Waste from electrical and electronic equipment (WEEE)

- quantities, dangerous substances and treatment methods

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Executive summary

Waste from electrical and electronic equipment (WEEE) is one of the priority waste streams of EU policy due to its complex and often hazardous composition and the steadily increasing quantities to be disposed of in the forthcoming years. Several difficulties are encountered for the successful management of WEEE, such as the absence of reliable statistical data of generated WEEE quantities, the inadequate separate collection and treatment of such waste as well as the limited application of recycling/recovery schemes, so that a considerable effort has to be undertaken in order to finally assess the extent of the environmental problem caused and to suggest effective reduction measures.

This report presents in summarised form the scope and main findings of a project (1997-2000) aimed at the development of models and tools for the projection of WEEE amounts, dangerous substances contained in WEEE and the resulting emissions from waste treatment.

Objective
The objectives of the project were:

- To develop a methodology for estimating potential quantities of WEEE and emissions of dangerous substances from WEEE management.
- To estimate potential quantities for selected appliances of WEEE for 1990-99 and generate projections for 2000-2010.
- To estimate emissions of dangerous substances from waste management of selected appliances of WEEE.
- To give recommendations on reduction of amounts of WEEE and emissions of dangerous substances.

Methodology
A computerised four-phase model has been developed by the European Topic Centre on Waste as the basis for the necessary analysis to show the emerging trends of WEEE in quantitative (waste quantities) and qualitative (dangerous substances emitted) form. This model forms the framework for the assessment of waste quantities and future trends as well as for the determination of dangerous substances emitted during treatment and disposal.

WEEE quantities are analysed in four phases: phase I (production/sales of electric/electronic equipment (EEE)), phase II (consumption (use) of EEE) and phase III (collection of WEEE), while in phase IV (treatment/disposal of WEEE) the composition of WEEE and emissions of dangerous substances are considered.

Six EEE appliances were selected as 'case studies' for the preparation and testing of the model: refrigerators, personal computers, TV sets, photocopiers, fluorescent tubes and small household appliances. The six types of appliances present different distinguishing features, so that the appliances represent products in already saturated and fast growing markets.

Conclusions
This report gives a first insight into the complex nature of WEEE generation and management by giving indications of many important issues to be analysed and assessed, in order to achieve an acceptable level of WEEE management in the next years, when the legislative and regulatory level of the forthcoming WEEE directive will form the context and framework to be followed by decision-makers and waste management authorities. The key conclusions of this project are summarised below:

- Data needed to carry out the calculations is rather poor. The absence of reliable data implies that the estimated potentials of future WEEE generation are of limited value and should be used only with great caution.

- A large recycling potential exists, which, if thoroughly explored, can significantly contribute to a reduction in the amounts of dangerous substances emitted as well as the recovery of considerable quantities of valuable materials. This is in line with the proposal for the WEEE directive where targets have been established for recovery and component, material and substance reuse and recycling. The recycling quota (ratio of kg recycled material per average weight of appliance) shows that the EU minimum rate of component, material and substance reuse and recycling in the proposed WEEE directive has been achieved by using the so-called 'state of the art' recycling schemes for all selected appliances except for PCs.

- With respect to the projections, the most interesting factors are trends and tendencies of how each appliance as well as the total potential may develop in the future, as it is considered to be too unreliable to forecast the actual quantities.

- The emission fraction (ratio of kg emitted dangerous substance per 1000 t input of appliance) is calculated for the selected appliances and shows that the lead emissions from recycling of PCs and TVs are the highest in comparison with the other appliances. Main contributors to these emissions are the copper and lead recycling plants. Given the fact that TVs and PCs account for approximately 55 % of the overall WEEE-potential of these appliances, lead emissions from the treatment of TVs and PCs must be considered to be potentially significant.

- To reduce the amount of WEEE and the emissions from the treatment of such waste, focus may be waste management oriented, product oriented and consumer-oriented.

  Waste management oriented measures:
  - Separate collection of WEEE is the first and very important step to enable appropriate treatment.
  - Dismantling and separation at pre-treatment facilities, where removal of parts containing dangerous substances takes place.
  - Improvement of recycling technologies.

  Product oriented measures:
  - The trend towards increased recyclability of products has led to the concept of design for recyclability (DFR) and disassembly (DFD). The product design determines to a large extent how easily a product can be recycled.
  - Substitution of dangerous substances, especially brominated flame retardants, Cd, Hg, Pb and PCB must be further supported.

