knowledge about imports in products and the chains which were not followed can be solved by a further search of the literature. In principle, it is not known whether emissions still occur in these chains which should be given priority. It is however doubtful whether (further) analysis of these chains will present a structurally different picture than is provided by the 99% of the chlorine chain which has been described. Product contaminants and the forming of pbt's are indeed a structural gap in our knowledge which extends to the entire chain. This last point is an important topic, especially in the United States, in the scientific and public debate about chlorine. The seriousness of the gap is unclear. After 20 years of registration of emissions and environmental policy, are the major environmentally hazardous substances and their sources known? Or do the current measurement and registration programmes still miss small emissions of unknown substances with similar effects to, for example, dioxins? We recommend starting research to fill this gap in our knowledge. This might start with a search of the literature, followed by (if so, to be fleshed out in more detail) analytical-chemical field research.

In the toxicity assessment the LCA method abstracts from the distribution and transformation of emitted substances in the environment. This weakness is compensated by assessing the most recently established, *actual* exposure concentrations in the environment for all substances with an LCA score against the background of the policy towards risk discussed with the Lower House. This approach does not relate surveyed emissions directly to environmental concentrations. Since the exposure data are often out of date and emissions appear to be declining, it would appear that the risks are more likely to have been overestimated than underestimated. We recommend testing 12 non-assessed emissions, which due to the absence of a classification factor also do not score with the LCA method, for breach of the NR/MAR. The assessment of toxicity risks will however continue to raise uncertainties. The level of some ADIs, NRs and MARs, for instance, is still under discussion. Nor is there yet a properly elaborated, widely applicable methodology for the evaluation of exposure to complex mixtures of substances. This study could therefore not take combination toxicity into account.

The previous section described the environmental bottlenecks, established through a survey and assessment of emissions which was, we feel, extensive. This section describes the gaps in our knowledge and areas of uncertainty. Resolving these constitutes a different type of priority than the approach to the proven bottlenecks, but certainly not a less relevant one. A definitive answer to or consensus on how the treatment of these gaps in our knowledge and basic principles is necessary. Only then can it be definitely shown whether the environmental burden from the chlorine chain is acceptable and will it be possible to make judgements in terms of a sustainability assessment. The report of the Advisory Council on Government Policy: 'Permanent Risks - a constant fact' (Duurzame risico's - een blijvend gegeven) can provide valuable reference points for this [WRR, 1994].

PART 1:

MAIN REPORT

A CHLORINE BALANCE FOR THE NETHERLANDS

1 INTRODUCTION

Chlorine is a relatively cheap raw material which is highly receptive to other substances. Consequently, chlorine has become a very attractive and frequently used building block for the chemical industry. Many products used in contemporary society contain chlorine. Examples include polyvinylchloride (PVC), pesticides, glues and bleach. Around 600 of the 4,000 medicines approved for human use since 1984 are organic chlorine compounds [CE News, 1994]. Other products, or the raw materials for them, are made from chlorine, including epoxy resins, modified starch and components of detergents. Although only a small percentage of the materials consumed in the economy consist of chlorine or chlorine compounds, the range of applications is very diverse. Roughly 60% of consumer goods contain chlorine or are produced with chlorine [WRR, 1994], demonstrating the importance of chlorine in today's society.

The literature describes more than 2,000 natural organic chlorine compounds [Gribble, 1994]. Around 10% of the approximately 70,000 commonly used chemical substances contain chlorine, of which 99% are organic. The production and use of chlorine (compounds) does, however, have a number of environmental effects, and most of the substances on the EU's black list contain chlorine. The environmental movement in the Netherlands and elsewhere has been campaigning against chlorine and organic chlorine compounds for a number of years. These substances are increasingly under the spotlight in international consultative fora. Some examples are:

- the ministers' declaration of Paris (Oslo and Paris Commissions, 21-22 September 1992) and the ministers' declaration at the Fourth North Sea Conference (8 and 9 June 1995 in Esjberg) state that by the year 2000 emissions of substances which are toxic, persistent and bio-accumulative (especially organic chlorine compounds) and could reach the marine environment must be reduced to levels that are not harmful to people or nature, with the target of phasing out these substances [NSC-4, 1995];
- the Declaration of Rio [UNCED, 1992] proposes that states could consider giving priority to banning releases of halogenated organic compounds which threaten to accumulate to dangerous levels in the marine environment.

More generally, the Declaration of Rio stipulated the precautionary approach, which is expressed as follows:

In order to protect the environment states should widely adopt the precautionary approach as far as possible. Wherever the threat of serious or irrevocable damage arises, the absence of complete scientific certainty should not be used as an argument for postponing cost-effective measures to prevent harm to the environment.

In response to international agreements, the Dutch government formulated a strict policy with regard to a number of specific groups of organic chlorine compounds. The use of substances such as chlorofluorocarbons (CFCs), polychlorobiphenyls (PCBs) and pentacholorophenol (PCP) has been or shall be banned in the future. Other chlorine compounds have been black listed or have been covered by agreements to reduce emissions within the framework of, for instance, the Rhine and North Sea Action Programme (RAP/NAP), industry's Integrated Environmental Targets (Integrale Milieutaakstelling Industrie) and the Hydrocarbons 2000 project (KWS-2000). As a result of these agreements, industry has already adopted a large number of measures to reduce emissions and develop alternatives in the last decade. The production and use of certain chlorine-containing compounds have also been phased out.

The Netherlands does not, however, have any policy on chlorine and organic chlorine compounds in general. Although the National Environmental Policy Plan (NMP) did state: 'The chemical industry is also requested to study the possibilities of reducing the use of chlorine as a basic substance or to make it fully manageable so that the risks to external safety are reduced' [Ministry of Housing, Spatial Planning and the Environment (VROM), 1989].

In 1990/91 McKinsey was commissioned by the Association of the Dutch Chemical Industry (VNCI), the Ministry of Housing, Spatial Planning and the Environment (VROM) and the Ministry of Economic Affairs (EZ) to conduct a study entitled 'Integrated Substance Chain Management'. The original intention was to study the entire chain. Because of the enormous number of applications of chlorine compounds, however, it was decided to limit the study to the development of a method of evaluation. This methodology is aimed at securing consensus between social groups in balancing the environmental safety and economic considerations of various environmental measures. The methodology was used in four case studies: dichloromethane in the pharmaceutical industry, HCFC-22 in refrigeration equipment, PVC in window frames and polycarbonate in glazing. The results of the study were published in December 1991 [VNCI/McKinsey, 1991].

Besides McKinsey's study, research into chlorine has also been carried out in a number of other contexts. Examples include the study 'Duurzame risico's - een blijvend gegeven' ('Sustainable risks - a constant fact'; which included a case study

on chlorine) by the Advisory Council on Government Policy (WRR), research into integrated chain management and the possible role of that various analytical instruments could play (substance flow analyses, life cycle assessments (LCAs) for products, McKinsey approach) and various LCA-like case studies in the area of plastics. The chemical industry also has a great deal of information (Akzo Nobel, other chlorine producers, EUROCHLOR, the Chlorine Institute, etc.).

Despite all this research, there was no complete picture of the chlorine chain in the Netherlands, leaks in it and the possibility or otherwise of closing them. On 31 March 1993, a meeting took place between Minister of Housing, Spatial Panning and the Environment and the Standing Committee on Environmental Management of the Lower House of Parliament to discuss the Strategy memorandum on the theme of dispersion of pollutants into the environment, at which the minister promised to conduct a strategic survey to produce such a comprehensive picture.

The Directorate for Substances, Safety and Radiation of the Directorate-General for the Environment drew up a memorandum to initiate the survey in consultation with industry and the environmental movement. The memorandum divided the survey into four phases. This report covers phase 1: to produce an inventory and assess leaks from the chlorine chain. The study was financed by the Ministries of VROM, Economic Affairs and Transport, Public Works and Water Management. It was carried out by TNO and the Centre of Environmental Science Leiden (CML).

2 *OBJECTIVE*

2.1 OBJECTIVE OF STRATEGIC SURVEY

The memorandum initiating the survey defines closing the chlorine chain as: "the management of the streams of chlorine and chlorine compounds which arise from social activities". The memorandum defines a leak as the unmanaged portion (emission) of these streams[1]. The goal of the survey is formulated as follows:

To determine, by conducting a strategic survey of the closing of the chlorine chain, the measures that are needed to close the leaks in the chlorine chain.

The survey will take around two years, and is divided into 4 phases:

- *Phase 1*: carrying out a theoretical survey with respect to the following questions:
  a. Where are the leaks in the chlorine chain?
  b. How large/relevant are the risks caused by the leaks from the chain?

- *Phase 2*: preparing an inventory of possible measures to close the leaks in the chlorine chain. Besides the environmental aspects of measures and alternatives, other social interests will also be analysed (such as economic and socio-cultural aspects). The memorandum initiating the survey refers to the VNCI/McKinsey method as a possible procedure for Phase 2.

- *Phase 3*: investigation of whether, and to what extent, it is necessary to take measures or introduce alternatives in the light of the results of phases 1 and 2. If so, the following survey will be carried out:
  a) the investigation by measure/alternative from phase 2 of the organizational possibilities of implementation (in the Netherlands and abroad);
  b) identification of the consequences for organizational structure, manpower, lead time and financing.

- *Phase 4*: the drawing up of a policy document for the Lower House of Parliament. The policy document will be prepared on the basis of the results

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[1] This definition was clarified in the course of the project. Outflow of chlorine in a non-dangerous form, specifically the release of chloride (salt) into brackish water, is not regarded as a leak. In the remainder of this report, the word 'emission' will be used to indicate outflows of theoretically environmentally harmful chlorine compounds (especially organic chlorine compounds). The term 'outflow' is used to indicate the entire flow into the environment (chloride and emissions). See also Appendix 6 (Definitions).

of phases 1, 2 and 3 and general principles of policy, such as the precautionary principle. The intention is to draw it up in consultation with industry and environmental groups.

Even in the framework of the strategic survey, it is impossible to produce a complete inventory of emissions from the chlorine chain. The number of chlorine applications is too large. The intention is to gain an insight into the major leaks and into the possibilities of closing them. The initiating memorandum proposes that the survey should be seen as a first step towards increasing the 'sustainability' of chlorine. The memorandum refers to the following limitations:

- naturally occurring chlorine compounds are not covered by the survey;
- the survey does not consider environmental harm caused by leaks from the chain in the past (such as situations requiring soil remediation);
- external safety during the processing, production and rail transport of chlorine are being studied in a separate context and are therefore not discussed in this study.

2.2 OBJECTIVE OF PHASE 1

This study relates to phase 1 of the strategic survey. In the initiating memorandum, the following elements constitute the objective of phase 1:

It must identify for at least 95% of the chlorine produced, imported or used in the Netherlands how the chlorine has been incorporated permanently in the chain (recycling, safe return to a place where it can cause no harm (as chloride in the sea, etc.) or how it has leaked into the environment (for example, in the form of leachate from pesticides, evaporation of solvents, dumping or release of waste). Where possible, the size and relevance of the risks posed by the leaks from the chain must be quantitatively assessed against the background of the policy concerning risks discussed and agreed with the Lower House.

In other words, the following streams had to be quantified for the 50 or so most important or most representative chlorine sub-chains and/or product chains:

- import;
- export;
- production;
- emission;
- waste flow.

Consequently, we were asked to analyze the production, consumption and waste stages. The memorandum also called for an inventory of the accumulation of substances in the economy which could later cause an outflow from the chain. The request for an analysis of the chlorine *chain* described in the memorandum therefore involved more than simply an analysis of the chlorine *industry* or the *chemical* itself. In the latter case, an analysis of the production stage would have sufficed. A limitation is that the envisaged analysis focuses only on *environmental* risks and not on *occupational health* risks, and furthermore only considers the chain in terms of chlorine. Other types of emission and environmental effects are ignored. Emissions arising from energy consumption and the use of other substances, and issues such as use of space or noise nuisance are ignored entirely. This limitation in phase 1 is necessary because the study would otherwise have been unmanageable. It is also logical, because phase 1 is intended to generate priorities established from the perspective of the use of the substance chlorine as such. The analysis of improvements in phase 2 is intended to produce integrated comparisons of alternatives. In that phase, the options for improvement will be compared on the basis of all relevant environmental effects with the aid of the environmental life cycle assessment of products (LCA).

The objective and structure of the project agreed during the tendering and commissioning procedure were expanded during the execution of the study at the request of the supervisory committee. Initially, the emphasis was on establishing the *priorities for research* in phases 2 and 3 of the survey. For that purpose, a fairly rough estimate of *relative* environmental risks would suffice. During the course of the study, however, it was increasingly felt to be important that phase 1 should already include the most thorough possible assessment of the *absolute environmental risks* still posed by the chlorine chain *after implementation of policy already formulated.* In fact, during phase 1 and prior to phase 3, the expectation was that to some extent an opinion could be expressed concerning the need to formulate supplementary policy. The project was therefore expanded, with the aim of being able, at least in part, to answer this question. With the extension of the terms of reference, the following objectives were added to the project:

- to compare the environmental burden in the existing situation with the burden remaining after implementation of the envisaged policy with effect from 1 January 1995;
- to indicate as far as possible the location-specific human toxicological and ecotoxicological risks from emissions of chlorine compounds on the basis of existing, easily accessible information and with the aid of existing functional methods of assessment. Development of new, specific methods for this project was expressly excluded.

2.3 SUPERVISION OF PHASE 1

A Supervisory committee was appointed for the phase 1 study. The committee consisted of members from:

- the Ministry of VROM (3 members);
- the Ministry of Transport, Public Works and Water Management (V en W);
- the Ministry of Economic Affairs (EZ);
- industry (4 members).

The environmental organizations were also invited to participate on the committee. They were, however, unable to accept the underlying principles of the survey: research into closing the chlorine chain. They felt their own position, i.e. termination of the use of chlorine and chlorine compounds, was not adequately reflected. They therefore declined to participate [SNM, 1993].

The members from VROM were supported by a feedback group, made up of members from the Directorate-General for the Environment (DGM). During the course of the study, interim assessments of results proved to have a strongly substantive character. A Technical working group was therefore appointed. This working group included a number of members who were technical experts from industry. Members of the DGM feedback group and a representative of V en W were also invited to join the working group. The working group's function was to advise the Supervisory committee on the technical aspects of the (interim) results of the study.

The recommendations in the final report were drawn up in consultation with the supervisory committee. The committee is not, however, responsible for the contents of the report. That responsibility rests with the research institutes.

Appendix 7 gives a list of the members of the various committees.

3 *METHODOLOGY AND WORKING METHOD*

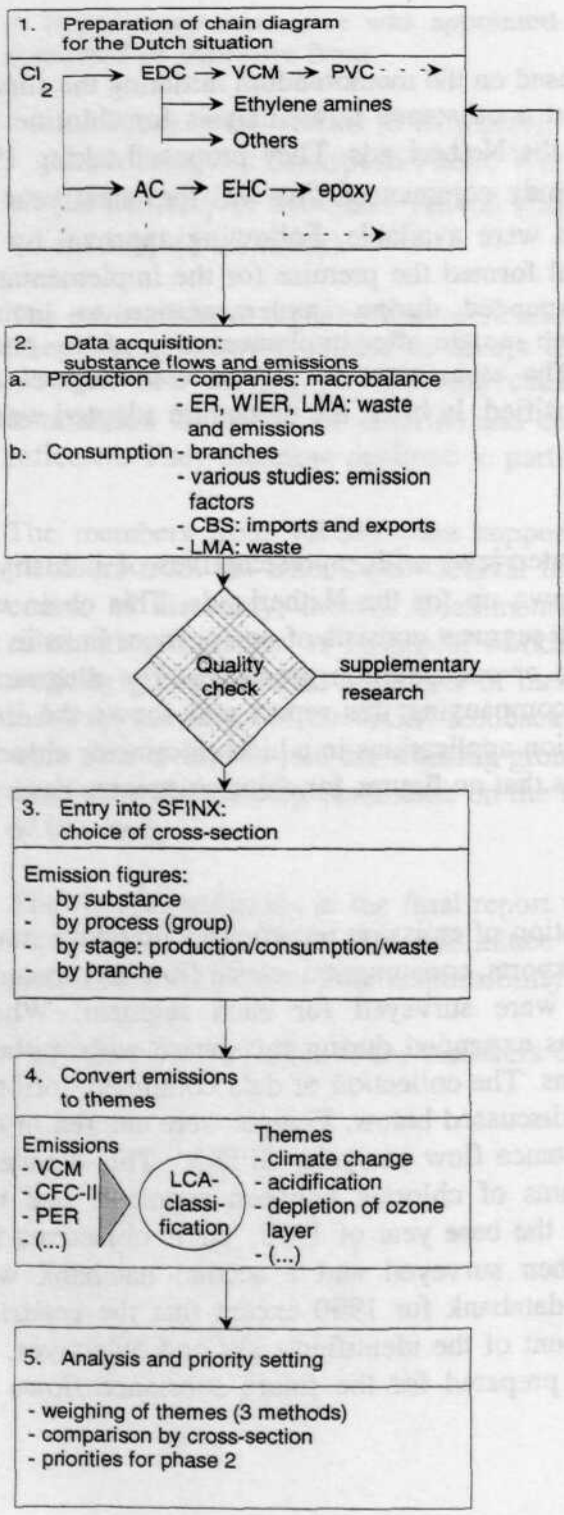
3.1 INTRODUCTION

TNO and CML produced an offer based on the memorandum initiating the survey, in which they proposed carrying out a substance flow analysis for chlorine and chlorine-containing compounds for the Netherlands. They proposed taking 1990 as the base year. At the time the study commenced this was the latest year for which the various emission records were available. Following approval by the supervisory committee, this proposal formed the premise for the implementation of phase 1. The project was expanded during implementation to include determination of the emissions which remain after implementation of the policy envisaged from 1 January 1995. The assessment of human toxicological and ecotoxicological risks was also intensified. In brief, the procedure adopted was as follows (see figure 3.1.1):

- *Step 1:*
  On the basis of literature and interviews with representatives of industry, a 'skeleton' chlorine chain was drawn up for the Netherlands. This chain was broken down into segments. Each segment consists of one or more links in the chain related through production or consumption processes. The diagram is presented in a fold-out page accompanying this report and shows the links between processes and consumption applications in which chlorine or chlorine compounds are used. 'Bare' means that no figures for chlorine streams have yet been entered.

- *Step 2:*
  On the basis of surveys, consultation of emission records and literature study, figures for production, imports, exports, consumption, waste flow and accumulation of chlorine compounds were surveyed for each segment. Where necessary, the chain diagram was expanded during this phase with initially unknown processes or applications. The collection of data continued until the database met the quality criteria discussed below. Figures were entered in the CML's computer model for substance flow analysis, 'SFINX'. This databank contains an outline of the streams of chlorine between segments and the emissions per segment or link in the base year of 1990. 'Hard' objectives for reductions of emissions were then surveyed and a second databank was created. This is identical to the databank for 1990 except that the *emission figures* were revised to take account of the identified tasks and objectives. In other words, no scenarios were prepared for the future substance flows in society.

Figure 3.1.1 Step-by-Step plan for chlorine study



Checkpoints:
- close balances, including imports
- covers all relevant top-40 substances in ER and WIER
- covers all relevant waste producers according to the Dutch Waste Notification System
- covers all emitted substances > 100 kg EOCl from RIZA study
- covers all companies with processes using chlorinated raw materials in ER
- Technical working group/external experts rule out further chains.

Accepted gaps:
- imports in products other than paint, paint removers, aerosols, glue, refrigerators, foams and products containing PVC
- chlorinated micropollutants: process emissions not included in WIER or ER; PCBs and dioxins are complete
- unintentional contaminants in products
- some small branches consiously not followed due to lack of data

- *Step 3*
  Groups of segments or substances from the chlorine chain were selected along various cross-sections with SFINX. These were cross-sections at the level of individual substances, segment groups, stages in the life cycle or sub-chains (entire branches) of the chlorine chain. Using SFINX, the total quantity of each substance emitted was calculated for the selected cross-section in the reference year 1990 and the situation after implementation of envisaged policy.