  Consumer-oriented measures:
  - A new approach to saving raw materials and resources is product leasing or selling service - the so-called eco-efficient services.

Introduction

This report contains consolidated information about waste from electrical and electronic equipment (WEEE) which is one of the priority waste streams to be managed in Europe in the forthcoming years. The report's objective is to give a first insight into the characteristics of this complex waste stream by providing data and information on quantities arising as well as the emissions of dangerous substances from WEEE treatment and disposal.

After the introductory chapters concerning environmental relevance and legal framework for WEEE at European level, a review of the existing situation concerning data coverage and availability as well as data evaluation and estimation of potential waste quantities has been made. The second part of the report (chapter 6) consists of an analysis of WEEE composition and of the treatment methods applicable for their elimination whereas the final chapter gives a summary of options for the reduction of waste amounts and emissions from WEEE.

During the period 1997-2000, the European Topic Centre on Waste (ETC/W), as part of its work for the European Environment Agency, has included in its activities the analysis and assessment of data concerning WEEE in a step-by-step basis. A four-phase model has been adopted and developed as the basis for this analysis, aiming to show the emerging trends of WEEE in quantitative (waste quantities) and qualitative (dangerous substances emitted) form. The main elements of this model are presented in this report.

1. Environmental relevance

The waste from electrical and electronic equipment (WEEE) is one of the priority waste streams of EU policy, since it will probably become one of the major challenges for waste management in the future.

Even if some parts of the electrical and electronic equipment (EEE) market show signs of saturation - e.g. TV sets, refrigerators, washing machines etc. - other parts of the market show clear signs of dynamic growth - e.g. IT-equipment, telecommunication equipment and electronic toys.

The environmental implications as well as the complexity of the subject will be briefly analysed below.

Increasing quantities
It is expected that WEEE quantities will be growing rapidly in the coming years. The amount of WEEE generated in the EU is estimated at 6.5-7.5 million tonnes per year in the late 1990s[1]. In the European Union the waste stream of electrical and electronic equipment constitutes 4 % of municipal waste, increasing by 16-28 % every five years – three times as fast as the growth of average municipal waste[2],[3]. Furthermore, it is one of the largest known sources of heavy metals and organic pollutants in municipal waste. However, a detailed calculation of WEEE amounts is almost impossible.

Because of the complex aspects related to product, production and consumption of EEE a detailed calculation of WEEE amounts is almost impossible. In some markets, for example in the market for mobile phones, the present annual increase of mobile phone users of 40-100 % has been predicted to last until 2002. After this the market will be saturated, with proposed annual growth of less than 3 % (EITO, 2000).

There is no reliable data on which of the two main sources, industry or households, produces most WEEE. Information is equally scarce on the quantity of old equipment, which is currently stored by waste producers and which will only appear when economically sound collection and treatment systems are available.

Complex waste stream
WEEE is one of the most complex waste streams requiring management. This is due to the fact that EEE covers a wide variety of products ranging from mechanical devices such as hair dryers to highly integrated systems such as computers and mobile phones.

Technological innovation accelerates changes in product composition, e.g. the replacement of CRT monitors by LCD displays, or the replacement of old products with new products, e.g. the replacement of record players by CD-players. In addition, electronic appliances are increasingly included as integral parts of other product groups, for instance, electronic systems in vehicles and machinery.

1.1. Potential for negative environmental impact

The potential for negative environmental impact resulting from the treatment of these wastes is high due to the presence of hazardous substances within the waste

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1 AEA Technology - National Environmental Technology Centre; *Recovery of WEEE: economics and environmental impacts. Final report*; A report produced for the European Commission DG XI; June 1997.

2 Press release of the European Commission, 13 June 2000, Commission tackles growing problem of electrical and electronic waste.

3 The amount of WEEE in Germany represents about 4 % of municipal solid waste arisings and it is expected to grow by 5 to 10 % annually over the next 10 years, Environmental Protection Agency Germany; Information Paper *Electrical Scrap*; Berlin; May 1998.

stream, e.g. capacitors containing PCB, bromine-containing substances in printed circuit boards, plastics stabilised with heavy metals, fireproofing in casings and semiconductors.

The risks, however, are difficult to quantify because the waste stream is made up of so many different complex appliances. Most of the WEEE is treated as municipal waste and disposed of in landfills or municipal solid waste (MSW) incineration plants, causing the release of dangerous substances into the environment. In addition, even more hazardous substances might be produced in thermal treatment plants without adequate control.

1.2. Inadequate collection and treatment

Even in regions or municipalities with separate collection schemes for WEEE, not more than 60 % of end-of-life appliances from households can be collected and thereby put into a recycling system: small appliances (e.g. electrical tools, tubes) are often mixed with household waste (Jentoft, 1999).

1.3. Lack of information

Since the official waste statistics normally do not include separate estimates of WEEE from households, offices and industry there is a lack of information on where WEEE presently ends up and the environmental fate of the waste streams. The extensive uncontrolled and unrecorded transboundary movements of these end-of-life goods or their components make tracking of WEEE and its final disposal routes difficult.

The way to obtain some indication of WEEE quantities is from economic statistics and market research institutes: the pieces of equipment, the quantity, the specific production area (country), imported/exported, availability on the market and sale to the consumer. In addition, secondary data, for instance how well equipped are households, the life span of equipment, and consumer attitude, is required in order to establish the amount of WEEE.

1.4. Treatment, re-use and recycling

Electrical and electronic end-of-life products contain significant quantities of valuable substances such as base metals, precious metals, high quality plastic and other components which should be recovered.

Various technical and organisational measures to reduce the amount of WEEE already exist. Methods for sorting, dismantling and treating WEEE aimed at re-using end-of-life goods, recycling components of WEEE, and recovering valuable material contained in WEEE have been developed but not yet fully implemented. It will require more time and effort to build up the necessary infrastructure for take-back systems and to implement adequate re-use or recycling measures. This effort could be more effective, if internationally recognised technical standards for separate collection, treatment and disposal of WEEE existed.

1.5. Integrated product policy and extended producer responsibility

The major producers of EEE are working on the 'greening' of product standards, e.g. Green TV, and also developing take-back systems for certain types of end-of-life EEE. These product-related efforts have already led to encouraging results, for instance the EcoPC requires less material (6 kg instead of 16 kg), fewer component parts (29 instead of 87), and less energy (70 W instead of 200 W).

EEE producers are subject to a proliferation of international environmental policies and standards which go beyond the traditional concerns about wastes and emissions from manufacturing processes to impact on corporate management practices, product design and marketability and post-consumer product disposal.

Despite the fact that a systematic approach to environmentally friendly life cycle management presents opportunities for producers to lower product costs, there is still a vast potential for improvement. Whilst many producers are taking their first steps in the right direction, many are also opposing proposed regulations concerning extended product responsibility at EU or national level. The success of integrated product policy measures and the introduction of extended product responsibility could be given considerable support world-wide by adopting standards on reparability and extending product lifetime.

2. Legal framework at EU level

To meet the challenge associated with WEEE, the European Commission and the European Parliament are setting out clear measures in the proposed Directive on Waste Electrical and Electronic Equipment and its amendments (2002/C 110 E/01)[4] that aims to:

- prevent waste from EEE;
- reuse, recycle and recover such wastes to reduce the disposal of waste; and
- improve the environmental performance of all operations involved in the life cycle of electrical and electronic equipment (EEE).

The objectives are to be achieved by means of a wide range of measures, such as:

- Producer responsibility: producers should take the responsibility for certain phases of the waste management of their products;
- Collection of WEEE from private households: separate collection has to be ensured through appropriate systems, so that private and professional users can return their electrical and electronic equipment free of charge;
- Treatment of WEEE: Member States shall ensure that producers set up systems to provide for the treatment of WEEE; Member States may set up minimum quality standards for the treatment of collected WEEE; and treatment plants must obtain a permit from the competent authorities;
- Information: to achieve better collection rates and to facilitate recovery of WEEE, users of EEE should be informed about their role in the system.

The proposal for the Directive provides definitions for EEE, divided into 10 categories (table 2.1).

Table 2.1: The 10 categories of WEEE included in the proposal for the directive

No	Category	No	Category
1	Large household appliances	6	Electrical and electronic tools
2	Small household appliances	7	Toys, leisure and sports equipment
3	IT & telecommunications equipment	8	Medical devices
4	Consumer equipment	9	Monitoring and control instruments
5	Lighting equipment	10	Automatic dispensers

The proposed Directive imposes Member States to take the necessary measures to ensure that a minimum rate of separate collection of four kilograms on average per inhabitant per year of WEEE from private households is reached. This target must be achieved within 36 months of the entry into force of the Directive. Member States are to provide to the Commission information on an annual basis on the quantities and categories of electrical and electronic equipment put on the market, collected and reused, recycled and recovered within the Member States. On the basis of this information a new and compulsory collection target of WEEE is to be formulated.