- *Step 4:*
  The quantity of each substance emitted was multiplied by a measure for its contribution to an environmental theme. So for each cross-section selected, the emission's contribution to the environmental policy themes of human toxicity, ecotoxicity, acidification, depletion of the ozone layer, (enhancement of the) greenhouse effect, smog formation, odour and volume of landfill were determined. This procedure was adopted from the environmental Life Cycle Assessment of products (LCA) and the VNCI/McKinsey study.

- *Step 5:*
  After weighting the scores on environmental themes and comparing the weighted total scores, priorities were established at the level of individual substances, segment groups or entire sections or branches of the chain. The assessment of human toxicity and ecotoxicity according to the LCA method is too rough for the purposes of this study and was only used for screening purposes. Substances or segment groups which scored on these themes were further assessed as to whether they exceeded the Negligible Risk level (NR) and Maximum Acceptable Risk level (MAR). Only after this further analysis was it decided whether they should be regarded as a priority.

Priorities were set on the basis of the situation after implementation of the envisaged policy after 1 January 1995. This is to be implemented before the year 2000, with two exceptions. These are the phasing out of PCBs in closed applications (2005) and HCFCs (2015). For the base year of 1990, a complete substance flow analysis was performed. For the future situation, only the emissions were estimated. Preparing a future balance required a considerable effort to develop scenarios for the use of chlorine compounds. This was regarded as pointless, since only the emissions are relevant for priority setting. The balance for 1990 provided insufficient insight into the degree to which the picture of the Dutch chlorine chain and its sources of emissions was complete.

The following sections deal in greater detail with the procedure followed and the methodology used. Part Two of the study describes how data were collected and

interpreted for each segment. As background, the report includes a fold-out page illustrating the segmentation of the Dutch chlorine chain that we adopted.

3.2 CHOICE OF THE SYSTEM BOUNDARIES

In this study a chlorine balance was drawn up for the base year of 1990. In theory, such a balance takes into account all streams of chlorine and chlorine compounds in the economic system. However, almost 7,000 different chlorine compounds are used worldwide. In practice, it is impossible to follow them all. The analysis is therefore limited in two respects.

First, the study focuses on *the Dutch* chlorine chain. Environmental burden caused abroad due to production of goods produced with chlorine (compounds) and supplied to the Netherlands is ignored. Environmental burden which is caused in the Netherlands through the production of export goods is, on the other hand, included. *Second*, the number of *product chains* to be included had to be selectively curtailed. Inorganic chlorine, with the exception of hypochlorite, was excluded from the study: the risks associated with such chlorides (salts) are of a different order to those of organic chlorine. Nor were chains that were phased out between 1990 and the start of the study followed: detailed insight into substance flows and emissions in 1990 are no longer important for priority setting.

In view of the purpose of the study, a two-fold approach was followed in establishing these restrictions: Top-down, the study focused on following the so-called bulk chemicals. These are compounds for which, on the basis of previous studies, it can be assumed that their consumption and/or production in the Netherlands is greater than 500 to 1000 tonnes a year. Bulk streams must be included to achieve the required coverage of 95%.

The *consumption* and *production* of a substance are not, however, always in direct relation to the size of the risk of the *emission* (leak). In following bulk streams of chlorine, one can easily miss small emissions of high-risk compounds. Total Dutch emissions of dioxins in 1989, for instance, amounted to only around 1 kg of toxicity equivalent. Nevertheless, the associated risks were regarded as so serious that installations emitting them (especially waste incineration plants) were closed and billions of guilders invested in reducing emissions. In this study we therefore also reasoned back from emissions and their associated risks - where they were known - to chains. As a tool for this, a list of 40 substances was drawn up. One of the requirements for the study was - as far as data were available - that it must in any case cover those chains which lead to relevant emissions of one of these

40 substances. The (known) emissions of other substances from these chains should also be included. The list is therefore not a comprehensive list of the substances which were followed in this study. Table 3.2.1. contains the list. Appendix 2 deals with the selection of these substances. In short, they are substances which:

- are used in bulk;
- appear on both the black list and the grey list;
- contribute at least 95% of the score of chlorine compounds to an environmental theme according to the emission data in the Individual Emission Records (ER-I).

A first 'bare' chlorine chain was drawn up on the basis of generally available literature [Akzo Nobel 1990, Berends 1990, ECTOEC 1991, FCI 1992]. This bare chain was filled in with figures concerning substance flows and emissions. Section 3.3. deals in more detail with the sources and validation of data. If necessary, the system limit adopted initially was extended. Some processes had to be added during the collection of data, for instance because balances could not be closed. In this way, the file was iteratively expanded. Section 3.3.3 deals with the quality and degree of comprehensiveness of the file achieved in this way.

Table 3.2.1: List of 40 substances

ORGANIC BULK CHEMICALS	*Various*
C1	α-chlorotoluene (benzyl-chloride)
monochloromethane (methylchloride)	PVC
dichloromethane (methylene chloride)	phosgene
trichloromethane (chloroform)	
tetrachloromethane (tetra)	INORGANIC BULK CHEMICALS
trichloromonofluoromethane (CFC-11)	chlorine
dichlorodifluoromethane (CFC-12)	hydrochloric acid
monochlorodifluoromethane (HCFC-22)	sodium hypochlorite
C2	titaniumtetrachloride
monochloroethane	
1,2-dichloroethane (1,2-EDC)	BLACK LISTED/PRIORITY SUBSTANCES
1,1,1-tricholorethane (1,1,1-tri)	hexachlorocyclohexane
monochloroethene (vinylchloride)	chloroanilines
1,1-dichloroethene (vinylidene)	chlorobenzenes
trichloroethene (tri)	chlorophenols
tetrachloroethene (per)	dioxins
trichlorofluoroethane (CFC-113)	PCBs and PCTs
dichlorotetrafluoroethane (CFC-114)	
C3	SUBSTANCES IN ER-I
1,2-dichloropropane	monochloroacetic acid
1,3-dichloropropene	trichloroacetic acid
3-chloropropene	polychloropropylethers
epichlorohydrine	HCFC 133
C4	HCFC 124
2-chlorine-1,3-butadiene (chloroprene)	HCFC 226

3.3 INVENTORY AND VALIDATION OF INFORMATION

3.3.1 Sources of data about on substance flows and emissions from production processes

Substance flows (in 1990)

TNO approached the selected companies with the request to provide a macro chlorine balance for their processes. Such a balance provides an insight into the various chlorine streams: the use of chlorine or chlorine compounds, the quantity of chlorine outflow in the form of product, the quantity of chlorine that is released into water in the form of chloride (salt) or the quantity of chlorine which is produced as HCl. In all cases, figures were aggregated for a production process. Companies did not indicate how they organized recycling or return flows internally, nor was this necessary for the purposes of the study.

The Dutch market for the compound produced was then estimated on the basis of import and export figures from the Central Office for Statistics (CBS) and EUROSTAT[2] [CBS 1991; EUROSTAT 1991]. This estimated market was compared with the consumption figures in adjoining links in the chain. The Individual Emission Records (ER-I) were also used. This system shows not only emission figures but also the *production figures* in general terms for each recorded process. The stated quantities of waste were compared with figures from the National Notification Centre for Waste Substances (LMA). Finally, the literature had also often provided global production or market figures. In this way, production figures provided by companies were validated or, if necessary, corrected in consultation with the company. Where corporate figures were missing, TNO and CML produced their own estimates from the sources referred to. At the request of the companies, the data is sometimes not given in this study or is given in aggregated form. The analysis of substance flows and emissions is naturally directly based on the data provided by the companies.

A macro balance does not normally show the emissions into air and water (except releases of chloride), which often account for less than one percent of the quantity of chlorine. It also proved difficult, too time-consuming or undesirable for most companies to supply separate emission figures for this study.

Emissions (in 1990)

Data on emissions during production processes were acquired from the ER-I (ER-I, 1994); see the description of the ER-I in the accompanying box. In 1995 most

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[2] EUROSTAT is the European Office of Statistics

companies in the chlorine chain published a (draft) corporate environmental plan (BMP) setting out the emissions that occurred in a number of reference years in the past and the reductions they will achieve by the year 2000. The BMPs are prepared in the framework of the Memorandum of understanding for the implementation of environmental policy in the chemical industry, which sets out the agreements reached between VROM and the chemical industry on reductions

The Individual Emission Registration (ER-I)

The ER-I is a register of the 700 most important companies causing emissions to air and water. Around half are chosen on the basis of recorded emissions during the previous round of measurements. The 350 companies with the highest (for MAC value) weighted total - emissions to air and water are in any case again recorded in the next round. At the request of the Regional Environmental Protection Inspectorates (RIMHs), water quality controllers, and provincial authorities, companies are added to and removed from that list of 350. This allows local government to ensure that companies they regard as significant and/or important are registered. Practically all larger producers of chlorine and organic chlorine compounds are recorded. Consumer applications in smaller companies (e.g. metal and electric industry and chemical cleaning companies) and households are not covered by ER-I.

The ER-I substance list contains around 900 substances. Around 150 of them are chlorinated compounds. The list of registered substances has been created in the last 20 years. The compilers estimate, on the basis of knowledge of the processes in a given company, information about emissions released during them and (public) discussions about emissions, which substances are emitted during a given process. In the record attention is focused on the substances in the list. If necessary, the ER-I substance list is expanded. This happened, for instance, a number of years ago when dioxins were added when it transpired that there were significant emissions from waste incineration plants (AVIs). In principle, the limit for the record has been set at an emission of 1 kg/year. For a few substances posing major risks, this quantity is 1 gram per year. The ER-I records not only source points, but also takes into account the diffuse emissions of a registered company (e.g. emissions to air from tanks and losses via flanges). In short, the ER-I can be expected to cover the major emissions and the most important known substances.

of emissions. The BMPs represented a second source of figures on emissions in the reference year 1990. Finally, we used WIER [RIZA 1994a]. This system concentrates on monitoring emissions into water by around 60 companies of the priority substances drawn up in the context of the Rhine and North Sea Action Programme. These include 11 organic chlorine compounds. Some companies provided figures themselves. *Consumption* emissions, such as the use of solvents, were also included as a 'consumable application' if they occurred at a production plant (see Section 3.3.2).

If for one and the same substance the emissions into water were described in both the ER-I and WIER, preference was given to the figure from WIER. WIER bases itself on measurements of emissions conducted in the context of the license granted for releases. These figures are regarded as the more reliable by those concerned with compiling both ER-I and WIER[3].

Emission figures from the ER-I and WIER were presented to the companies for their reaction and validation. The BMP figures were supplied by the companies themselves, and it can therefore be assumed that companies approve the figures cited. Figures cited here were constantly reported back to the companies. If there were differences between the ER-I, WIER and the BMP, as a rule we consulted the company for an explanation. It was on this basis that TNO and CML chose the figures to adopt for the base year of 1990. Part Two provides detailed reasons in support of those choices.

The use of figures from ER-I and WIER provides no absolute guarantee that a complete picture has been acquired of the chlorine-containing emissions from a given process. ER-I concentrates on the most important, known emissions. WIER focuses on monitoring 11 priority organic chlorine compounds in the context of the Rhine/North Sea Action Programme. For example, up to a few years ago, dioxins were not included in the ER-I and would have been 'missed' if a chlorine study had been conducted at that time. The ER-I sometimes also only states the release of salt into water, while for a number of companies (although not all) the release of extractable or absorbable organic halogenated compounds (EOX/AOX) has since been demonstrated [RIZA, 1994b]. In other words, the release of unintentional by-products has not been completely covered in all cases. Such unidentified emissions shall, until such time as their safety or otherwise has been determined, be termed chlorinated micropollutants. If it is likely that these chlorinated micropollutants contain persistent, bio-accumulating and toxic substances, they are referred to as pbt's.

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[3] From the reference year 1992 the figures in ER-I and WIER will be reconciled.

In this project, no alternative, more thorough approach to the identification of emissions was possible than the one adopted by ER-I, WIER or in drawing up the BMPs. The possibility of supplementing the databases with measurements or in-depth, process-specific literature studies was beyond the scope of this project. After consulting the supervisory committee, it was decided to concentrate on other emissions only in so far as easily accessible literature was available for them. Emissions of dioxins and PCBs proved to be particularly well documented in research by Bremmer et al. [1994], Raad et al. [1993] and Coppoolse et al. [1992]. Emission figures could sometimes be supplemented with those given in a process description prepared by the National Institute of Public Health and Environmental Protection (RIVM) in the framework of the Project for Collaboration on Description of Processes in Industry in the Netherlands (SPIN). A study of foreign literature provided little extra quantitative information. It proved to focus mainly on PCBs, dioxins and processes which are irrelevant to the Dutch situation, such as bleaches from paper pulp [e.g. IJC 1991, 1993a, 1993b, Dolan 1993, FCI 1992, Greenpeace 1994]. The emissions for each process registered in the LCA databases of TNO and CML were also investigated. These two databases contain the data from the LCAs carried out by a large number of domestic and foreign institutes. In contrast to the figures compiled in this project, these are not data from a single company but average values for a process at, for instance, the European level. This, however, was no barrier to a cross-check, which provided practically no new information. It usually showed that the survey described above provided more and more detailed emission data than were included in the LCA databases.

Emissions (after envisaged policy)

For the processes which scored highest in the 1990 situation, we investigated the future reductions in emissions that could be expected. Only 'concrete' measures which had been formulated as of the 1 January 1995 reference date or reductions that had already been achieved by then were included. 'Concrete' measures are regarded as being target reductions which can be enforced by or by virtue of government regulation or to which both the government and the relevant target groups have formally committed themselves. These refer to:

- requirements in licenses that have been issued for reductions of emissions in a reference year in the future;
- agreements in existing memoranda of understanding on environmental targets (IMTs) and covenants, unless consultation with the target group has since shown that the technical feasibility of certain targets is dubious;
- target reductions in Dutch or supranational regulations.

For the chemical industry the Memorandum of understanding for the implementation of environmental policy in the chemical industry, and the BMPs drawn up on

the basis of it, constituted the most important source for estimates of the future emission situation. For each company, and often for each process, the BMPs set out the emission reductions to which the company has committed itself. These are based on targets which have been agreed for the year 2000 in the BMPs. If a substance was not covered by the BMP, the emission figure for 1990 was used. An exception was made if the company had implemented measures to reduce emissions of the substance in the period 1990-1995. In that case, the emissions after implementation of the measures was used as the starting point. No account was taken of the companies' own plans if they were provisional or if they could not be forced to implement them by the government.

3.3.2 Sources of data on substance flows and emissions in consumption applications

Substance flows and emissions in 1990

The consumption applications of chlorine compounds occur in a large number of households and companies. It was naturally impossible to approach them individually. To estimate consumption applications, we therefore decided to use earlier studies, figures from branches of industry, SPIN documents, the collective Emission Records (ER-C)[4], surveys previously conducted by third parties or other monitoring activities. We tried to validate estimates as far as possible by comparing studies that were conducted independently of each other. For many consumption applications, emission factors to water, air and waste were available from studies conducted for ER or SPIN[5]. On the basis of estimated consumption, it was in this way possible to estimate the quantity disposed of in waste and emissions to water and air. The quantity disposed of in waste was compared as far as possible with figures from the database of reported hazardous waste substances of the National Notification Centre for Waste Substances (LMA).

It was sometimes impossible to link the final percentages of a substance to a clear consumption application. In such cases, leaks were estimated on the basis of the average emission factors for other sectors.

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[4] Editor's note for the English translation: the ER-C estimates the emissions from the most important diffuse sources like households, traffic and small unit processes by multiplying an emission factor with an adequate statistical value indicating the economic activity of the source

[5] Editor's note for the English translation: SPIN is a Dutch project that is aimed at producing process descriptions for the most important production processes in the Dutch industry. SPIN documents include emission figures.

It cannot be entirely ruled out that certain chlorinated compounds or products which are themselves chlorine-free but produced with chlorine compounds contain *unintentional contaminants*. For instance, in the production of derivatives of epichlorohydrine (ECH), the chlorine from ECH is converted into chloride (salt) and released into water. According to German research, during production the derivatives are contaminated with organic chlorine compounds. AOX emissions result when the derivatives are used in the paper industry [Mobius, 1990]. Whether, and if so to what extent, such problems could occur could not be systematically and quantitatively investigated in this study. In consultation with the supervisory committee it was decided to formulate this point as a recommendation for further research.

Emissions (future situation)

For the consumption applications that scored highest in the situation as of 1990, we investigated the likely reductions of emissions in the future. As with process emissions, only 'concrete' measures which had been formulated or implemented by 1 January 1995 were included. For consumption applications the most important measures are laid down in:

- agreements in existing IMTs and covenants;
- reduction targets in Dutch or supranational regulations;
- regulations governing the implementation of technical measures for certain activities.

Here also the tasks and objectives which were still under discussion were not included. An example is the proposal to ban dichloromethane in paint removers. Wherever 'concrete' data about emission reductions were lacking, the emission figures for 1990 were retained. The analysis does not taken into account any growth or decline in the market for a particular consumption application.

3.3.3 Quality of the compiled data set

As stated in section 3.2., the data set was compiled as completely as possible through an iterative process. In principle, we tried to close all balances before 1990 unless there was a reasonable explanation for the difference (such as stock differences and normal inaccuracies). In this way, we acquired a data set which - on the production side - encompassed in any case the following companies:

- companies with production processes which lead to relevant emissions included in ER-I and WIER. Companies that were not regarded as relevant could account in total for a maximum of 5% of the emissions recorded in WIER or

ER-I of one of the 40 selected substances listed in table 3.2.1 [ER-I 1994, RIZA 1994];

- companies that were covered by the AOX/EOX study that RIZA carried out in mid-1992 and which according to that study released more than 100 kg/year of EOX into water [RIZA 1994a][6];
- companies with production processes from which, according to the National Notification Centre for Waste Substances, more than around 30-50 tonnes of chlorine a year in waste containing halogenated hydrocarbons (HHC) is released [v.d.Steen 1991][7];
- companies where, according to the ER-I, there are process installations in which, according to the literature, chlorine or chlorinated substances are used as a raw material[8].

We consciously decided not to follow selected chains representing 1% of the chlorine flow. No companies or consumers could be found through the above sources or suppliers. Either no reference could be found in generally available literature (such as the VNCI manual, the ABC Guide and guides to chemicals) to companies which could use such a compound, or telephone enquiries showed that references to the effect that they did were inaccurate. The chains not followed are listed in Table 4.2.1. On the basis of information from the producer or other sources, it is likely that the chain diagram on the fold-out page is otherwise comprehensive. For a more detailed motivation, see the description of segments in Part II.

On the consumption application side, all substances followed are allocated for 100% to accumulation or emissions to water, air and waste. An exception is a quantity of chloroform and a number of smaller import flows (see Table 4.2.1).

It is possible that import flows that are not explicitly registered as products containing organic chlorine by the CBS[9] were missed. These would probably be fine chemicals and products which contain chlorinated compounds (e.g. medici-

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[6] None of the companies that release less than 100 kg of EOX use chlorinated compounds as a raw material.

[7] This system constitutes a compulsory record of deposits of (dangerous) chemical waste, except where it is deposited in small-scale chemical waste depots.

[8] Partly to calculate emissions, the ER-I includes, among other things, data by company on types of process and quantities of product produced per process per year.

[9] Imports and exports of most products containing chlorohydrocarbons, such as paint removers, paint, glue, foam, refrigerators and PVC (products) and pesticides are included.

nes). This study has in any case ignored organic chlorine compounds which are imported as contaminants in products[10].

On the quality of emission figures for production processes, see section 3.3.1. On the validation of figures for consumption applications, see section 3.3.2. Briefly, on the production side the study in effect includes all emissions of dioxins, PCBs and the emissions in WIER, BMPs and the ER. The study has missed process emissions which are not specified in these (extensive) databases. The consumption applications side is balanced, if we ignore contaminants from products and imports of chlorinated compounds in certain products. The study has also missed emissions which occur in that 1% of the chlorine chain which was not followed.

3.4 DATA PROCESSING AND ASSESSMENT OF EMISSIONS

3.4.1 Data processing

The data collected was processed using the computer program SFINX (Substance Flow InterNodal eXchange) to produce a coherent picture of chlorine management in Dutch society. The program was used like an accounting system, in which all substance flows and emissions were entered. The program requires that all substance balances are closed for all links in the chain. It therefore constituted an important tool for checking the consistency of the data supplied by the various parties as described in section 3.3.3.