The proposal for the Directive imposes Member States to ensure that producers meet specific targets as regards recovery as well as component, material and substance reuse and recycling. The targets are not equal for all categories of WEEE (table 2.2).

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[4] Common position (EC) No 20/2002, adopted by the Council on 4 December 2001 with a view to adopting Directive 2002/…/EC of the European Parliament and of the Council of …on waste from electrical and electronic equipment, (2002/C 110 E/01).

Table 2.2: Targets on recovery, reuse and recycling in the proposal

	Minimum recovery rate	**Minimum rate of component, material and substance reuse and recycling**
Large household appliances, by an average weight per appliance	80 %	75 %
IT and telecommunications equipment and consumer equipment, by weight of the appliances	75 %	65 %
Small household appliances; lighting equipment; electrical and electronic tools; toys, leisure and sports equipment; monitoring and control instruments; and automatic dispensers, by an average weight per appliance	70 %	50 %
Gas discharge lamps, by weight of the lamps	-	80 %
Year to achieve targets	46 months of the entry into force of the directive	

Source: Common position (EC) No 20/2002, adopted by the Council on 4 December 2001 with a view to adopting Directive 2002/…/EC of the European Parliament and of the Council of …on waste from electrical and electronic equipment, (2002/C 110 E/01).

Furthermore, five years after the entry into force of the Directive the European Parliament and the Council shall establish targets for recovery and reuse/recycling, including for the reuse of whole appliances as appropriate, and for medical devices, for the years thereafter.

3. Scope of work and objectives

3.1. Scope of work

One of the aims of the project was to provide WEEE data and information to waste management authorities, EEE producers and other stakeholders in the different EU Member States. This will assist them in getting a fair idea of quantities to be collected and treated, as well as the distribution of WEEE on categories and sources of generation. This may be helpful in the future planning of transposition measures, collection infrastructure and treatment capacity.

Another aim of the project was to give a first insight into the characteristics of this complex waste stream by providing data and information on substances contained in WEEE, and emissions of dangerous substances from their treatment and disposal.

3.2. Objectives

The objectives of the project were:

- To develop a methodology for estimating potential quantities of WEEE and for emission of dangerous substances from waste management of WEEE.
- To estimate potential quantities for selected appliances of WEEE for 1990-99 and generate projections for 2000-2010.
- To estimate emissions of dangerous substances from waste management of selected appliances of WEEE.
- To give recommendations on reduction of amounts of WEEE and emissions of dangerous substances.

The initial step in the project focused on collection of data and information available for the Topic Centre partner countries at that time: Austria, Denmark, Germany, Ireland and Spain. Under this step, six types of appliances were selected: refrigerators and freezers, personal computers, TV sets, photocopiers, fluorescent tubes and small household appliances. Later in the project, data collection was extended to cover some more of the EEA member countries (depending on data availability).

The six types of appliance are presented in table 3.1. The table shows for each type of appliance which category under Annex IB to the WEEE Directive it corresponds to. Furthermore, the reasons for selection of the specific appliance are outlined, and the main dangerous substances included in the appliance are stated. It appears that the six types of appliances present different distinguishing features, so that the appliances represent products on already saturated and fast growing markets, and they all represent contents of various dangerous substances. Finally, the selected appliances cover together a broad selection of EEE.

Table 3.1: Selected appliances

Selected appliances	Corresponding category in proposal for the WEEE directive	Reasons for selecting the appliance	Main dangerous substances included in the appliances
Refrigerators and freezers	Cat. 1: Large household appliances	• example of a well-defined WEEE • example of a saturated market and 'steady-state model' • regulations for collection and treatment in some countries implemented	CFCs, Hg
Personal computers	Cat. 3: IT & telecommunication equipment	• rapidly growing market and the treatment of used PCs is an increasing problem • example of 'dynamic-state model'	Pb, PbO, Hg, Cd, PCB, PVC, flame retardants
TV sets	Cat. 4: Consumer equipment	• same remarks as for refrigerators	Pb, PbO, Cd, PCB, PVC, flame retardants
Photocopiers	Cat. 3: IT & telecommunication equipment	• example of up to 85 % take-back and re-use of parts and components	Se
Fluorescent tubes	Cat. 5: Lighting equipment	• widespread, common appliance • different collection and treatment schemes	Hg
Small appliances	Cat. 2, 4, 6, 7: Small household appliances, consumer equipment, electrical and electronic tools, toys	• most of these appliances are disposed of with household waste • take-back systems are not yet available	Hg, Cd

4. Systematic network

4.1. General aspects of material flow schemes

The analysis, presentation, and interpretation of both material flow and energy flow within a specified system, such as production site, region, or country, is one of the most important tasks in the field of general environmental management, and it is becoming increasingly important in waste management.