With the aid of SFINX it was possible to select different cross-sections from the chlorine chain and to determine the total emission figures for these cross-sections. The following cross-sections were chosen:

- emissions by group of segments;
- emissions by substance, aggregated over all processes;
- emissions by life cycle phase: production, use and waste processing;
- emissions by sub-chain (branch) of production and consumption.

Part III provides more background information on how SFINX was used in this study. The following section discusses how emissions from these cross-sections were assessed. SFINX files were created for both the base year of 1990 and the

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[10] One might expect that some of the substances concerned are non-volatile, which will ultimately emit primarily into water. RIZA is unable to properly explain household emissions into sewage pipes of 20 to 30 tonnes of AOX [RIZA 1994c]. If one assumes that this gap has to be covered by similar diffuse sources, the impression could be given of the quantities concerned.

situation after implementation of the envisaged policy from 1 January 1995. The file for the future situation is identical to the file for the base year. Only the outflow to the environment (emissions) was revised on the basis of the expected effects of policy measures.

3.4.2 Assessment of emissions according to the LCA classification step

The outflow from the chain expressed as a quantity of chlorine provides absolutely no indication of absolute or relative environmental risks. A kilo of salt and a kilo of dioxins contain comparable quantities of chlorine. The first quantity is consumed by an average family in a few months; the second quantity is assessed as an environmental bottleneck justifying investment of billions of guilders in flue gas treatment. The outflow therefore has to be assessed in one way or another. We opted to prioritize emissions by scoring them on their *potential* contribution to various environmental themes deemed important in Dutch environmental policy. This gives an indication of the emissions initially deserving of priority in phases 2 and 3 of the survey; the overall picture of the chlorine streams through the entire chain is primarily of importance for the question how they should be prioritized. The scoring method for emissions was adopted from the environmental life cycle assessment for products (LCA). It was used earlier in the previously mentioned VNCI/McKinsey study. Scores were given on the following environmental themes (also known as environmental problems):

- human toxicity;
- (aquatic) ecotoxicity;
- acidification;
- depletion of the ozone layer (also referred to as ozone depletion: ODP);
- (enhancement of) the greenhouse effect (also known as global warming: GWP);
- photochemical smog formation
- odour nuisance;
- volume of landfill.

So-called equivalency or classification factors were used for the scoring. The factors are taken from the CML Guide for environmental life cycle assessment of products [Heijungs et al., 1992]. This Guide is currently regarded as one of the leading reference works for the performance of environmental life cycle assessments, both in the Netherlands and elsewhere. The Guide's classification and characterization step is one of the most detailed methods of scoring emissions of substances across a broad set of environmental themes. The factors closely match the approach adopted in the Uniform Substance Evaluation System (USES) and the

so-called environmental policy performance indicators, which are used as a monitoring instrument in environmental policy [Adriaanse, 1993].

Equivalency factors are drawn up by substance and by theme. They are a measure of the *potential* contribution of the substance to the various themes. By multiplying the emission of a substance by the factor, the emission is, as it were, translated into a potential contribution to a theme. In this way, emissions of various substances are denominated under the eight themes referred to. Formula 3.4.1. shows the general structure of the calculation. For the selection of relevant themes, the determination of the equivalency factors, the elaboration of the method of calculation by theme and further background information, see Part III and the LCA Guide [Heijungs, 1992]. The calculations were made with emission figures for 1990 and emission figures for the situation post-implementation of the envisaged policy from 1 January 1995. We deliberately did not assess on the theme of terrestrial ecotoxicity because the set of equivalency factors for this theme is far from complete, which would result in meaningless, structurally underestimated scores on this theme. An assessment on the theme of aquatic ecotoxicity is assumed to provide an adequate (initial) insight into ecotoxicological bottlenecks.

$$S_{i,e} = Q_{i,e} * M_e \qquad (3.4.1)$$

Where: $S_{i,e}$ = score of the emission of substance (e) on theme i;
$Q_{i,e}$ = equivalency factor of the emitted substance (e) for theme i;
M_e = size of emission (e)

This scoring method has the following limitations:

- the set of equivalency factors has gaps, especially for aquatic ecotoxicity and to a lesser extent for human toxicity. In this study, further equivalency factors were drawn up for human toxicity and the remaining gaps appear to be reasonably acceptable. Reasons supporting this are in Appendix 4. See also Part III, chapter 1;
- the method assesses generically and fails to take account of the time and location of the emission. Local concentrations and threshold values are not taken into account. The *potential* contribution to a theme may consequently be underestimated or overestimated compared with the effect occurring *in reality*. One example is an emission that leads to very high local concentrations and serious effects, while on the other hand a diffuse emission in a concentration below a threshold value leads to no actual effects;
- the method does take into account exposure-effect relations in assessment of human and ecotoxicity, but does not yet take into account the behaviour of the substance in the environment. Distribution over the environmental compart-

ments, metabolite formation and a decline in concentrations through the decomposition of a substance are ignored[11].

The memorandum initiating the chlorine chain study states that 'risks (...) should be assessed where possible against the background of the policy concerning risks discussed and agreed with the Lower House of Parliament'. Because of the limitations referred to, the LCA method gives insufficient insight into the themes human toxicity and ecotoxicity. For these themes, therefore, the LCA impact assessment was used for screening purposes. Substances that scored on these themes are then re-assessed with another method. Only then is an assessment of the toxicity risk given. This extra step in the assessment is dealt with in the following subsection.

3.4.3 Further analysis of toxicity, weighting and priority setting

The scores on the various environmental themes can produce different results for each emission. When a specific emission produces a high score for depletion of the ozone layer compared with the other emissions, for instance, the score for acidification may be relatively low. In order to set priorities, it may therefore be necessary to weight scores on different environmental themes against each other and aggregate them. The scientific and public debate on weighting and the principles to be adopted for it is still going on [SETAC-WIA 1994; RMB 1994]. To allow for this, in this study scores of emissions from a process (group) on the different themes were expressed in *three* ways in a single measure:

1. As a first step, the scores on each of the eight themes are *normalized* by expressing them as a percentage of the score of *all* Dutch emissions. For each theme, this gives an impression of the contribution of emissions from a process (group) in the chlorine chain to the total score for the Netherlands. LCAs also normalize at the level of global or European totals. The geographical delineation of the system for the chlorine chain study is the territory of the Netherlands. The most logical and clearest step is to normalize at the level of the Dutch total.

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[11] The USES and other (generic) assessment systems available since 1994, which use so-called level III Mackay models, do not have this disadvantage. VROM commissioned a study into the implementation of the USES in the LCA assessment step for the toxicity themes. This study could not anticipate the result of that project. Such multi-media models must be 'supplemented' with a large quantity of substance properties and data about the physical environment. For the Netherlands, the latter are available in USES; an inventory of substance properties would have called for a disproportionate amount of effort in this project, however.

2. The normalized scores on the eight themes can be weighted and aggregated to a single measure, which can be regarded as the integrated environmental burden of the segment group concerned. This allows priorities to be set among them. A (tentative) comparison with a measure for the overall Dutch environmental burden is also possible. This is calculated by integrating the total Dutch score on the eight themes using the same procedure. In a recent LCA of processing options for plastic waste, weighting factors were developed on the basis of the 'Distance to target' (DTT) approach [Sas, 1994]. The weight of a theme is calculated by dividing the current total score for the Netherlands on a theme by the policy objective for the year 2000. The degree to which the objective is currently exceeded therefore influences the weighting factor. In this method, it is assumed that a 1% exceedance on one theme is as important as a 1% exceedance on another theme. Table 3.4.1 gives a list of weighting factors.
3. Depletion of the ozone layer is very dominant due in part to the very high DTT weighting factor. This is partly because policy is focused on phasing out substances that deplete the ozone layer. Table 3.4.1 shows that depletion of the ozone layer accounts for over 73% of the total of the weighting factors. This influence is clarified by also calculating an integrated score in which depletion of the ozone layer is given a weight of zero.
4. The procedure can also be carried out without weighting factors. In adding them up, each theme is then in fact given a weight of 1. This is an alternative way of acquiring an insight into the influence of weighting on the priority setting.

Formulas 3.4.2 and 3.4.3 show the normalization and weighting steps. As weight sets for W in the three methods of integration we therefore chose:

- the weights from table 3.4.1;
- the weights from table 3.4.1, with a weight = 0 for depletion of the ozone layer;
- a weight = 1 for all themes.

$$N_{i,e} = S_{i,e} / A_i \quad \text{(normalization)} \qquad (3.4.2)$$

$$X_e = \Sigma_{i=1..n} W_i * N_{i,e} \quad \text{(weighting and integration)} \qquad (3.4.3)$$

Where:
- X_e = the integrated, weighted score in a single measure over themes 1 t/m n of emission (e), also known as environmental-index
- W_i = weight of theme i ;
- $N_{i,e}$ = normalized score of emission (e) on theme i;
- $S_{i,e}$ = score of emission (e) on theme i;
- A_i = current total score of all Dutch emissions on theme i

Table 3.4.1: Table of weighting factors and the share of a weighting factor in the sum of the weighting factors

ENVIRONMENTAL THEMES	WEIGHTING FACTOR	% OF THE SUM OF THE WEIGHTING FACTORS
human toxicity	0,85	0,18 %
aq. ecotoxicity	0,85	0,18 %
acidification	2,6	5,4 %
ozone depletion	35,3	73,2 %
global warming	1,2	2,5 %
smog formation	2,3	4,8 %
odour	2,0	4,1%
landfill	3,1	6,4%
TOTAL	48,2	100 %

The future scores are normalized and weighted in the same way as those for the base year. The advantage is that the assessments of emissions in the two situations remain easy to compare. However, the methodology is open to discussion. For instance, the future effect scores are normalized at the level of the total Dutch effect scores for 1990. Furthermore, weighting factors derived from policy objectives for 2000 are used, while the emission situation concerned will sometimes only be reached in the year 2005 or later[12].

Emissions which score as a result of their contribution to human toxicity or ecotoxicity were further assessed. Such emissions are regarded as a priority if this further assessment indicates toxicological risks for people or the environment. The assessment is performed on the basis of a survey by the RIVM of the so-called 'substances demanding special attention' [Janus, 1994]. This report presents a toxicological risk assessment for each substance (demanding special attention) based on the most recent figures for the *actual* exposure concentrations *in* the environment. The exposure concentrations are the combined result of transport,

[12] Implicitly, this method is also used in every LCA for long-life products. Window frames, for instance, have a life of dozens of years; the emissions relating to the waste phase of this product will therefore occur long after the year 2000. In an LCA, however, this aspect is usually ignored. The emissions are added up over the entire life cycle regardless of the point in time, and then usually normalized on the basis of the Netherlands' or European total effect scores for 1988 or 1990.

accumulation and conversion of a substance that has been emitted. The RIVM systematically focuses on preventing local *worst-case* situations involving exposure. An example is the relatively high concentrations at point sources. The Negligible Risk (NR) and Maximum Acceptable Risk (MAR) constitute the most important assessment criteria. With respect to substances for which a limit can be established below which concentration no further effect occurs (threshold value), this is the MAR for humans. For substances without a threshold value, the MAR is defined as the concentration at which it is estimated, on the basis of linear extrapolation, that the chance of death is one in a million per annum. The MAR should also protect ecosystems. In practice, the approach taken is one in which protection of 95% of species is ensured. The NR is the concentration below which the risk of effects which can be regarded as negative occurring is deemed to be negligible. This NR is 1% of the MAR. This framework for assessment is in line with the results of the discussions with the Lower House of Parliament about the policy regarding risks from environmentally hazardous substances.

Part III discusses normalization, weighting and the associated data used and the assumptions made, in greater detail. Part II also provides a further analysis of substances which scored on human toxicity and ecotoxicity in this study. Leaving aside the appearance of gaps in our knowledge, such a procedure should be sufficient to establish priorities among the emissions.

3.4.4 The chlorine chain and other processes - a benchmarking procedure for environmental burden

After integration, the relative priority of emissions within the chosen system (the chlorine chain) is acquired. This, however, does not answer the question of how 'well' or 'badly' the chlorine chain scores compared with other social sectors which contribute to the environmental burden in the Netherlands. Such a comparison calls for the selection of a key by which the current environmental burden in the Netherlands can be allocated to different social sectors. Comparison of the actual burden with the allocated burden indicates whether the sector scores relatively 'well' or 'badly' on a given theme. A feasible basis for such a benchmarking procedure could be [see, for example, Smeets et al., 1994]:

- the quantity of environmental burden per guilder of added value in the chlorine chain versus that for the Netherlands;
- the quantity of environmental burden per employee in the chlorine chain versus the average environmental burden per Dutch employee.

As with the weighting, there is no scientific or social consensus on this topic. We have opted to use material streams as the basis for comparison. According to an analysis in Part III, the material consumption in the chlorine chain is around 0.4% of the total consumption of materials in the Netherlands' economy. Relatively speaking, the chlorine chain should therefore also contribute around 0.4% to the total Netherlands score for each environmental theme. A rough calculation, with the added value as the allocation key, shows a similar figure in terms of the order of magnitude. The basis of comparison chosen is essentially random, however, while the calculation is also fairly crudely produced. Other assumptions may lead to figures which diverge by factors. Finally, a major criticism of such allocation methods is that they are premised on a confused, pound-for-pound division of environmental burden between social sectors. A sector is compared in every aspect, regardless of its function, with an 'average' environmental burden. Carried to extremes, for instance, water consumption in the drinking water production sector would be compared with average water consumption in the Dutch economy. This would be to ignore the fact that in macroeconomic terms it would be useful and logical to permit a sector, given its function, an above-average burden on one aspect and a below-average burden on other aspects. To sum up, the figure of 0.4% must be seen as primarily indicative.

In principle, such a benchmarking procedure also opens up the possibility of a comparison with sustainability levels. For the Netherlands, a sustainable level would then have to be chosen for each theme, a portion of which is allocated to the sector to be evaluated [see inter alia Buitenkamp, 1992; Buise, 1993]. The choice of level to be regarded as sustainable has important normative elements, however [see inter alia WRR, 1994]. These lead, for global warming for example, to a margin of choice of a factor of 10 or more [v.d. Loo, 1994]. Partly in view of the uncertainties described earlier in the benchmarking procedure itself, this framework of assessment is, with the current state of the social and political discussion about sustainability levels, insufficiently robust to use in this study. The *policy* objectives that have been set by the politicians in the NMP are, furthermore, less stringent than the most tentative derived sustainability levels [see e.g., Adriaanse, 1993]. Basing ourselves on sustainability levels would therefore mean that in this study the evaluation would be far more stringent than in the policy that has been formulated for other target groups of Dutch environmental policy.

3.5 HIATUSES, LIMITATIONS AND REASONING OF THE APPROACH ADOPTED

Within the framework of this study, we have chosen to use existing, operational methods of assessment. Developing a separate method of assessment specifically

for this project would have been beyond the scope of the study. To sum up, the approach ultimately chosen is based on a substance flow analysis, supplemented by an extensive inventory of emissions from various records linked to the LCA impact assessment step. The final assessment of the toxicity risks is based on the RIVM report "Substances demanding special attention in the Netherlands Environmental Policy." Due to missing or incomplete information and flaws in the assessment method, the approach adopted has the following limitations:

- the record of emissions includes almost all known, easily accessible data on measured and recorded emissions. Given the limitations of current knowledge we can consider the record to be very comprehensive. However, the chance that there are important omissions in terms of effect cannot be ruled out. This is especially true of pbt's and product contaminants (see section 3.3.3).;
- emissions are sometimes not given in usual terms, but rather, for example, as the sum of parameters for EOCl or AOX. These can be expressed in terms of their weight in kilograms of chlorine but cannot be scored on their contribution to the themes;
- the study looks at the chorine chain purely in terms of chlorine. The environmental effects caused by emissions which do not contain chlorine and environmental effects unrelated to substances containing chlorine, have been ignored. This limitation was necessary in phase one as the study would otherwise have been too vast. By means of a wider, LCA-like method, the priorities from phase one will be compared with alternatives in phase 2;
- the equivalence factors in the LCA Guide are incomplete, particularly in relation to ecotoxicity and, to a lesser extent, human toxicity[13]. The chlorine compounds concerned are listed in Appendix 4. In some cases, factors have been calculated and added to the list in Part III of this study;
- particularly with regard to ecotoxicity, the Dutch total score contains uncertainties which could amount to a factor 2 or more. The normalization stage (comparison with the Dutch total) for this theme therefore contains serious inaccuracies. There are also uncertainties in the Dutch total for human toxicity, odour and smog formation, but these are significantly smaller and seem to be acceptable. Part III, chapter 1.11 discusses this in greater detail;
- the scoring method does not take local situations into account and could therefore both overestimate and underestimate the actual effects;
- the scoring method takes no account of the quality of the various chlorine streams within the economic system. For example, it does not reveal whether

[13] This is mainly due to the absence of data on toxicity which produces a bottleneck in every form of risk assessment, not just LCA.

there are bottlenecks in the recycling of waste or whether encapsulated hydrochloric emissions could be reused.

- the LCA scoring method is based on a greatly simplified view of real life, especially with regard to human toxicity and ecotoxicity. It ignores diffusion over environmental media, metabolite formation and decrease in concentration due to decomposition of a substance. For these themes, therefore, the LCA method is used mainly for screening purposes in order to select emissions which should be subjected to further analysis.

At the present stage of methodology development, the LCA impact assessment step is the most detailed method of quantitatively and comparatively assessing emissions which occur in many different locations over a wide range of environmental themes. The most important shortcoming is that the diffusion and transformation of substances in the environment is neglected when assessing human toxicity and ecotoxicity. These limitations do not apply to the USES and other systems which use the level-III Mackay multi-media models. However, no LCA classification factors defined on the basis of such models are as yet available for toxicity themes, and calculating such classification factors within this project would have taken a disproportionate amount of effort. It would entail surveying and processing a sometimes extensive amount of information on the properties of each substance. Furthermore, no Dutch total scores in USES terms are yet available, scores which are essential to the normalization stage. In principle, this assessment with modified classification factors is generic and not location-specific. It should, however, be noted that in certain cases the USES does allow for assessments which are more location-specific.

The analysis in the RIVM report "Substances demanding special attention in the Netherlands' Environmental Policy" which has been adopted in this study, does give an assessment with a detailed insight into local, *worst case* situations. The RIVM report compares the latest available, *actual* concentrations in the environment with the MARs and NRs for a substance. Given the downward trend in emissions (see part II), this assessment based on exposure data which is frequently already outdated appears to overestimate rather than underestimate the toxicity risks. The lack of a direct, schematic correlation between the emissions surveyed in this study and the concentrations in the environment therefore seems less of a problem. The added value of using USES-like models which do make such a connection appears to be limited. The extra effort required is extensive. Furthermore, the USES is not intended for location-specific risk assessments. With the approach adopted, it is impossible to make any judgements about exceedance or otherwise of the NR or MAR for substances not dealt with in the RIVM report.

Part III, chapter 2.2 gives a more detailed analysis of the advantages and disadvantages of using the LCA method, multi-media models and the report on "Substances demanding special attention" as a basis for assessing the risks of toxicity. Incidentally, none of the methods satisfactorily considers combination toxicity and metabolite formation; an increase or even decrease in the effects of exposure to a combination of substances. Current knowledge in the area of combination toxicity is still limited. As far as we know, there are no widely applicable operational methods of assessment available which do take such factors into account.