The difficulty to set-up material flow balances often lies within the complexity of the system and in the lack of reliable data and information. Therefore, the modelling of material flow schemes requires a simplified system and method of calculation, based on data representing the 'real' situation as well as assumptions.

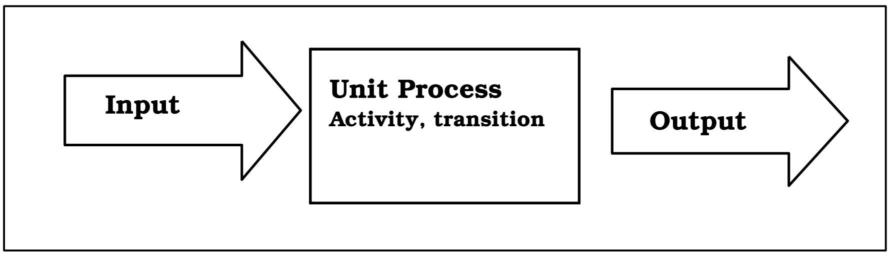
Material and energy flow models are normally based on accounting methods, for instance input/output balances or inventories for the activities or processes being examined, and networks to connect the activities or processes being examined, thus indicating the flow of material or energy.

This enables the user to put data and information in a systematic mathematical context, to reflect and assess data and information relevant to decision-making and to make projections about future prospects, even if the conditions within the system might change.

The model developed by ETC/W for WEEE is based on the 'unit process approach': a unit process represents processes or activities. It is the smallest portion of the system for which data is collected. There are two different kinds of unit process: The first type receives material and energy stocks, without any alteration: no losses and no conversions. Therefore, input is equal to output; e.g. use and collection of EEE. In the second type, a conversion of materials and/or energy takes place, thus creating new materials (products, waste, etc.); e.g. treatment of WEEE in an incineration plant or disassembly plant.

Arrows indicating the flow of material or energy link the unit processes. The material flow model considers all unit processes and flows within a defined boundary. The boundary is the interface between the system being examined and the external environment or other systems (Fig. 4.1).

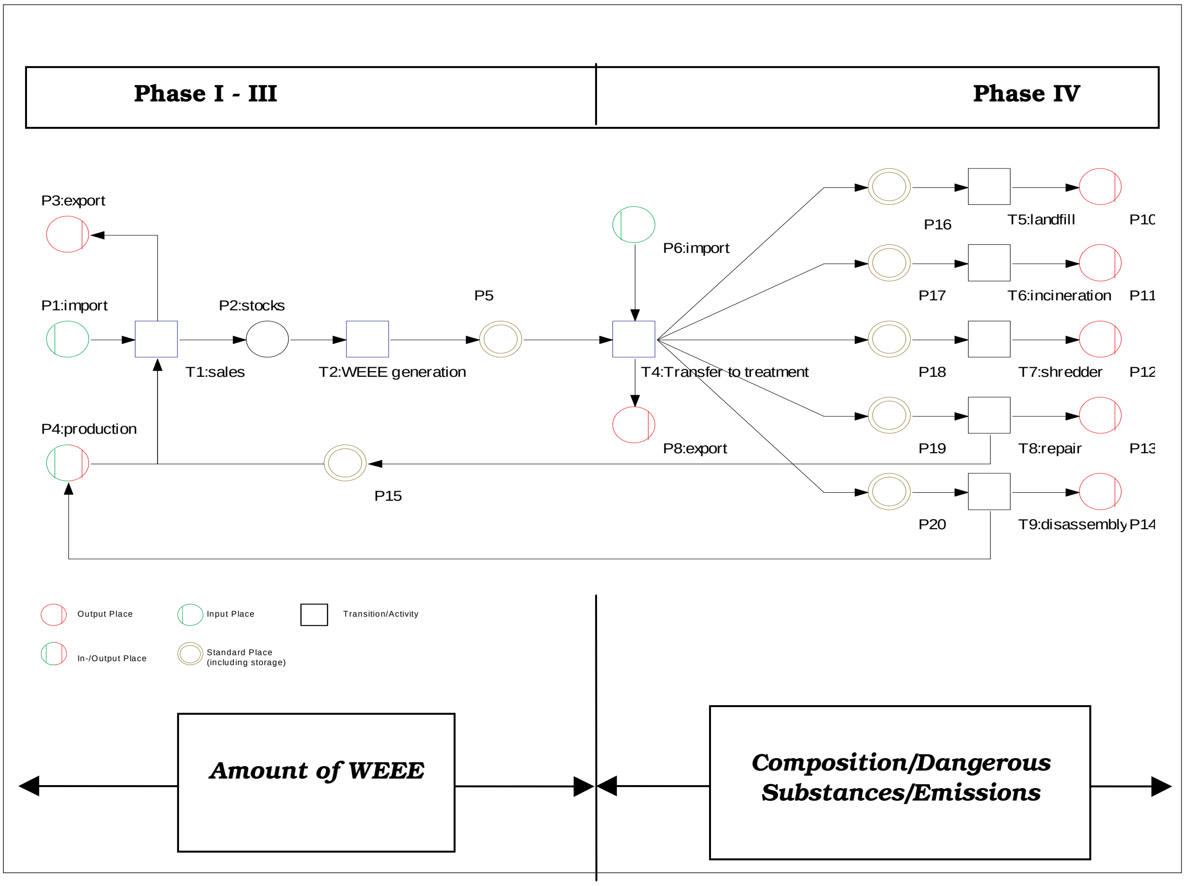
Figure 4.1: The unit process approach (simplified)