4 *SUBSTANCE FLOWS AND EMISSIONS FROM THE CHLORINE CHAIN*

4.1 SUBSTANCE FLOWS IN THE ECONOMY IN 1990

The figure in the fold-out page gives an outline of the Dutch chlorine chain. The *structure* of the chain is here described in brief. The chlorine chain is divided into segments. A more detailed description of processes and consumption applications, chlorine streams and the way in which figures were acquired for each segment is given in Part Two. See below for the relevant section number. The structure is explained in more detail below. All figures relate to 1990, are expressed in kilotons of chlorine and are exclusive of internal company recycling, unless otherwise indicated.

a. Five companies in the Netherlands produce chlorine, which is usually used at or close to the location. Consumption in 1990 was 486 kt (segment 1).

b. 1,2-dichloroethane (EDC) is produced from chlorine (149 kt in 1990) and ethene or hydrochloric acid and ethene. Some of it is cracked to produce vinyl chloride (VCM; segment 2), from which PVC, and to a small extent PVC-copolymers are produced (segments 3 and 4). PVC is largely used in long-life products which accumulate in the community. Short-life and discarded long-life PVC products are disposed of as waste (segment 5). Around 57 kt were used as EDC in the production of ethylene amines (segment 6). Segment 7 includes the other, very limited uses of EDC.

c. 131 kt of chlorine were used in the production of epichlorohydrine (ECH) via allylchloride (AC). The ECH is largely used on-site for the production of epoxy resin (segment 8). Some of the AC is sold externally. By-products of ECH production are tri- and dichloropropane (incinerated as waste), and dichloropropene (used as soil decontaminant in agriculture; segment 38). Polymers, flocculants and ECH derivatives are produced externally from ECH. The latter are used to improve cellulose and paper (segment 10).

d. There were 63 kt of chlorine used in the on-site production of phosgene, which is used directly in the production of polycarbonate or methylenediphenyldi-isocyanate (MDI; a raw material for polyurethane foam). All chlorine is converted into salt or hydrochloric acid in the process (segments 11 and 12).

e. Aramide fibre is produced via the intermediate product Terephthaloyldichloride (TDC). Chlorine is also released here in the form of chloride (segment 13).

f. Chlorine and acetic acid are raw materials for monochloroacetic acid (MCA; segment 14). From MCA or (imported) chloropropionic acid the pesticides

MCPA and MCPP are prepared using chlorine (segment 15). MCA is also used to produce modified cellulose and starch; in this case all chlorine escapes as chloride (Segment 16). 32 kt of chlorine were used.

g. In a number of mutually linked processes, chlorine (50 kt in 1990), hydrochloric acid (5 kt in 1990) and methanol are used to produce dichloromethane, chloroform and tetra (the so-called chloromethanes). Up to mid-1990 perchloroethane (PER) was also produced (segment 17). Chloroform is a raw material for HCFC-22 (segment 18), which is itself a raw material for teflon (segment 19). Tetra is a raw material for CFC-11 and 12 (segment 22), PER for CFC 113 and 114. For this, 7.5 kt were used in 1990 (segment 26). These substances also have, together with imported 1,1,1-tri, tri and other (H)CFCs, other (open) consumption applications. Those of tetra, 1,1,1-tri and (H)CFCs will in fact be phased out in the future. Depending on the substance, these are (Segments 22-34):

   - degreasing, stripping and cleaning agents (e.g. dry cleaning);
   - solvents;
   - propellants;
   - cooling agents;
   - aerosol.

h. From imported 1,1,2 trichloroethane, vinylidene chloride is produced, all of which is in turn exported. (Segment 35).

i. Chlorobenzenes are entirely imported and used for the production of, among others, pesticides and medicines (segment 36) and in consumption applications (segment 37). Pesticides are for the most part imported and used in agriculture, etc.(Segment 38).

j. Segment 39 describes the other imports of organic chlorine compounds. These include halon 1211 (phased out after 1994) and chloroethane.

k. Chlorine is also used to produce inorganic substances such as hydrochloric acid, iron chloride and tin chloride (Segment 43; 19 kt), titanium oxide (Segment 42; 2 kt) and hypochlorite (Segments 40 and 41; 14 kt).

l. Emissions occur during transport and transhipment (some of it in transit) which can not be easily allocated to any of the previously mentioned processes or consumption applications (Segment 44).

m. Wherever possible, emissions of dioxins and PCBs are allocated to the previously mentioned segments. Diffuse sources are described in segment 45.

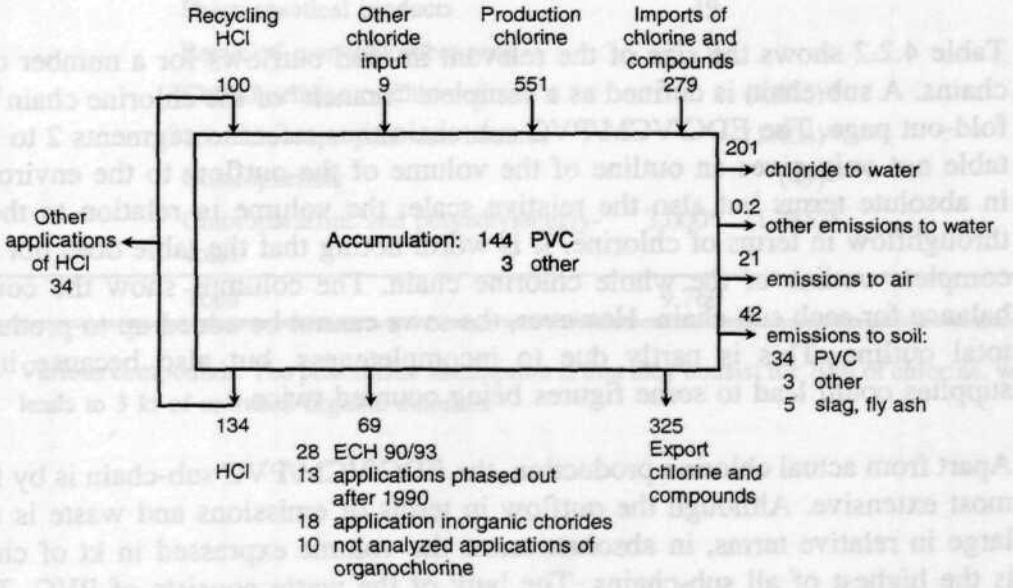
n. Waste is released from the aforementioned segments. Waste that is processed internally by companies is included under the relevant production process. External processing of waste is covered in segment 46.

Certain processes which lead to a large consumption of chlorine abroad do not occur in the Netherlands. This applies for example to the use of chlorine to bleach paper pulp and the production of chlorobenzenes and propylene oxide. The latter is made in the Netherlands but by means of a chlorine-free synthesis method.

4.2 THE DUTCH CHLORINE BALANCE IN 1990

Figure 4.2.1 shows the total chlorine balance in the Netherlands in 1990. No balance has been made of the situation after implementation of the envisaged policy from 1 January 1995. Only the *emissions* to the environment have been estimated and assessed for this situation (see reasons given in section 3.1).

Figure 4.2.1: Chlorine balance in the Netherlands in 1990 (in kt chlorine)



In 1990 the total inflow of chlorine amounted to 939 kt, of which 551 kt came from chlorine production. Approximately 11% of the inflow consisted of secondary chlorine: HCl produced as a by-product in a certain process and used again as a raw material. About 279 kt of (organic) chlorine compounds are imported. Furthermore, about 9 kt of chloride is introduced into the chlorine chain (especially via waste-processing). An uncertainty in the (significant) import of PVC influences the accumulation figure (147 kt), but does not affect emission figures. The known outflow from the chain to the environment was 264 kt chlorine (28% of the inflow). This concerned 201 kt of chloride (salt), mainly discharged into salt water. In addition there were emissions of about 21 kt to water and air and 42 kt to the soil (mainly PVC-waste).

There are three accounting discrepancies in the balance. There is only a production balance for AC/ECH for 1993. About 28 kt more chlorine was used in 1990 and this appears as a difference in the total balance. About 13 kt was not traced as the use of chlorine has since been phased out. Inorganic uses, which were beyond the scope of this study, accounted for 18 kt. Due to a lack of information we did not follow some smaller chains of organic uses; they are listed in table 4.2.1. These involved about 10 kt of chlorine. These are not emissions but streams which have not been followed. *Briefly, the study traces 99% of the 939 kt of chlorine inflow in 1990.*

Table 4.2.2 shows the size of the relevant in- and outflows for a number of sub-chains. A sub-chain is defined as a complete "branch" of the chlorine chain on the fold-out page. The EDC/VCM/PVC sub-chain thus refers to segments 2 to 7. The table not only gives an outline of the volume of the outflow to the environment in absolute terms but also the relative scale: the volume in relation to the total throughflow in terms of chlorine. It is worth noting that the table does not give a complete outline of the whole chlorine chain. The columns show the complete balance for each sub-chain. However, the rows cannot be added up to produce the total outline. This is partly due to incompleteness, but also because internal supplies could lead to some figures being counted twice.

Apart from actual chlorine production, the EDC/VCM/PVC sub-chain is by far the most extensive. Although the outflow in terms of emissions and waste is not so large in relative terms, in absolute terms the volume expressed in kt of chlorine is the highest of all sub-chains. The bulk of the waste consists of PVC. This is true also for the accumulation in the economy. This is not in itself harmful but could be an indicator of a future increase in PVC waste which will need to be processed.

The third largest is the chloromethanes sub-chain. The fourth largest sub-chain is the ECH/allylchloride chain, from which outflow in the form of emissions and waste is relatively small; the largest outflow here is chloride. The emissions from the pesticide and 1,1,1-trichloroethane chain are also worth noting - they are small in absolute terms but relatively large (100% of the inflow!).

Table 4.2.1: Substance chains not followed (in tons of chlorine; in brackets tons of substance)

Segment	Substance	Quantity in 1990	
4	PVC-copolymer	3.000	
9	Allylchloride	800	
10	Epichlorohydrine	1.083	
	Copolymer	168	
	Dichloropropanol	108	
	ECH derivative	988	
14	Monochloroacetic acid	101	
21	Chloroform	100	
36,37	Other chlorinated aromates	385	
	Pharmaceutical products	19	
	Recycled monochlorobenzene	9	
39	Chloromethane or chloroethane		(1.375)*
	1,2 dichloropropane and butanes		(1.404)*
	Chlorophenols		(49)*
	Chloroparaffins and polyethyleneglycoles	3.000*	(1.385)*
	Total	9.760	

* Various compounds. The pessimistic assumption is that they consist for 70% of chlorine, which leads to 3 kt of untraced organic chlorine.

Table 4.2.2: Chlorine balance per sub-chain in the figure on the fold-out page in 1990 (in kt of chlorine)

Sub-chain:	Chlorine	EDC/VCM/-PVC	AC/-ECH/-epoxy	MCA	Chlorome-thanes	1,1,1-tri	VDCM	Aromates	Pesticides	Hypochlorite	TiO_2
Includes segments:	1	2-7	8-10	13-16[2]	17-30	31	32	36-37	38	40-41	43
In											
prim.chlor.prod	551	-	-	-	-	-	-	-	-	-	-
import	29	c	3	1	49	4	4	3	1	1	-
dom. supply	-	c	103	32	58	-	-	-	0	14	2
dom. supply HC1	-	c	-	-	5	-	-	-	-	-	-
TOTAL IN	580	420	106	33	112	4	4	3	1	16	2
Out											
emiss.and waste	0	45	4	0	16	4	0	0	1	0	0
salt releases	-	57	69	7	7	-	2	2	-	14	2
dom. supplies	486	-	-	-	-	-	-	v	-	-	-
releases of HC1	-	-	22	14	52	-	-	-	-	-	-
export	94	171	7	11	35	-	3	v	-	2	-
unknown	0	3	3	0.1	0	-	-	0.4	-	-	-
TOTAL OUT	580	276	106	33	110	4	4	3	1	16	2
ACCUMULATION	-	144	-	-	2	-	-	-	-	-	-

1): Figures for 1993

2): Including use of MCPA in segment 38

c: Confidential

N.B.1 Additions sometimes not correct due to difference in rounding off

N.B.2: Due to deliveries between sub-chains and the absence of some sub-chains in the table, adding up the inflow and outflow items for the sub-chains in the table here will not give the total balance in Figure 4.2.1.

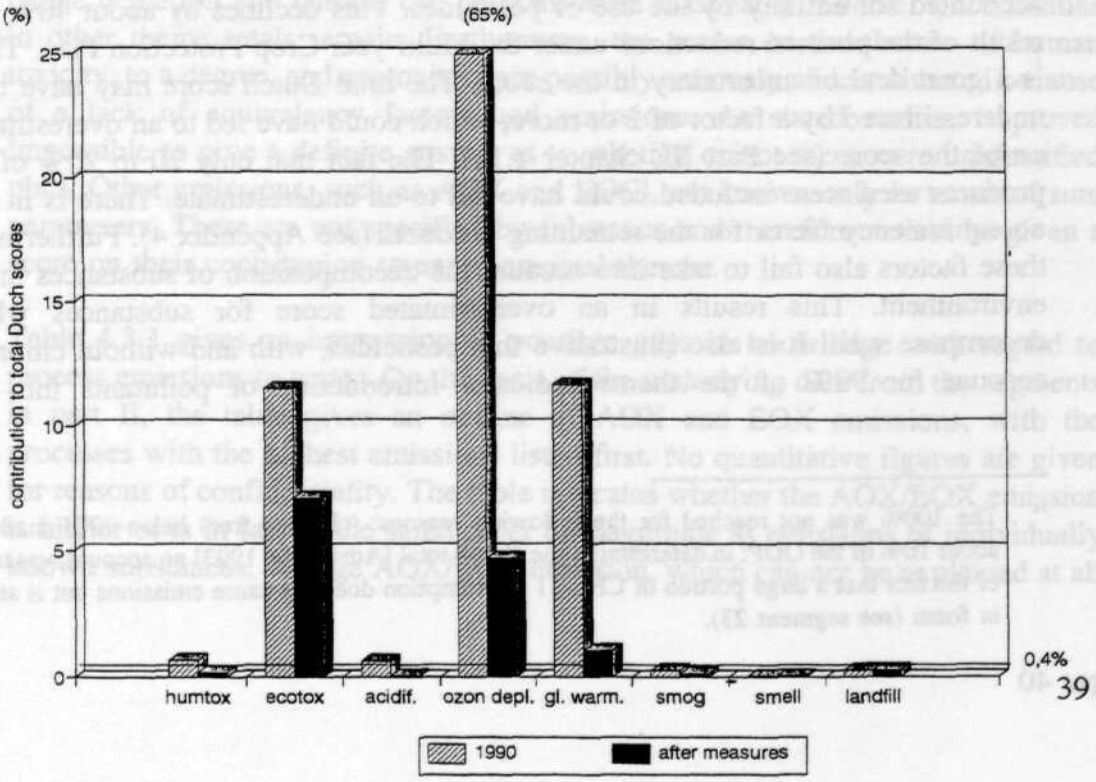
4.3 TOTAL EMISSIONS IN 1990 AND AFTER ENVISAGED POLICY

This section places the chlorine chain in the context of other environmentally harmful activities in the Netherlands. It also gives an insight into the reductions which should result from the policy envisaged from 1 January 1995.

Figure 4.3.1 compares the emissions from the chlorine chain in 1990 with the total Dutch emissions, expressed as a contribution to the environmental themes mentioned in § 3.3.1. The Dutch total in 1990 is set at 100%. Part III gives details of the data on which this Dutch total is based. The figure also gives the score of emissions from the chlorine chain after implementation of policy already formulated in relation to this same Dutch total in 1990. A direct comparison between reductions in the chlorine chain and the national reduction targets is given in section 4.4.4; figure 4.3.1 is less useful for this purpose.

The chlorine chain has a low score on a number of themes. This can be partly explained by the limited number of processes in the chlorine chain compared to the total number of Dutch processes. Furthermore, a chlorine chain analysis of a process only considers emissions *which contain chlorine*. Figure 4.3.1 in itself therefore provides no basis for stating how "well" or "badly" the chlorine branch scores by comparison with other sectors.

Figure 4.3.1: Score of emissions from the chlorine chain on environmental themes as % of the Dutch total in 1990. Scores for 1990 and after envisaged policy.



For this reason we have made a tentative comparison with a Dutch average. Calculations in Part III of this report show that the use of material in the chlorine chain amounts to about 0.4% of the total consumption of material in the Dutch economy. In proportion, the chlorine chain should therefore contribute about 0.4% to the Dutch total on each environmental theme. The line in figure 4.3.1 shows this level for 1990. There are other conceivable means of comparison and the calculations were made rather roughly. Different assumptions could lead to figures which differ by factors. The 0.4% should thus be seen as indicative. No comparison was made between the present and future share of the chlorine chain in the desired sustainability levels. No reliable figures have yet been developed for sustainability levels in terms of LCA scores.

In 1990 the chlorine chain accounted for 65% of the Dutch score on ozone depletion[14]. The most important cause was the production and use of CFCs, halon 1211, tetra, 1,1,1-trichloroethane and, to a lesser extent, HCFCs. In 1990 these substances were also largely responsible for the 12% contribution to global warming. After the phasing out of HCFCs (from 2015) and remaining substances (from 1995), the contributions to ozone depletion and global warming will decline to 5% and 1% of the Dutch total in 1990 respectively. Given the complete phasing out of the above-mentioned substances, this is surprisingly high. Emissions from processing and use will indeed play a subordinate role in the future: the scores result mainly from the emissions of CFC-11 from foam which has accumulated in Dutch society.

The score on aquatic ecotoxicity came to 12% of the Dutch total in 1990, accounted for entirely by the use of pesticides. This declines by about 40% as a result of the planned reductions under the Multi-year Crop Protection Plan. There is a great deal of uncertainty in the score. The total Dutch score may have been underestimated by a factor of 2 or more, which could have led to an overestimation of the score (see Part III, chapter 1.11). The fact that only 20 to 25% of the products used were included could have led to an underestimate. There is in fact no equivalency factor for the remaining products (see Appendix 4). Furthermore, these factors also fail to take into account the decomposition of substances in the environment. This results in an overestimated score for substances which decompose well. It is also illustrative that pesticides, with and without chlorine, account for 90% of the theme indicator introduction of pollutants into the

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[14] The 100% was not reached for the following reasons: (chlorine-free) halon 1301 made up about 10% of the ODP; in determining the Dutch total [Adriaanse, 1993] no account was taken of the fact that a large portion of CFC-11 consumption does not cause emissions but is stored in foam (see segment 23).

environment in the annual Environmental Progress Report [VROM, 1993e]. They are therefore possibly "penalised" in the various assessment methods by doing precisely what they were intended to do: protecting against (undesired) organisms. They have, however, already passed a statutory approval procedure and in that sense they are a consciously accepted emission. In its report on "Substances demanding special attention", the RIVM states that for most pesticides containing chlorine "in view of the approval procedure the risks to *humans* are minor to negligible" [Janus et al., 1995] However, the score cannot be completely ignored: in connection with exceedance of the NR in water, the RIVM recommends putting substances such as MCPA and MCPP on the list of priority substances unless sufficient reductions are achieved [Janus et al., 1995].

At 0.3% of the Dutch total in 1990, the score for landfilling is about average. This quantity is calculated as chlorine and not as volume of product (especially PVC). In reality, therefore, there is more landfill than indicated here. The future score is uncertain because no account has been taken of the possibility of extra releases of residue from the purification of chlorine-containing flue gas or of PVC still accumulated in society or, indeed, of a decrease in landfill due to PVC-recycling. Chlorine compounds make up about 0.5% of the Dutch total on human toxicity and smog formation in 1990, about the same as the Dutch average. Their contribution to acidification and odour was even smaller. In future, the scores on acidification and human toxicity in particular will be significantly reduced.

The level of the totals for a theme is a cause of uncertainty in the figure. This applies especially to ecotoxicity. The totals for acidification, global warming, ozone depletion and landfill can be considered reasonably reliable. Uncertainties in other theme totals remain. Furthermore, the scores on the themes of human toxicity, to a degree, and ecotoxicity are possibly seriously underestimated because of a lack of equivalency factors and emissions. As stated earlier, it proved impossible to give a definite answer as to whether or not there were unidentified pbt's. Other emissions, such as AOX and EOCl, are known only in terms of sum parameters. These are not specified by substance and therefore cannot be given a score on their contribution to environmental themes.

Table 4.3.1 gives an impression of possible gaps in knowledge with regard to process emissions to water. On the basis of the underlying data from the segments in part II, the table gives an outline of AOX and EOX emissions, with the processes with the highest emissions listed first. No quantitative figures are given for reasons of confidentiality. The table indicates whether the AOX/EOX emission is higher or is in fact of the same order of magnitude as emissions of individually known substances. A large AOX/EOX emission, which can not be explained at all

with the individually known substances, indicates a gap in knowledge with regard to emission figures.

Table 4.3.1: Comparison of AOX/EOX emission with quantity of chlorine in individually registered substances

Segment	Process	AOX	EOX
8	Production of AC/ECH/epoxy	appears similar	appears similar
45	Storage, transhipment and cleaning	not compared	5-6 * individual
41	Application of hypochlorite in households[a]	8 tons/yr; no known individual compounds	not known
2,15,1[b]	Production of EDC/VCM, MCPA/M-CPP and chlorine	appears similar	appears similar
6[b], 35	Production of ethyleneamines and VDCM[c]	5-8 * individual[c]	5-8 * individual[c]
18,19,26	Production of (H)CFCs and Teflon	difference explicable by 'CFCs - not otherwise known' item in ER-I	see under AOX
17,6[b],1[b]	Production of HHCs, ethyleneamines and chlorine	appears similar	appears similar
7	Production of FGZ	appears similar	appears similar
7,10	Use of EDC as solvent, production of flocculant	>> individual	< detection limit
11	Production of polycarbonate	2-3 * individual	< detection limit
12,36	Production of MDI	>> individual	4-5 * individual
13	Production TDC/Aramide	3-4 * individual	appears similar
16	Production of CMC	no individual substances in E-R/WIER	< detection limit
36	Production of tetradiphon and dichlobenil	not known	a few kilo's/year
36	Production of organotin	a few kilo's/year	< detection limit
36	Production benzylalcohol	n.i.	n.i.
14	Production of MCA	n.i.	n.i.

a) Estimate on basis of FIFE [1994]. Consumption since 1990 declined by 40 %, so emission of AOX from household hypochlorite is still 4.8 tons. This has no effect on classification. No AOX/EOX emission was quantified for other applications of hypochlorite.

b) Process also takes place at other locations.

c) VDCM production has since stopped; EOX and AOX emissions already lower

n.i Not included as priority company in the monitoring programme for the Rhine and North Sea Action Programme or in the AOX/EOX measurement programme of RIZA 1992 [RIZA, 1994b]

4.4 A MUTUAL COMPARISON OF EMISSIONS FROM THE CHLORINE CHAIN

4.4.1 Introduction

This section gives the score of emissions at various levels of aggregation. In this study we have chosen the following cross-sections:

- § 4.4.2 groups emissions by substance, totalled over sections;
- § 4.4.3 groups emissions by segment or group of segments;
- § 4.4.4 groups emissions according to stages in the life cycle. Investigates which stage has the highest outflow of chlorine compounds and which stage scores highest on the environmental themes
- § 4.4.5 groups emissions by complete sub-chain, in which production and consumption are taken together.

Table 4.4.1 explains how segments are clustered and classified according to stage in the life cycle. In Part Two an outline is given of the emissions occurring in each segment, unless companies did not give permission for publication on grounds of confidentiality. In this way calculations can be checked to a certain extent. On the basis of priorities for the different cross-sections, section 4.4.6 presents the conclusions with regard to the priority setting.

4.4.2 Cross-section 1: total emissions per substance

Appendix 4 provides a summary by substance of the total emission of the chlorine chain in 1990 and after envisaged policy, as well as the scores on the 8 environmental themes. The scores for each theme are normalized at the level of the Dutch total according to the "Distance to target" method and integrated to one measure. This can be regarded as the integrated environmental burden of the substance. Figure 4.4.1 shows the integrated scores per substance in 1990 and after implementation of the envisaged policy. The figure also gives an impression of the contribution of each substance to the total burden on the environment. This is calculated by integrating the *total* Dutch score in 1990 on the 8 themes according to the same procedure and set at 100% in the figure.

Table 4.4.1 Clustering of segments in segment groups, classified by stage in the life cycle

PRODUCTION	CONSUMPTION	WASTE
chlorine	tri (trichloroethene)	transp.
1 production of chlorine	32 consumption	45 transport and storage and transhipment
43 production of other inorganic chlorine compounds	1,1,1-tri (chloroethane)	
Cl.meth	31 consumption of 1,1,1-tri	waste(processing)
17 production of chloromethanes		46 waste processing
	halon (halon 1211)	
hcfc 22	39 other imports containing halon 1211	
18 production of HCFC 22		
F-pol (fluor polymers)	dcm (dichloromethane)	
19 production of teflon	30 consumption of DCM	
CFCs	cl.form (chloroform)	
22 production of CFC 11/12	21 consumption of chloroform	
26 production of CFC 113/114		
	hcfcs	
arom (atic chlorine compounds)	20 consumption of HCFC-22	
36 production with chloroaromates	34 consumption of HCFC-142b	
AC/ECH (epichlorohydrine)	tetra (tetrachloromethane)	
8 production of ECH/allylchloride/ epoxy resins	25 consumption of tetra	
	cfcs	
hypo (hypochlorite)	23 consumption of CFC 11	
40 production of hypochlorite	24 consumption of CFC 12	
	27 consumption of CFC 113	
MCA (monochloroacetic acid)	28 consumption of CFC 114	
14 production of monochloroacetic acid	33 consumption of CFC 115	
15 production of MCPA/MCPP		
16 production of modified starch, production of CMC	PER (tetrachloroethene)	
	29 consumption of PER	
MDI (methylenediphenyldiisocyanate)	arom (atic chlorine compounds)	
11 production of MDI	37 consumption applications chlorine aromates	
PC (polycarbonate)		
12 production of polycarbonate	hypo (hypochlorite)	
	41 consumption of hypochlorite	
EDC/PVC (polyvinylchloride)		
2 production of 1,2-EDC/VCM	PVC (polyvinylchloride)	
3 production of PVC	5 consumption of PVC	
4 production of VCM-copolymers		
	pest(icides)	
TiO2 (titanium dioxide)	38 consumption of pesticides in segment 38, including MCPA and tetradiphfon	
42 production of TiO2		
TDC (terephtaloylchloride)		
13 production of TDC and aramide	Other appl(ications)	
	7 other consumption applications of EDC	
VDC (vinylidenechloride)	44 various sources of dioxins, PCBs and PCP	
35 production VDCM		
Other prod.		
6 production ethyleneamines		
10 other production with ECH		

The substances which deplete the ozone layer come to the fore in figure 4.4.1, both for 1990 and the future situation. This is due to the extremely high weighting factor for depletion of the ozone layer. In the future, CFC-11 will still be emitted from foam accumulated in society and therefore has the highest score. Other CFCs will be phased out and therefore disappear. Figure 4.4.2 takes no account of the score on depletion of the ozone layer. In the diagram the weight of this theme has in fact been fixed at zero. However, in the future situation CFC-11 still remains the most important substance here, in this case on account of the score on global warming. Some (H)CFCs are also visible because of their score on global warming. They come from the production of teflon and the production of CFCs for essential applications. DCM and trichloroethene have comparable scores, but this is due to their contribution to the theme of smog formation. HCl appears because of the contribution to acidification. EDC is shown because of the score on human toxicity and is therefore selected for closer analysis. No pesticides are included in the figures.

4.4.3 Cross-section 2: emissions by segment group

Figure 4.4.3 gives an outline for each segment (group) of the total outflow of chlorine into the environment in 1990, divided into chloride (salt) and other chlorine compounds. Figure 4.4.4 shows the situation after implementation of current policy. Quantities are expressed in kt of chlorine. The largest outflow occurs in the form of chloride (salt). This is usually discharged into brackish water. This is the case, for example, in the production of ECH/epoxy resin, ethylene amines (included under 'other production') and polycarbonate, and the use of hypochlorite. The main emission from waste processing is salt in incinerator residues and emission of chloride to water. These examples show that the *volume* of the outflow of chlorine to the environment from a process does not in itself provide any relevant information for environmental policy: outflow of chloride to (salt) water is not explicitly referred to as a problem in the memorandum initiating the project. When comparing the figures it is interesting to note that the outflow of chlorine *compounds* from *consumption applications* will decrease significantly.

To gain more insight into the *nature* of the outflow to the environment, this has been scored according to its contribution to the various environmental themes. These scores for 1990 and the situation after implementation of envisaged policy are shown in figures 4.4.5 to 4.4.12. In each case, the score is in relation to the total Dutch score on a theme in 1990. The scoring method is aimed at determining potential contributions to environmental themes. For this reason, it is impossible

Figure 4.4.1: Integrated scores by substance, themes normalized at the level of Dutch total and added up by "Distance to target". Integrated total Dutch score in 1990 = 100.

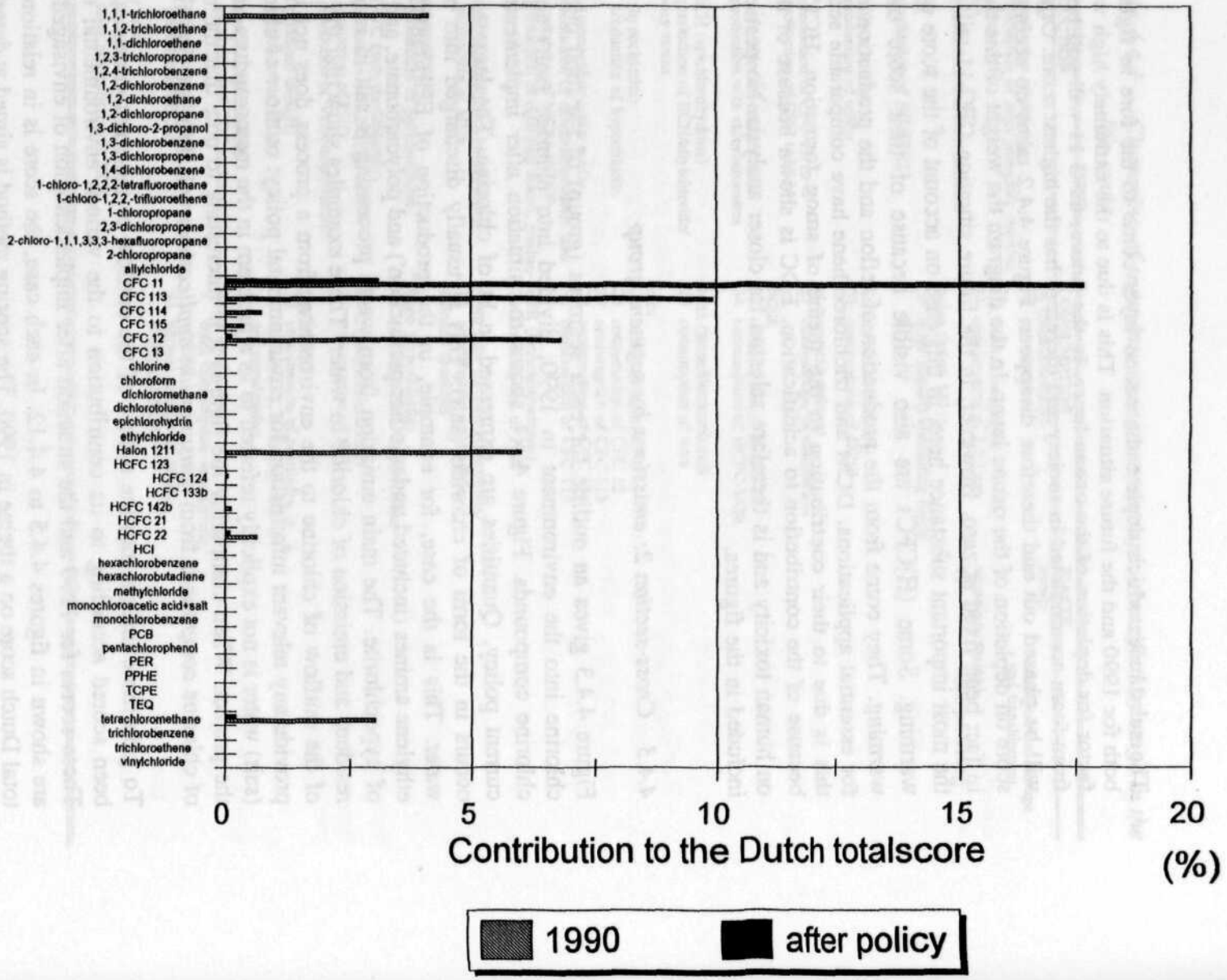


Figure 4.4.2: Integrated score by substance, themes normalized at the level of Dutch total and added up by "Distance to target". Integrated total Dutch score in 1990 = 100 (excl. score on ODP).

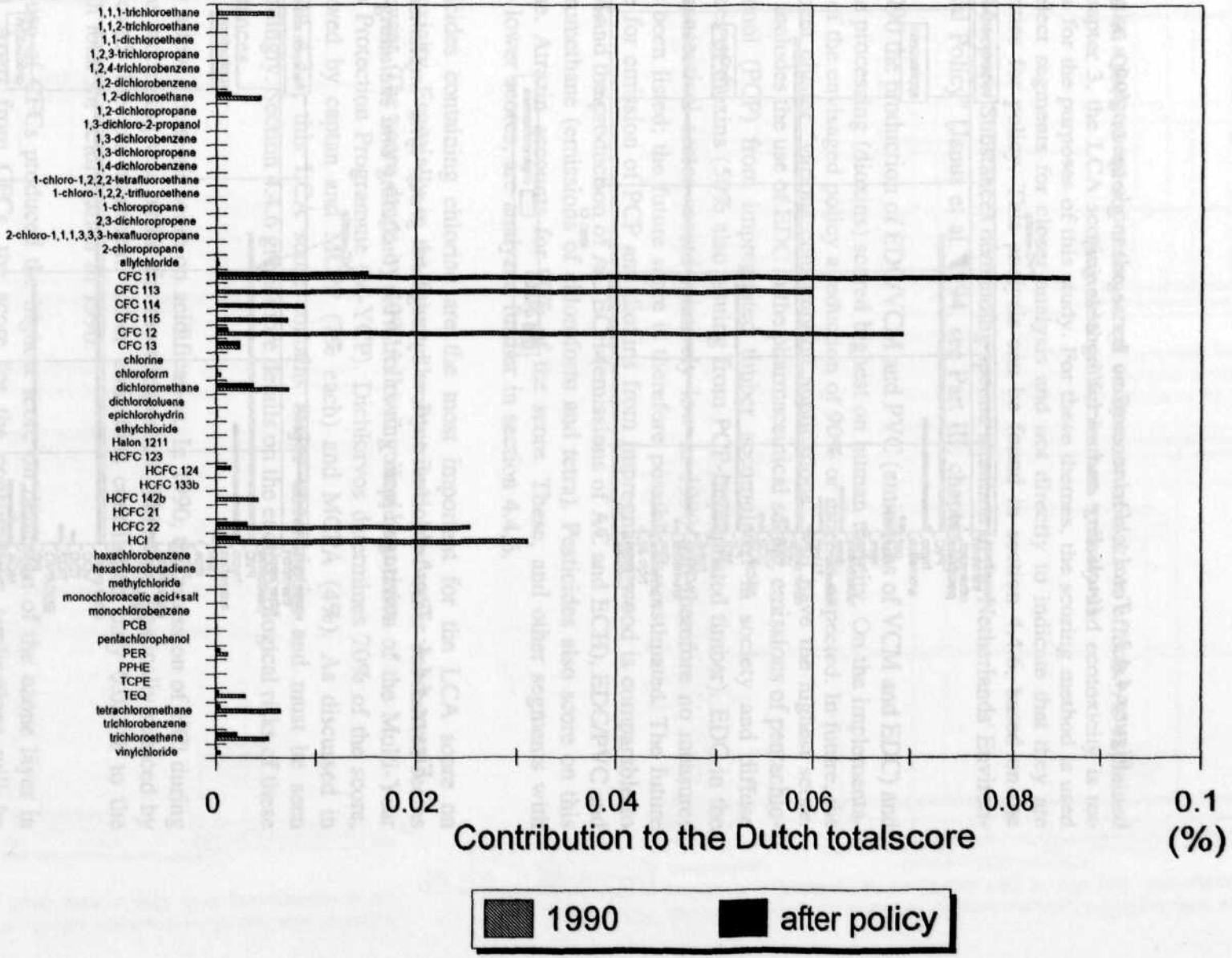


Figure 4.4.3: Total chlorine outflow by segment group in 1990 in kt chlorine (including and excluding chlorine)

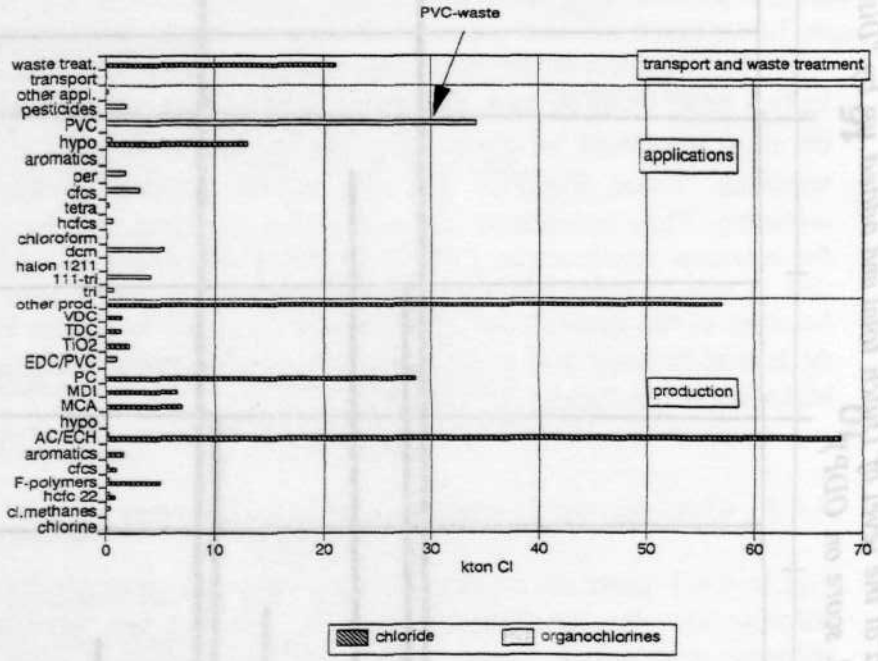
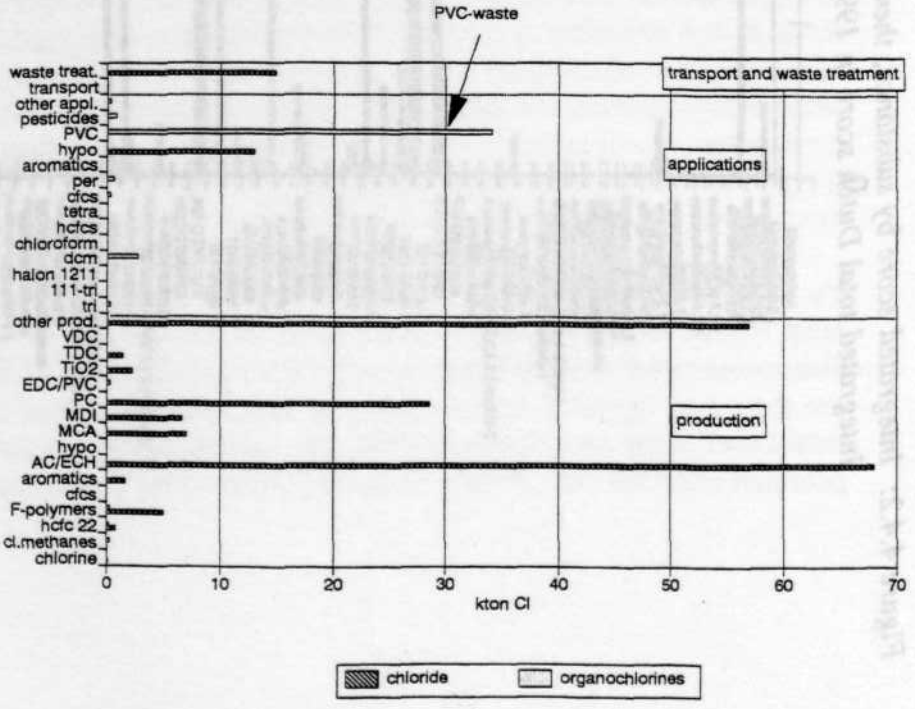


Figure 4.4.4: Total chlorine outflow by segment group after implementation of envisaged policy in kt chlorine (including and excluding chlorine)



to make a judgement about the actual occurrence of risks or effects. As explained in chapter 3, the LCA scoring method for human toxicity and ecotoxicity is too crude for the purposes of this study. For these themes, the scoring method is used to select segments for closer analysis and not directly to indicate that they are priorities for policy. This analysis can be found in section 4.4.6, based on the RIVM report "Substances demanding special attention in the Netherlands' Environmental Policy" [Janus et al. 1994, see Part III, chapter 2].