The 'Four-Phase-Model' — from EEE to WEEE
The material flow model covers four phases of EEE as well as end-of-life EEE (WEEE):

Phase I:	Production and sales of EEE, including import, export, and input of equipment for re-use from repair of WEEE.
Phase II:	Consumption of EEE, use of EEE in households, offices and industry.
Phase III:	Collection of end-of-life EEE (WEEE), including transfer to treatment/disposal sites, import/export.
Phase IV:	Treatment/disposal alternatives for WEEE, landfill, incineration, shredder, repair and disassembly, material as well as energy recovery, including the emitted material or substances.

Figure 4.2: From EEE to WEEE - The 'Four-Phase-Model'



The model has to be designed with clear mathematical rules and features. Therefore, unit processes as well as flow of different material streams in the phases I to IV have to be clearly defined (see Table 4.1)

Table 4.1: The four phases

Phase I — Production / Sales	
Relevant for the design of the model in phase I is the mass or number of pieces of equipment sold to consumers within a specified time period (t). It is assumed that no losses occur and no conversion of material takes place. Therefore Input = Output.	Input/Output for Sales: Input (t) = Production (t) + Import (t) + re-use of collected WEEE (t) – Treatment/Disposal of non-saleable EEE (t) Output (t) = Consumption (t) + Export (t)
Phase II — Consumption	
Relevant for the design of the model in phase II is the mass/number of pieces of equipment bought and used by the consumers. After a certain time span (average life time t) the end-of-life goods are passed on for collection. It is assumed that in the consumption period no losses occur and no conversion of material takes place. The model will not consider the servicing of the equipment, the replacement of parts etc. Therefore Input = Output.	Input/Output for Consumption: Input (t) = Output Sales (t) - Export (t) Output (t) = WEEE generated (t)
Phase III — Collection	
Relevant for the design of the model in phase III is the mass or number of goods collected after the consumption period. It is assumed that in the collection period no losses occur and no conversion of material takes place. In addition the import of WEEE has to be considered. The transport itself and its need for energy are not considered. Therefore Input = Output.	Input/Output for Collection: Input (t) = WEEE generated after consumption (t) + import of end-of-life EEE (t) Output (t) = end-of-life goods transferred to disposal/treatment/re-use [possibilities 1 .... n (t)] + export (t)

Phase IV - Treatment / Disposal	
Relevant for the design of the model in phase IV is the mass or number of WEEE collected and transferred to the different treatment/disposal activities. Within these activities a conversion or transition of the WEEE takes place, thus creating new materials (fractions, components, dangerous substances). In phase IV the model has to be designed for each specific type of treatment/disposal, taking into account the material input and the conversion of the material. Output depends on conversion/transition of the material and will lead to specific transfer factors.	Note: Depending on situation treatment/disposal may comprise one, two or even more successive steps with different technologies used. The calculation formula will be developed together with the development of the model specifically for each of the relevant treatment/disposal alternatives.