In 1990 the production of EDC/VCM and PVC (emissions of VCM and EDC) and waste processing (dioxins) scored highest on human toxicity. On the implementation of the envisaged policy a reduction of 90% or more is expected. In future, the segment cluster "various consumption applications" will have the highest score. This includes the use of EDC in the pharmaceutical sector, emissions of pentachlorophenol (PCP) from impregnated timber accumulated in society and diffuse sources of dioxins (50% also issuing from PCP-impregnated timber). EDC in the pharmaceutical sector scored relatively low in 1990 and therefore no measures have been listed; the future score is therefore possibly overestimated. The future score for emission of PCP and dioxins from impregnated wood is comparable to DCM and the production of AC/ECH (emissions of AC and ECH), EDC/PVC and chloromethane (emissions of chloroform and tetra). Pesticides also score on this theme. Atrazin accounts for 90% of the score. These, and other segments with even lower scores, are analyzed further in section 4.4.6.

Pesticides containing chlorine are the most important for the LCA score on ecotoxicity. Especially in the future, the contribution of other substances seems irrelevant. The score drops by 40% following implementation of the Multi-Year Crop Protection Programme (M-YCP). Dichlorvos determines 70% of the score, followed by captan and MCPP (7% each) and MCPA (4%). As discussed in section 4.3.1, this LCA score contains major uncertainties and must be seen accordingly. Section 4.4.6 gives more details on the ecotoxicological risks of these substances.

Only a few emissions score on acidification. In 1990, the emission of HCl during waste processing was by far the most important. This was drastically reduced by improved flue gas treatment. Other emissions contributed only 0.025% to the Dutch total for acidification in 1990.

The use of CFCs produced the highest score on depletion of the ozone layer in 1990. Apart from CFCs, the score for the consumption applications will be completely erased with the phasing out of CFCs, halon 1211, tetra and 1,1,1-tri

Figure 4.4.5: Score on human toxicity caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990. Excl. decomposition in the environment.

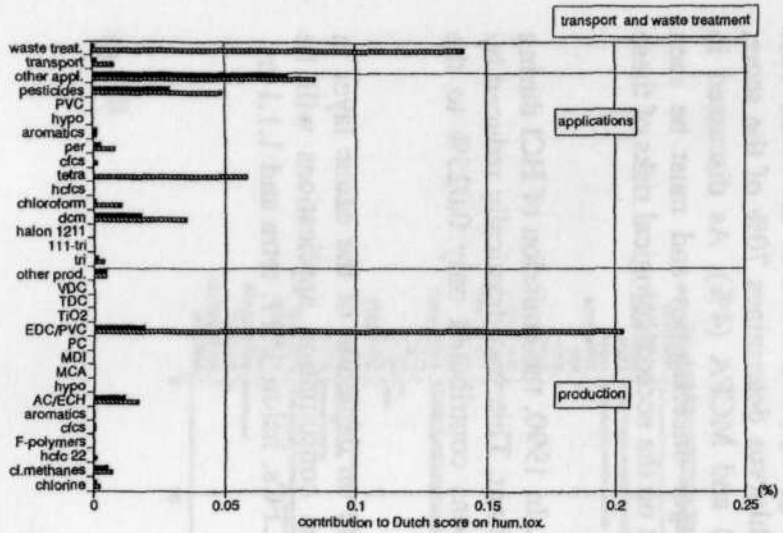


Figure 4.4.6: Score on aq. ecotoxicity caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990. Excl. decomposition the environment.

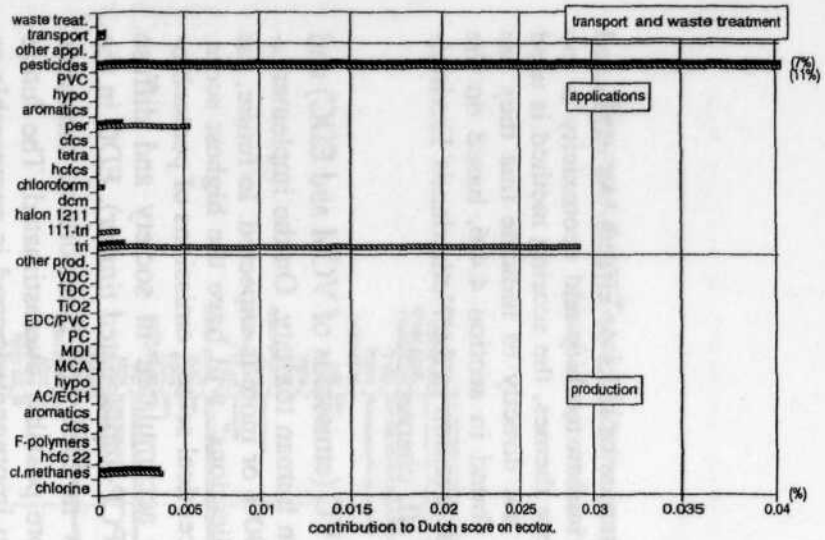


Figure 4.4.7: Score on acidification caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990.

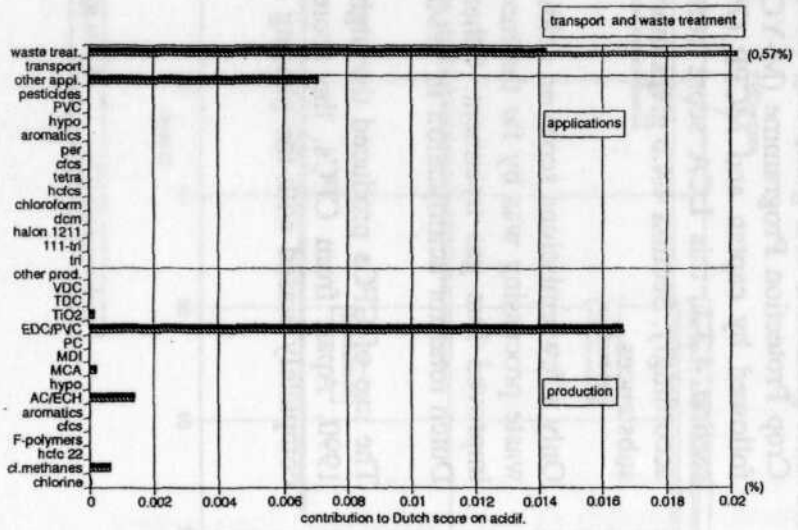
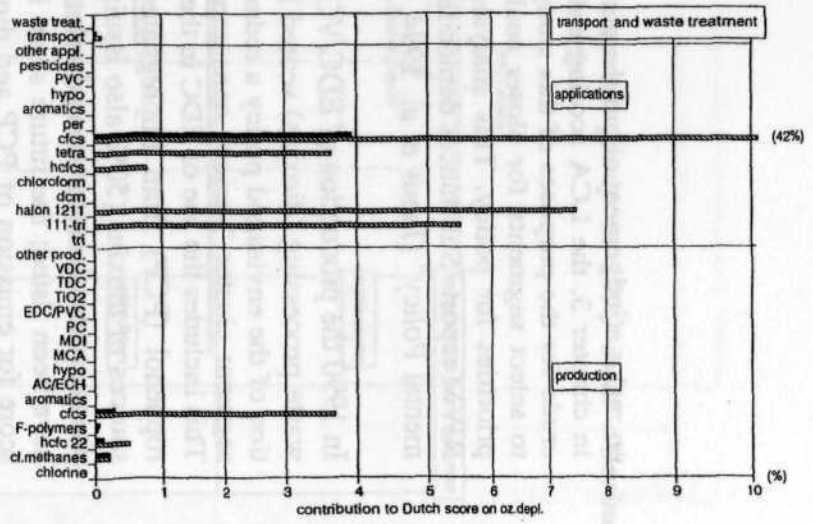


Figure 4.4.8: Score on ozone depletion caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990.



1990 after policy

Figure 4.4.9: Score on odour caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990.

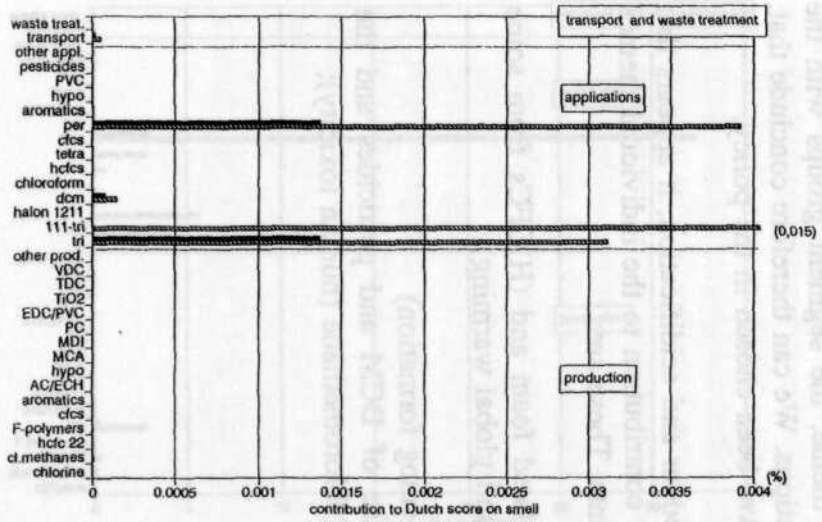


Figure 4.4.10: Score on global warming caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990.

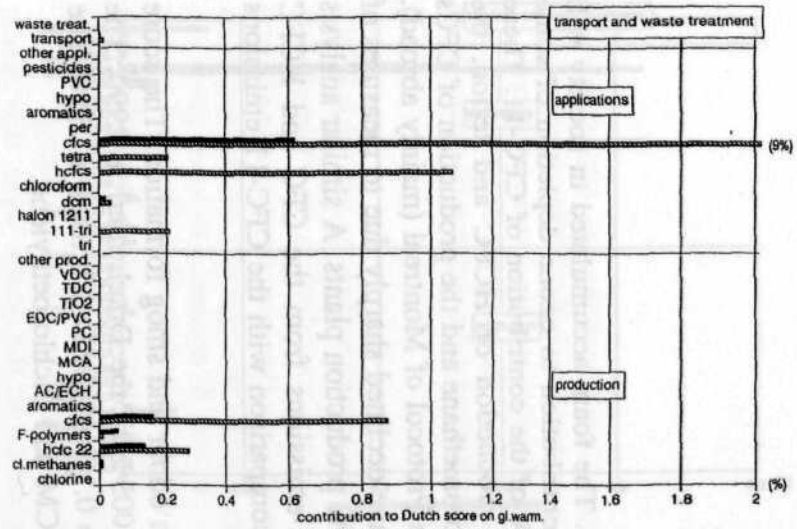


Figure 4.4.11: Score on smog formation caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990.

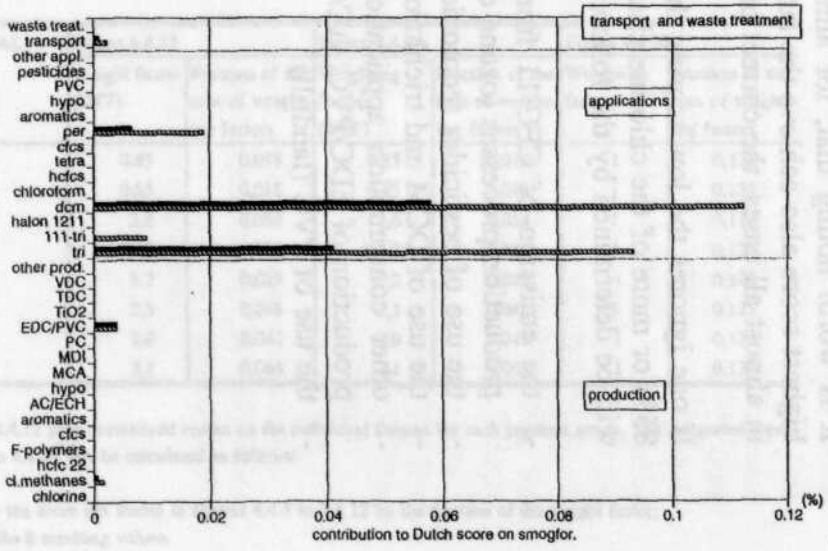
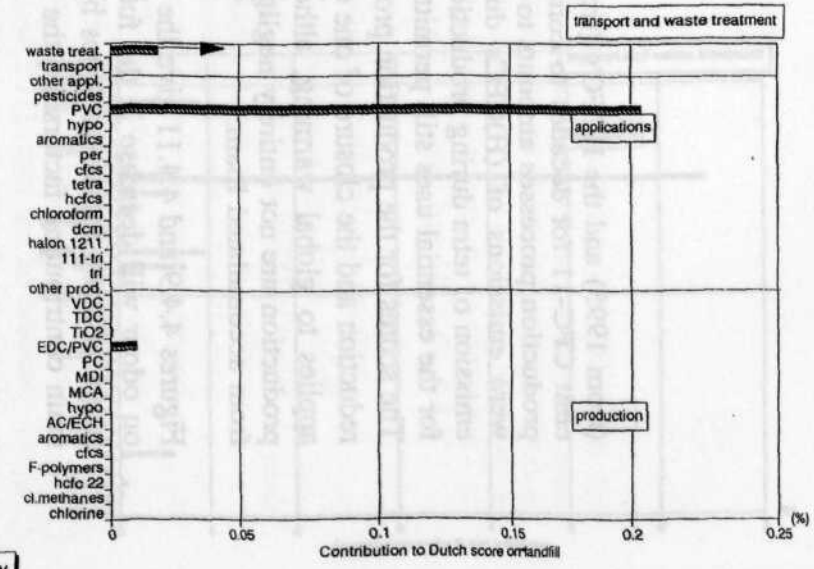
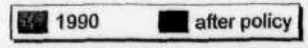


Figure 4.4.12: Score on landfilling caused by chlorine compounds in 1990 and after envisaged policy, as a percentage of the Dutch total in 1990. Amount calculated in kg chlorine.





(from 1995) and the HCFC's (from 2015). The foam accumulated in society will emit CFC-11 for decades to come. The contribution to ozone depletion of some production processes amounts to only 20% of the contribution of CFC-11. These were emissions of (H)CFCs during the production of HCFC and teflon, the emission of tetra during production of chloromethane and the production of CFCs for the essential uses still permitted by the Protocol of Montreal (mainly abroad). The scores for the production processes have declined sharply due to measures of reduction and the closure of one of the CFC production plants. A similar analysis applies to global warming, although the emissions from the CFC and HCFC production are not entirely negligible by comparison with the CFC-11 emissions from accumulated foam.

Figures 4.4.9 and 4.4.11 give the scores on odour and smog formation. The score on odour will decrease in the future to 0.003% of the Dutch total in 1990. The score on smog formation drops by 50% to 0.1% of the Dutch total in 1990. The main contributing factors are the use of DCM and trichloroethylene.

In figure 4.4.12 we can see that the use of PVC and processing of waste (by release of salt) score on landfilling. Improved flue gas treatment leads to an (unquantified) extra output of chloride in the cleaning residue during waste processing. The future score for PVC use takes no account of the extra amount of accumulated PVC which may be released or of a decrease in landfill due to recycling.

It is worth noting that, for almost every theme, the segment groups with the highest score also achieve the largest reductions. We can therefore conclude that, in almost all cases, the correct priorities have been chosen in the policy.

If one ignores the low scoring themes of odour and acidification, it appears that 85% or more of the chlorine chain's future contribution to the individual themes will be determined by the following segments. These are:

- the emission of CFC-11 from accumulated foam and (H)CFCs from some production processes (ozone depletion and global warming);
- the use of pesticides (ecotoxicity);
- the use of DCM and trichloroethylene (smog formation)
- other consumption applications, the use of DCM and pesticides and the production of EDC/PVC, AC/ECH and chloromethane (human toxicity);
- the use of PVC (landfill).

Figure 4.4.13: Integrated score for each segment group, themes normalized on basis of Dutch total and calculated according to DTT weight. Integrated Dutch total score 1990 = 100. Situation 1990 and after envisaged policy.

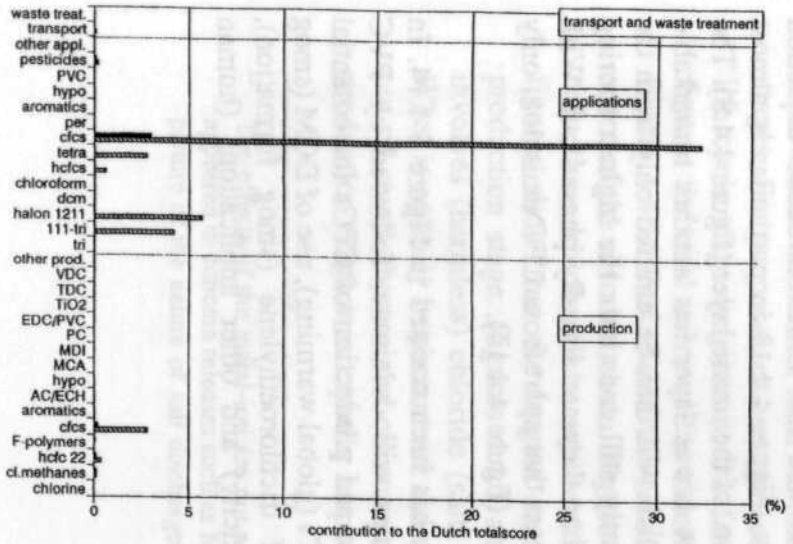


Table 4.4.2: List of weighting factors used in Figures 4.4.13, 4.4.14 and 4.4.15

ENVIRONMENTAL THEME	Figure 4.4.13		Figure 4.4.14		Figure 4.4.15	
	Weight factor (DTT)	Fraction of the sum of weighting factors	Weighting factor (DTT)	Fraction of the sum of weighting factors	Weighting factor	Fraction of the sum of weighting factors
human toxicity	0,85	0,018	0,85	0,018	1	0,125
aq. ecotoxicity	0,85	0,018	0,85	0,018	1	0.125
acidification	2,6	0,054	2,6	0,054	1	0.125
ozone depletion	35,3	0,732	(35,3)	(0,732)	1	0.125
global warming	1,2	0,025	1,2	0,025	1	0.125
smog formation	2,3	0,048	2,3	0,048	1	0.125
odour	2,0	0,041	2,0	0,041	1	0.125
landfill	3,1	0,064	3,1	0,064	1	0.125

Figures 4.4.5 t/m 4.4.12 give normalized scores on the individual themes for each segment group. The integrated scores in figures 4.4.13 to 4.4.15 can be calculated as follows:

- multiply the score per theme in figures 4.4.5 to 4.4.12 by the fraction of the weight factor;
- add up the 8 resulting values.

Figure 4.4.14: Integrated score for each segment group, themes normalized on basis of Dutch total and calculated according to DTT weight. Integrated Dutch total score 1990 = 100. Situation 1990 and after envisaged policy (excl. score on ODP).

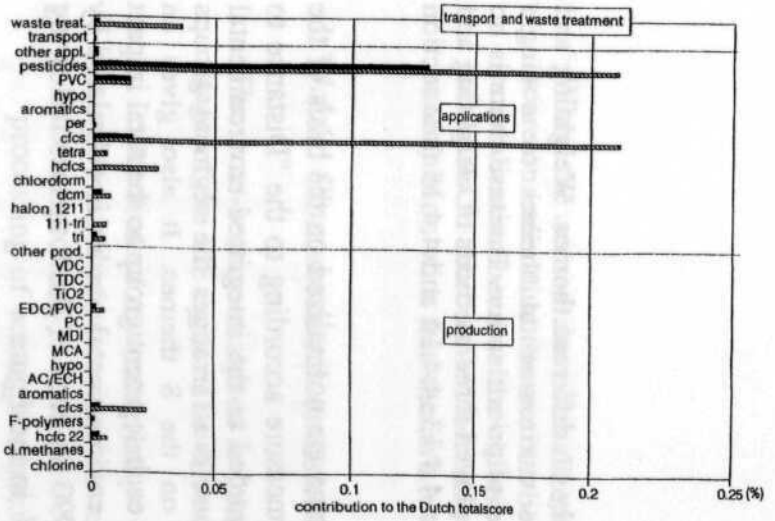
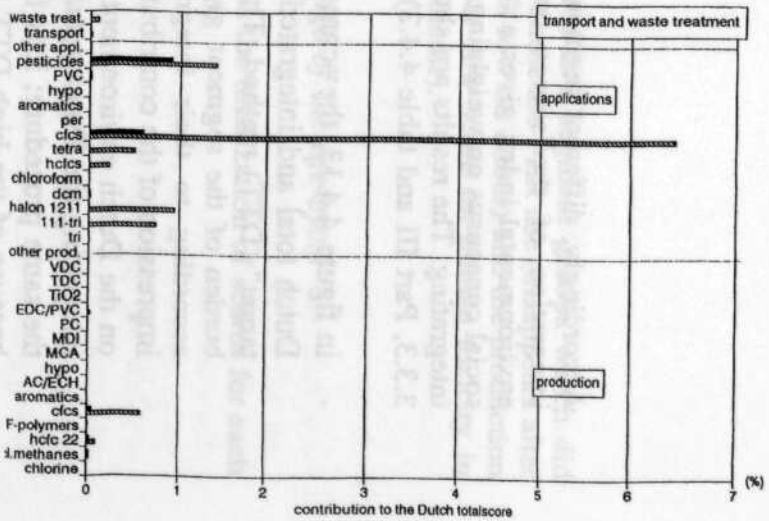


Figure 4.4.15: Integrated score for each segment group, themes normalized on basis of Dutch total and calculated without weighting. Integrated Dutch total score 1990 = 100. Situation 1990 and after envisaged policy.



1990 after policy

Accordingly, different segments score highly on different themes. Weighting and integration of the scores on the various environmental themes to a single environmental index gives a further method of prioritization. Because there is no social consensus on weighting, we have employed three methods of weighting and integrating. The results are shown in figures 4.4.13, 4.4.14 and 4.4.15 (see section 3.3.3, Part III and table 4.4.2):

- in figure 4.4.13, the scores for each theme are normalized on the basis of the Dutch total and integrated in a single measure according to the "Distance to target" (DTT) method. This can be regarded as the integrated environmental burden of the segment group. The figure thus arranges the segment groups according to their integrated scores on the 8 themes. It also gives an impression of the contribution made by each segment group to the total impact on the Dutch environment. This Dutch environmental burden is calculated by integrating the Dutch *total* scores in 1990 for each of the 8 themes following the same procedure; it is fixed at 100% in the figure.
- because of the high DTT weight for depletion of the ozone layer, this theme dominates in the figure, and the chlorine chain has a high score in comparison to the integrated total Dutch environmental burden. For comparative purposes, the score on depletion of the ozone layer is not included in figure 4.4.14.
- calculations were not weighted in figure 4.4.15. In effect, a weighting factor of one was used for each theme.

Although the absolute figures differ, the relative scores in figures 4.4.13 and 4.4.15 are almost identical. The use of these weighting methods therefore has little effect on the result. This follows from the fact that the score on ozone depletion dominates within the integrated total score. Figure 4.4.13 in particular is almost identical to the individual score on depletion of the ozone layer (figure 4.4.8). The high weighting factor for depletion of the ozone layer has another remarkable effect in figure 4.4.13.In future, CFCs, which will then be emitted only from the foam accumulated in society, will apparently still constitute the highest scoring emission from the chlorine chain, even when they are actually phased out. With the unweighted integration method, it appears that apart from CFC emission, only the use of pesticides will have a high score (figure 4.4.14).

The score on depletion of the ozone layer has been omitted in Figure 4.4.14. In the future situation, the score of pesticides will dominate, followed by PVC (landfill), the CFC-11 emission from foam and production of CFCs for essential use (global warming), production of HCFC's (global warming), use of DCM (smog formation and human toxicity), use of trichloroethylene (smog formation), EDC/PVC (acidification and human toxicity) and other applications (human toxicity).

When the scores are normalized and weighted, two segment groups which did score on individual themes can be discounted. These are PER use (disappears after normalization because the chlorine chain scores low on odour) and the production of AC/ECH (discounted because of a relatively low score on human toxicity in combination with this theme's low weighting factor).

4.4.4 Cross-section 3: emissions for each stage of the life-cycle

The cross-section analyzed in this sub-section is the totalization of scores for each stage of the life cycle. The different stages are:

- extraction of raw materials;
- conversion of raw materials to products;
- use of products;
- processing of waste products.

The first stage is not relevant to this study. The exhaustion of resources is an important aspect of this stage. This does not apply to the chlorine chain due to the existence of an abundance of easily extractable NaCl (salt). This is a benefit of using chlorine rather than other raw materials. Emissions occur during extraction but not in the form of chlorine compounds other than chlorides. Production, usage and processing of waste will, however, be considered.

Figures 4.4.16 and 4.4.17 show the scores for 1990 and the future situation for all environmental themes, with the totals divided among the three remaining life cycle stages. For purposes of comparison the outflow of chlorine (compounds) at each life cycle stage is given at the far left, expressed in tonnes of chlorine. In both figures the total score of the chlorine chain for each theme in 1990 is fixed at 1. Figure 4.4.16 thus shows the relative contribution of one link in the chain to the score of the chlorine chain. Figure 4.4.17 also shows this but further indicates the reductions which will be achieved after implementation of envisaged policy. Both figures show that the largest amount of chlorine leaves the chain during the production stage. Figures 4.4.1 and 4.4.2 have already shown that this mainly involves (harmless) chloride (salt) which is usually discharged into salt water[15]. What is actually important are the contributions to environmental themes: for five out of seven themes the consumption stage had the highest score in 1990. The production stage was equally important for human toxicity. In 1990 waste

[15] The effects of the metal-ion are not a subject of investigation in this study. In most cases it appeared to concern releases such as NaCl (salt), but specific investigations to give a complete picture of the nature of salt discharges were beyond the scope of this study.

Figure 4.4.16: Contribution of stages in the life cycle to the outflow of chlorine and scores on environmental themes in 1990 (total for each theme = 1)

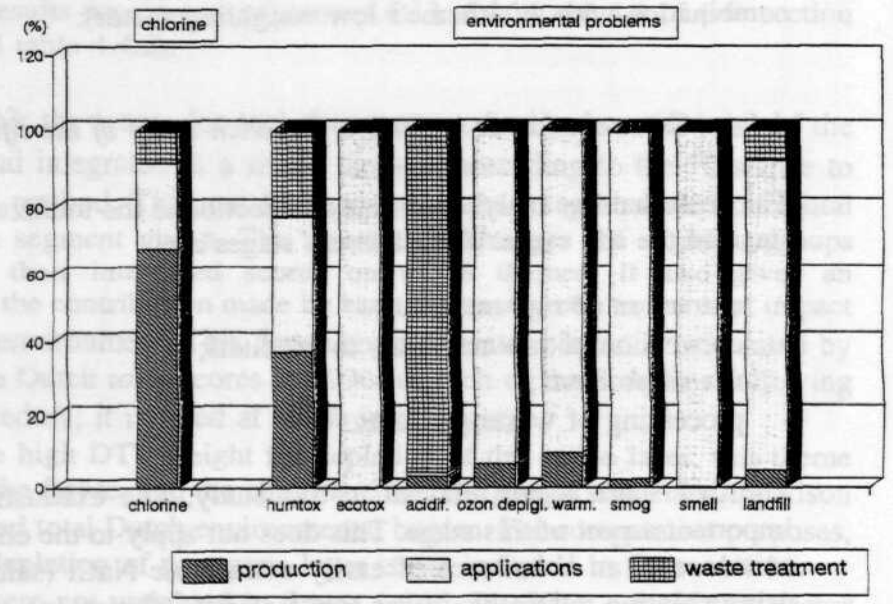
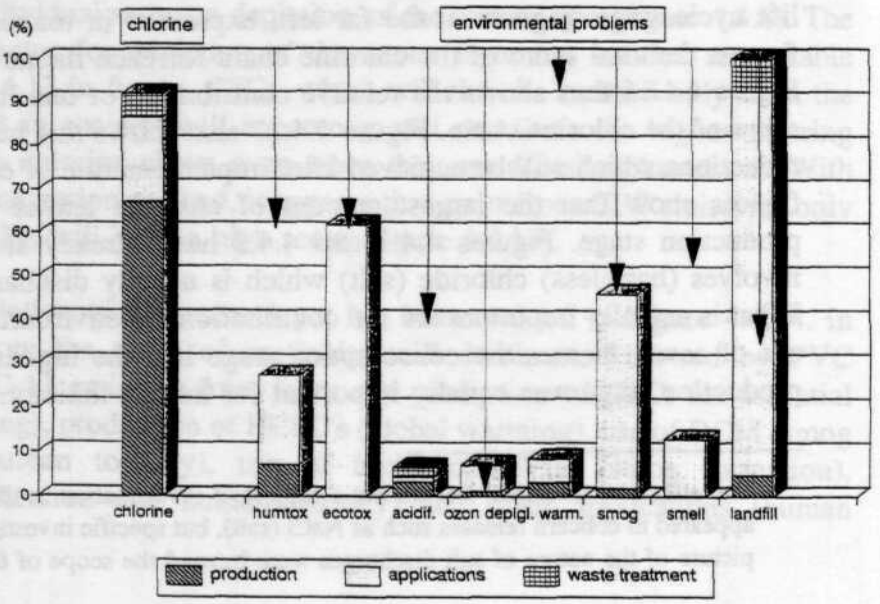


Figure 4.4.17: Contribution of stages in the life cycle to the outflow of chlorine and scores on environmental themes after envisaged policy (total for each theme = 1)



processing was most significant for acidification. In future, the stringent limitations on emissions from waste processing installations will result in relatively sharp declines at this stage: the score on human toxicity is no longer visible and the production stage will become the most important for acidification. Because of a relatively sharp reduction at the production stage, the consumption stage will produce the highest contribution to human toxicity in the future.

The presentation in figure 4.4.17 is also useful for comparing the expected reduction percentages for the chlorine chain with the reduction targets for the Netherlands as a whole. For each theme, the arrows in figure 4.4.17 show the reduction targets for the Dutch total[16] for the year 2000. The chlorine chain will achieve future reductions of 75 to 90%, except on the themes of ecotoxicity, smog formation and landfill. To compare: measured in tonnes of chlorine, the outflow declines by only 10%. Apart from landfill and the depletion of the ozone layer, the reductions achieved in the chlorine chain are equal to or greater than the reductions in the average targets. For global warming, the difference is exaggerated. The general policy objective for this theme in fact already takes into account the complete phasing out of CFCs, and consequently an above-average reduction through the chlorine chain.

4.4.5 Cross-section 4: emissions by sub-chain

Finally, the emissions from the chlorine chain are aggregated at the level of sub-chains. This involves six of the sub-chains in table 4.2.1, which consist of related processes of production and use. A sub-chain is defined as a complete "branch" of the chlorine chain on the fold-out page. The EDC/VCM/PVC sub-chain therefore refers to segments 2 to 7. The scores of chlorine production and waste processing should, in principle, be divided between the sub-chains. However, these are all-embracing processes that cannot be easily allocated to the various sub-chains. This has therefore not been done. Taking a sub-chain as a whole is relevant, because any changes in a process or product will almost inevitably affect other processes and/or products within the sub-chain. In this way, account is already taken of phase 2 which deals with the options to minimize the emissions.

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[16] Policy objectives have only been formed for theme indicators which use a somewhat different classification of environmental themes than the LCA-themes used here. Part III details the necessary conversion method. The comparison is evened out a little because PCBs (contribution to human toxicity) will only be phased out in 2005 and HCFCs (contribution to ozone depletion and global warming) only in 2015. However, the conclusion is not significantly affected.

In figures 4.4.18 and 4.4.19, the scores for each theme are normalized on the basis of the Dutch total and integrated to one measure according to the "Distance to Target" method. This can be regarded as the integrated environmental burden of the sub-chain. The figure thus ranks the sub-chains according to their integrated scores on the 8 themes. It also gives an impression of each sub-chain's contribution to the total Dutch environmental burden. This Dutch environmental burden is calculated by integrating the *total* Dutch scores for each of the 8 themes following the same procedure. The integrated Dutch environmental burden is set at 100% in the figure. Due to its high weighting factor, depletion of the ozone layer accounts for more than 73%. Most ozone depleting substances contain chlorine and come from the chloromethane chains. As figure 4.4.18 shows, this resulted in 1990 in a dominant contribution from this chain to the integrated Dutch environmental burden. This is significantly lower after the phasing out of CFCs. The figure also shows that the future score will be determined by the emission of CFC-11 from foam accumulated in society.

Figure 4.4.19 does not take the production and use of CFCs (therefore the theme of ozone layer depletion!) into consideration. The chloromethane chain (C1-chain) has the highest score in 1990 because of the contribution of HCFCs to ozone depletion and global warming. There are no apparently obvious differences between the sub-chains after the phasing out of HCFCs.

4.4.6 Comparison of priorities for each cross-section and closer analysis of toxicity

In the previous sub-sections, emissions from the chlorine chain are aggregated in different ways. Priorities are then set for each method of aggregation. This sub-section compares the priorities stipulated for the different cross-sections. We have confined ourselves to the situation after implementation of the envisaged policy from 1 January 1995. It must be emphasized that the scores are possibly incomplete, firstly because of the lack of a definite answer as to whether the unidentified chlorinated micropollutants contain pbt's, and secondly because the emissions have not been scored due to (a) being expressed in EOCl or (b) lack of equivalency factors.

1. In all cross-sections the emission of CFC-11 from foam accumulated in society is shown to have the highest score, especially because of the contribution to the themes ozone depletion and global warming. This emission takes second place even when integration occurs without weighting or if the weighting used does not account for ozone depletion.

Figure 4.4.18: Integrated score for each sub-chain, themes normalized on the basis of Dutch total and calculated according to DTT weighting. Integrated Dutch total score 1990 = 100.

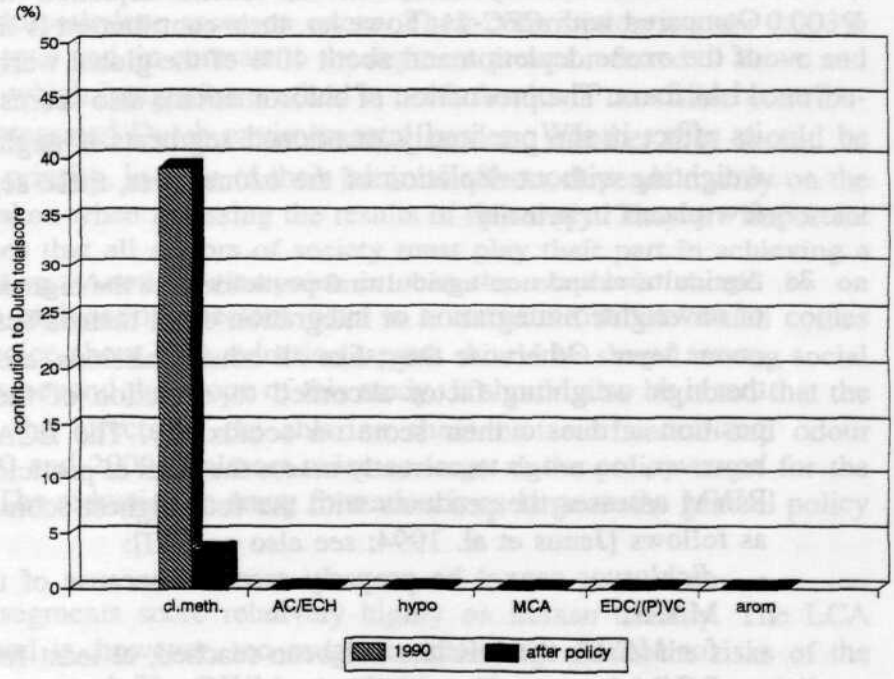
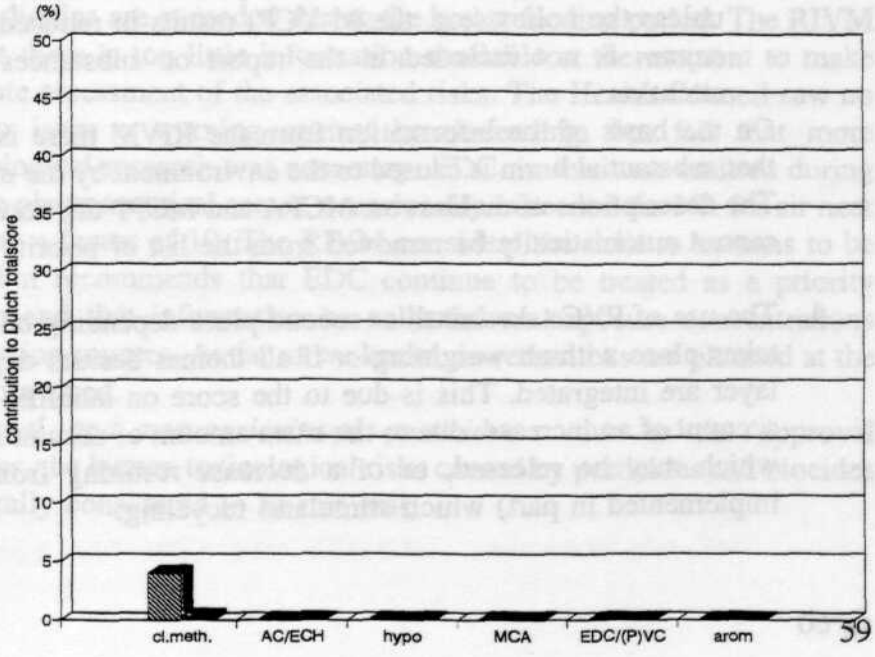


Figure 4.4.19: Integrated score for each sub-chain, themes normalized on the basis of Dutch total and calculated according to DTT weighting. Integrated Dutch total score 1990 = 100. Excl. score CFCs



2. On the basis of a DTT-weighted or unweighted integration of themes, CFC-11 is followed by emissions from the production of CFCs for essential use as still permitted by the Protocol of Montreal and the production of HCFCs/teflon. Like CFC-11, they score on the ozone depletion and global warming. Compared with CFC-11, however, their contribution is limited: less than 20% of the ozone depletion and about 40% of the global warming caused by CFC-11 in foam. The production of chloromethane also scores on these themes, but its effect in the previously mentioned segments is negligible. In the case of weighting without depletion of the ozone layer, these segment groups drop a few places in priority.

3. Agricultural and non-agricultural pesticides are the highest priority in the event of unweighted integration or integration of all themes besides depletion of the ozone layer. Otherwise they, like all other emissions, are invisible because of the high weighting factor accorded to depletion of the ozone layer. Their position is due to their score on ecotoxicity. The LCA scoring method is, however, too rough to correctly assess the risks of pesticides and biocides. The RIVM assesses the products with the four highest scores on aquatic toxicity as follows [Janus et al. 1994; see also part III]:
   - *dichlorvos* cannot be properly assessed because of the lack of NRs and MARs;
   - for *MCPP*, the NR has not been reached, at least for surface water. The RIVM suggests that MCPP be placed on the list of priority substances unless the policy (e.g. the Multi-Year Crop Protection Programme (M-YCP)) results in reduced emissions.
   - for *MCPA* the NR has also not been reached, at least not for surface water. The RIVM suggests that MCPA be placed on the list of priority substances unless the policy (e.g. the M-YCP) results in reduced emissions.
   - *captan* is not included in the report on substances demanding special attention.

   On the basis of the information from the RIVM there is no clear indication that substantial harm is caused to the environment by the use of these products. The descriptions of dichlorvos, MCPA and MCPP do, however, show that they cannot automatically be removed from the list of priority substances.

4. The use of PVC takes sixth or second place depending on whether integration takes place without weighting or if all themes besides depletion of the ozone layer are integrated. This is due to the score on landfill. This study takes no account of an increase, due to the extra amount of accumulated PVC in society which may be released, or of a decrease resulting from a policy (already implemented in part) which stimulates recycling.

5. In future, waste processing and the production of EDC/PVC will together account for only 0.03% of the Dutch total for acidification in 1990. DCM and trichloroethylene score on smog formation. On implementation of envisaged policy, their joint contribution drops to only 0.1% of the Dutch total in 1990. Per and trichloroethylene score on odour. Their contribution is only 0.003% of the Dutch total and, in contrast to the segment groups referred to above and regardless of which integration method is used, results in no visible contribution to the integrated Dutch environmental burden. Whether they should be considered a priority, in spite of their minimal effects, depends mainly on the perspective taken when assessing the results of this study. They are important if one assumes that all sectors of society must play their part in achieving a policy objective. Another viewpoint is that the emphasis should be on reductions in high-scoring sectors. This is a normative debate which comes down to a choice about how reduction targets should be shared among social groups and is beyond the scope of this study. It should also be noted that the reduction in the effects of the chlorine chain on acidification and odour between 1990 and 2000 is almost twice as large as the policy target for the Dutch total. The reduction in smog formation is as large as the general policy objective.

6. Finally, six segments score relatively highly on human toxicity. The LCA scoring method is, however, too rough to accurately assess the risks of the substances concerned. The RIVM assesses the relevant substances as follows [Janus et al.; see also part III]:
   - *other applications:* the diffuse emissions of PCP and dioxins probably present very little risk to humans. The RIVM does recommend continuing to treat them as (priority) substances demanding attention. Recommended levels of dioxins are exceeded during the breast-feeding period. The RIVM finds that there is too little information available at the moment to make an accurate assessment of the associated risks. The Health Council saw no reason to issue a warning against breast-feeding, but felt that more epidemiological research was necessary. EDC, in this case emitted during use in the pharmaceutical sector, occasionally exceeded the NR for air near sources by a factor of 10. The RIVM considers the risks to humans to be limited, but recommends that EDC continue to be treated as a priority substance and that information be collected on exposure concentrations near emission sources. As far as we know, no reductions are planned at the source concerned.
   - *Agricultural and non-agricultural pesticides:* due to the approval procedures, the human toxicological risks caused by pesticides and biocides are generally considered to be minimal;

- *Dichloromethane:* the risks to humans and the environment are probably minimal, except in the indoor environment and close to sources. The NR is exceeded at sources. In the indoor environment breaches of the MAR usually occur due to poor ventilation and the use of DCM in aerosols and paint removers. No policy has in fact been formulated for these very uses.
- *Production of EDC, VCM and PVC:* the score is entirely due to VCM and EDC. On the basis of information from 1984, the RIVM concludes that VCM can be removed from the list of priority substances. Reductions by a factor of 10 compared with 1985 will be achieved before the year 2000. The annual average concentration of EDC calculated in 1984 near to the EDC production plant exceeded the NR to a certain extent (at 4 kilometres) and by a factor of 10 (at 1 kilometre). The RIVM considers risks to humans limited, but recommends that the substance be treated as a priority substance and that information be collected on exposure concentrations near emission sources. It appears from this study that emissions will be reduced by a factor of 10. It is possible that the NR will not be exceeded, but that can not be assessed within the framework of this study.
- *Production of AC/ECH:* the score is entirely determined by emissions of AC and ECH to the air. The general risks to humans and the environment are very small. However, there are no data on the situation near the only source, so no location-specific assessment can be carried out. On this process, it should be noted that a substantial emission of hexachloropropyl-ethers to water was not scored in the absence of an equivalency factor;
- *Production of chloromethane:* this concerns emissions of chloroform and carbon tetrachloride to the air. The RIVM argues that the NR of chloroform is regularly exceeded at industrial source points and that the substance should be treated as a priority substance. A similar analysis applies to carbon tetrachloride. Reductions in emissions of about 40-50% are expected at the plant concerned in 2000;
- *Other segments:* for the sake of completeness we have also assessed those segments with a low score on human toxicity. This shows that the use of 1,4 dichlorobenzene (DCB) in toilet blocks can lead to a breach of the NR in the indoor environment, the use of *hypochlorite* in swimming pools causes chloroform concentrations which lead to the MAR being exceeded among competitive swimmers for a limited number of years, and the concentrations of PER near dry cleaners exceeds the MAR. In the case of PER, it is unclear to what extent the planned 50% reduction of emissions will affect this assessment. As regards trichloroethylene, the target level in the soil from diffuse sources, will not be reached in spite of the planned reduction in emissions. Apart from their uses in the foregoing segments EDC, chloroform and carbon tetrachloride are also used in the production of ethyleneamines, HCFC-22 and CFCs for essential applications.

However, the LCA scores in these segments are much lower than in the other segments in which these substances are emitted. The breaches of the NR, as referred to in the segments referred to above, will probably occur to a much lesser extent in the segments dealt with here.

In brief, DCM in the indoor environment exceeds the MAR as does PER in dry cleaners. The MAR or NR are probably exceeded by chloroform in swimming pools, 1,4 DCB in the indoor environment, DCM near sources, EDC in the pharmaceutical sector and carbon tetrachloride/chloroform in the production of chloromethane. Further reductions in emissions are needed to achieve the target level for trichloroethylene in the soil. The assessment of the risks of dioxin in breast milk requires closer examination. As regards the production of AC/ECH and EDC/PVC it is as yet unclear to what extent the NR and MAR are (still) exceeded close to sources and what effect the agreed emission reductions is likely to have. They can therefore not simply be dropped as priorities. With the LCA method, the segments mentioned score somewhat higher than the diffuse emissions of dioxin and PCP from impregnated wood which is accumulated in society. It must be emphasized that we did not assess all the substances included in the inventory of emissions. There are 18 organic chlorine compounds (excluding (H)CFCs) which did not score on human toxicity in 1990 due to the lack of a classification factor. Appendix 4 shows that this probably makes a difference of about 5 to 10% for the LCA score for the total chlorine chain, which gives a rough impression of their relative importance to this theme. Four of them are discussed in the "Substances demanding special attention" report. Two can already be phased out due to the closure of a production plant. This study can pass no judgement on whether the remaining 12 listed organic chlorine compounds do or do not exceed the NR or MAR. They are presented in Table 4.4.3. On the basis of recent analysis, it is impossible to entirely rule out breaches of the NR [BKH, 1995]. Finally, there are substances which do not appear in the list of emissions for the chlorine study but which are dealt with in the "Substances demanding special attention" report. With the exception of possible chloroparaffins, about which no clear judgement is expressed, these descriptions give no reason to suggest extra substances as priorities.

Some reservations have to be expressed about a number of the priorities mentioned which are important for determining the need for possible supplementary policy or research. These concern:

1. the emission of CFCs from accumulated foam is an historical legacy 3 to 4 times the score of CFC emissions in 1990 on ozone depletion and global warming. This historical legacy largely overshadows the second priority, i.e. some production emissions of (H)CFCs.

2. for pesticides there is an unambiguous, specific assessment framework: the approval policy;
3. the policy with regard to PVC during the waste stage has already been partly implemented;
4. the emissions from the chlorine chain which contribute to acidification, smog formation and odour score lower than in other sectors. A normative choice determines the degree of priority. One can only aim at reductions in sectors which contribute significantly to the Dutch total score. Alternatively, one could demand (extra) reductions from all sectors, including the chlorine chain, regardless of the absolute contribution. Between 1990 and 2000, the reductions by the chlorine chain on these themes are already the same or greater than required by general policy objectives.
5. of the sections which score on human toxicity, breaches of the MAR occur in the indoor environment with DCM and in dry cleaners with PER. The MAR or NR are probably exceeded by chloroform in swimming pools, 1,4 DCB in the indoor environment, EDC in the pharmaceutical sector and carbon tetrachloride/chloroform in the production of chloromethane. Extra reductions in emissions are needed to achieve the target level of trichloroethylene in the soil. More research is needed on the risk-assessment of dioxins in breast milk. As regards the segment AC/ECH and EDC/PVC, the fact that the exposure data are dated means that there is still a question as to the extent to which AC, ECH and EDC exceed the NR locally as well as the effect of the agreed emission reduction of 90% in the case of EDC.

Table 4.4.3: Surveyed emissions of substances which have not been assessed for exceedance of NR or MAR, after envisaged policy (in tonnes of chlorine)

x[2]	ton TCPE	x	ton 2,3 dichloropropene
x	ton PPHE	x	ton 1-chloropropane
x	ton monocholoroacetic acid	5,8	ton 1,3 dichloropropene
242	ton methylchloride	x	ton dichloropropanol
x	ton ethylchloride	3	ton 1,2 dichloropropane
x	ton 2-chloropropane	x	ton trichloropropane

1) These are substances which, because they do not appear on the list of substances demanding special attention, are not dealt with in the RIVM's report "Substances demanding attention in the Netherlands' Environmental Policy". Appendix 4 provides a tentative analysis which shows that these substances could account for a total of 5 to 10 % of the score of the chain in 1990.
2) The values marked with 'x' are not given because they are emissions from a single company. The substances marked with 'x' account for a total of around 100 tons of organic chlorine compounds. Monochloroacetic acid accounts for the major share of it.

5 *CONCLUSIONS AND RECOMMENDATIONS*

5.1 INTRODUCTION

On the basis of the results of the study, this chapter will assess the priority emissions of the chlorine chain following implementation of the envisaged policy from 1 January 1995. It also indicates existing gaps in knowledge which are of such importance that, if the facts were known, they could have possibly resulted in different conclusions. Thanks to its internal cohesion and reasonable completeness, the outline provided by this study can certainly form an important basis for further expansion or for closer analysis as proposed in phase 2 of the chlorine chain study.

5.2 CONCLUSIONS WITH REGARD TO SUBSTANCE FLOWS AND EMISSIONS

5.2.1 Substance flows

The study shows that the throughflow in the Dutch chlorine chain amounted to 939 kt in 1990. The destination of about 99% of this chlorine has been traced. About 1% of the production and consumption chains, amounting to 10 kt of organic chlorine, were purposely not followed due to lack of information.

Of the 939 kt, 16% (147 kt chlorine) accumulates in the economy, particularly PVC. About 14% is released as HCl and recycled, 11% in the chorine chain itself and 3% externally. Exports, uses which have since been phased out, and a limited number of verifiable accounting discrepancies make up 41%. About 28% (264 kt chlorine) flows out to the environment. Of this outflow, 76% is discharged as salt to water. The remaining 24% comprises 42 kt (mainly PVC-)waste and emissions of 7 kt HCl and 14 kt organic chlorine to air, as well as 0.2 kt emissions of organic chlorine to water.

The figures indicate that there would be no sense in making "Closing the chlorine chain", or "Chain management of chlorine", in the traditional sense of closing a substance cycle, a policy objective. More than three- quarters of the outflow of chlorine from the chain occurs in the form of salt, mainly to brackish water. In effect, this means a shift of salt from geological reservoirs to the sea. Closing such a substance flow would only make sense from the perspective of resource management. Given the abundant nature of salt as a raw material, this is of absolutely no importance in the case of chlorine. As stated in the memorandum

initiating the strategic survey, "closing the chain" is only relevant for the other outflows: emissions and waste.

5.2.2 *Priority emissions after implementation of envisaged policy from 1 January 1995*

The present and future emissions from the chlorine chain were first assessed according to the classification step of the LCA method and compared with the Dutch total score on a theme. This shows:

- in 1990 the chlorine chain scored relatively (very) high on ozone depletion and global warming by comparison with other social activities;
- after implementation of the policy since 1 January 1995 the chlorine chain achieves greater reductions on several themes than the national objectives for 2000, with the exception of landfill and depletion of the ozone layer. The reductions are 75 to 90% compared with 1990, except for ecotoxicity (40%), smog formation (50%) and landfill;
- when these reductions are achieved the chlorine chain will still make a significant contribution to the Dutch total for ozone depletion and global warming (through emissions of CFC-11 from foam accumulated in society).

All reductions will take place before the year 2000, except those relating to the phasing out of PCBs in closed applications from 2005 and HCFCs from 2015. In general, it appears that the current policy has set the correct priorities. Segments which had the highest scores in 1990 achieve the greatest reductions on almost every theme. As a whole, the future scores of the chlorine chain are low compared with the Dutch total scores in 1990 for acidification (0.03%), odour (0.003%) and smog formation (0.1%) For the purpose of this study, the LCA scoring method is too rough for human toxicity and ecotoxicity. For this reason, and because of uncertainties in the Dutch total score, it is impossible to draw direct conclusions from the high LCA scores on ecotoxicity due to the use of pesticides.

The segment groups with the highest scores on an environmental theme are ranked in order of priority after weighting of the themes. Substances which score on toxicity themes in the LCA have been assessed as to whether the current, *actual* concentrations exceed the MAR or NR. These substances are also given priority. The priorities are:

1. for every cross-section chosen and for every method used to weight the themes, emission of CFC-11 from accumulated foam appears to have a high priority. These are stocks built up in society, the size of which is 3 to 4 times the score of CFC emissions in 1990 on ozone depletion and global warming.

These will be released over the coming 50 years. This legacy largely overshadows the second priority, some process emissions of (H)CFCs. CFC-11 is already being recovered from the limited amount of foam in discarded refrigerators. This is not yet done with other foams;

2. according to the LCA classification stage, the use of pesticides and biocides also score highly on ecotoxicity. The RIVM has suggested placing two of the highest scoring substances on the priority substance list because of breaches of the NR in water. There is a specific assessment framework for pesticides, namely the approval policy, whereby all approved pesticides have already been tested for toxicity risks;

3. the score for the use of PVC is high because of the volume of landfill. No account has been taken of a decline due to implementation of a recycling policy or an increase due to the extra release of PVC accumulated in society;

4. the contribution of the chlorine chain to acidification (the EDC/VCM production and waste processing), smog formation (use of DCM and trichloroethylene) and odour (use of PER) is low compared to other social sectors. A normative choice determines the degree of priority. One may only aim at reductions in sectors which contribute significantly to the Dutch total score, but one could also choose to require all sectors, including the chlorine chain, to make extra reductions, regardless of their contribution in absolute terms. The reductions achieved by the chlorine chain on these themes is already greater than or equal to the requirements of the general objectives.

5. as regards human toxicity, breaches of the MAR occur in dry cleaners with PER and in the indoor environment with DCM from paint-strippers (in practice, combined with poor ventilation). MARs or NRs are possibly exceeded by EDC near a pharmaceutical application, carbon tetrachloride/chloroform near a production plant for chloromethane, DCM at sources, 1,4 DCB in the indoor environment, and also (in the case of top competitive swimmers) chloroform in swimming pools formed by the use of hypochlorite. More research is needed on the risk-assessment of dioxins in breast milk. Extra reductions in emissions are needed to achieve the target level for trichloroethylene in the soil. As regards the production of AC/ECH and EDC/PVC, the fact that the exposure statistics are dated means that it is uncertain whether AC, ECH and EDC exceed the NR locally, and what the effect will be of the agreed emission reduction of 90% in the case of EDC.

The study shows that the implementation of the envisaged policy will remove many bottlenecks which existed in 1990. For some themes, the point is approaching when direct emissions from the chain will be of equal importance to historical

legacies: the emission of CFC-11 from accumulated foam and the emissions of dioxins and PCP from impregnated timber accumulated in society. For the sake of completeness, it must be added that this study expresses no judgement on whether products could better be made with or without the use of chlorine (compounds). Environmental product assessments must discover whether the use of chlorine (compounds) results in an increase, or even a decrease, in the environmental burden caused by manufacture of a particular product.

5.3 GAPS IN KNOWLEDGE AND RECOMMENDATIONS FOR RESEARCH

All the conclusions have to be seen against a background of gaps in knowledge with regard to emissions and limitations in the methodology as described in section 3.4. This study makes no attempt to estimate which processes could be so influenced by gaps in knowledge, or the *likelihood* thereof, that they should be recommended as a priority in phase 2. TNO and CML therefore make the following recommendations for research which could fill the gaps.

Slag and fly ash from combustion installations is polluted with about 1 kg TEQ dioxins. It is unclear whether, and if so how, these dioxins reach the environment. They therefore do not score in this study. There is an ongoing debate on whether the use of hypochlorite results in the formation of harmful organic chlorine compounds. Hypochlorite barely scores on the themes because emission data are only known for sum parameters such as AOX and not for individual substances. Given this information, it is conceivable that waste incineration and the use of hypochlorite will be selected for closer analysis in phase 2, even though no scores on the themes have been determined. As regards hypochlorite, the fact that household consumption alone of hypochlorite in 1990 makes it one of the top three Dutch AOX sources could equally be a reason for selection (see table 4.3.1). Another reason could be the breach of the MAR for competitive swimmers resulting from chloroform due to its use in swimming pools.

There are a number of (possible) gaps in knowledge with regard to the occurrence of emissions. These concern:

- the inventory of the *import of chlorine compounds in products* is limited to the 8 most important product groups: paint-strippers, paint, aerosols, foam, refrigerators, pesticides and products containing PVC;
- the study misses emissions from a limited number of untraced production and consumption chains. About 1% of the Dutch chlorine flow is involved here: 3 kt polymers and 5 kt of other substances, including chloroparaffins;

- in certain cases products appear to contain unintentional pollutants which could result in emissions when used. Apart from dioxins and PCBs, these are not taken into account;
- as instructed, the inventory of emissions at the production stage focused on dioxins, PCBs and substances listed in the Emission Record of VROM (ER-I), the WIER record system of the Directorate General for Public Works and Water Management, corporate environmental plans and a number of LCA databases. The study misses emissions if they are not covered by these (extensive) databases (chlorinated micropollutants). No assessment can be made on whether, and if so to what extent, these gaps in knowledge influence assessment of chlorinated micropollutants and whether they include persistent, bio-accumulating and toxic substances (pbt's) which have an environmental impact which should not be overlooked.

The gaps in knowledge with regard to the import of products and the chains which were not followed could be supplemented by literature search. In theory, it is unknown whether emissions occur in these chains which deserve priority. However, it is doubtful whether a (further) analysis of these chains would produce a structurally different picture than that given by the 99% of the chlorine chain which has been surveyed. Product pollutants and formation of pbt's make up a structural gap in knowledge which applies to the whole chain. The latter plays an important part in the scientific and social debate about chlorine, particularly in the United States. The seriousness of the gap is unclear. Are the main environmentally hazardous substances and their sources known after 20 years of emission registration and environmental policy? Or are small emissions of "unknown" substances with similar effects to dioxins for example, being missed by existing programmes for measuring and registering? Research to bridge this gap in knowledge is recommended. First, one could consider literature search, followed by analytical chemical field research (to fill in the details).

In the assessment of toxicity, the LCA method conjectures from spread and transformation of substances emitted to the environment. This hiatus is offset by assessing the latest available *actual* exposure concentrations in the environment for all substances with an LCA score, against the background of the policy concerning risks agreed with the Lower House of Parliament. This approach does not directly relate surveyed emissions to environmental concentrations. However, the risks are probably overestimated rather than underestimated as the data on exposure are outdated and the emissions appear to be declining. The recommendation is that 12 emissions which have not been assessed, and which do not score using the LCA method due to lack of a classification factor, should still be tested for breaches of the NR/MAR. The assessment of the toxicity risks will, however, still be somewhat uncertain. For example, there is still a debate about the level of some Acceptable Daily Intakes (ADIs), NRs and MARs. Nor is there a fully elaborated,

widely applicable method for evaluating exposure to complex mixtures of substances. This study therefore takes no account of combination toxicity.

The previous sub-section describes the environmental bottlenecks, established by means of a survey and assessment of emissions which is, in our opinion, extensive. This sub-section describes the gaps in knowledge and uncertainties. Their resolution constitutes a different kind of priority than the approach needed for proven bottlenecks, but is nonetheless very relevant. A definitive answer to or consensus on the treatment of the gaps in knowledge and assumptions referred to is needed. Only then can it be definitively stated whether the environmental burden of the chlorine chain is acceptable and will it be possible to make judgements in terms of a sustainability assessment. The report from the Advisory Council on Government Policy (WRR), "Duurzame risico's - een blijvend gegeven" (Permanent risks - a constant fact) offers valuable points of reference for such a debate [WRR, 1994].