5. Data coverage

5.1. Data sources

Statistics
Production, import and export data regarding sales of electric and electronic products were mainly obtained from Eurostat and secondly from national statistic offices.

Reports/scientific publications
- Reports produced for the European Commission DG Environment
- Reports produced for national and international institutions e.g. - Nordic Council of Ministers, Copenhagen
- Italian National Agency for New Technology, Energy and Environment, Rome
- Federal Environment Agency, Berlin
- Other reports from universities and institutes

Publications from market research institutions
- Euromonitor
- Young and Rubicam
- EITO (The European Information Technology Observatory 1993–2000)
- Gartner Group
- AC Nielsen
- International Data Corporation

Interviews/contacts
With representatives from ETC/W partner countries, Eurostat, NGOs, public authorities, manufacturers, and manufacturers' associations.

Others
- Articles in professional journals
- Internet

5.2. Evaluation of data

5.2.1. Statistical data
In this technical report, official statistical data has an important position. To ensure comparability of data from different countries, Eurostat was used as the primary data source. The published population data from Eurostat as well as the data relating to economic development and employment is of fundamental importance for the calculations. The production data for the products under investigation was often found to contain inconsistencies, which made the calculation of WEEE difficult.

Unusual features, characteristics found in European statistics

Data from different sources
Sales data was calculated from production data, import and export statistics. Difficulties arose because the classification method used for production data differs from that used for import and export data. As a result, direct comparison of the two sets of data is problematic. Also, classification numbers for some products (PCs and TV sets) had changed over the years.

Confidential data
In countries such as Ireland or Austria, where the manufacture of certain items is small, most of the data on production is not published due to confidentiality laws. In these cases it becomes impossible to calculate sales unless production information can be obtained from industry sources.

Potential inaccuracies in data
It was found that production, import and export statistics had a high potential for error, e.g. trade statistics are normally taken from commercial documents presented to customs whenever goods cross a national border. Only when certain threshold levels of monetary value and/or net weight of a shipment are exceeded is the data passed to the statistic offices. Difficulties arise due to different methods of valuation, for example, external trade valuation.

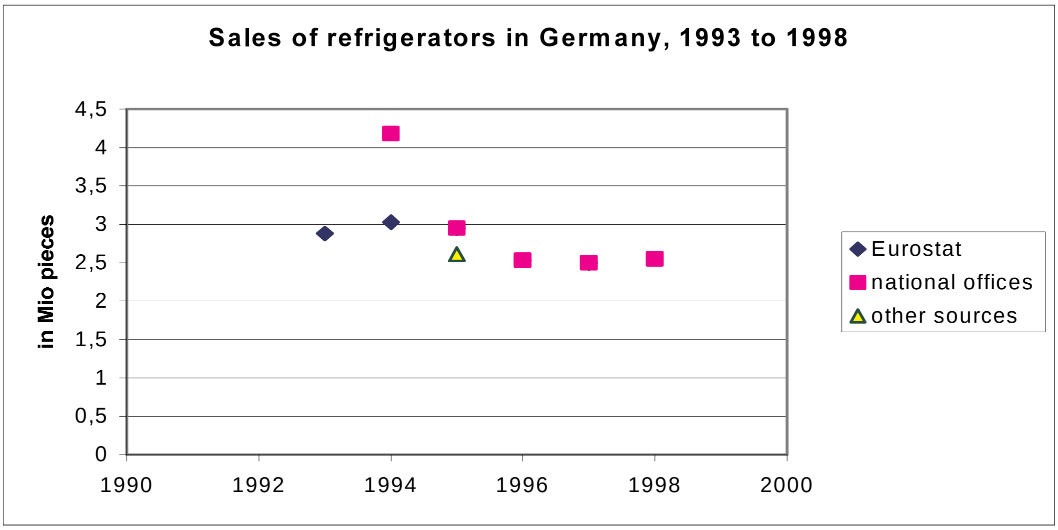
Industry sources also identified that the classification of items was confusing and may result in incorrect data supplied.

Eurostat data not matching country data
It was found that the national data compiled and published by Eurostat did not always match that published by the statistics office of the respective Member State. Differences of up to 30 % (Figure 5.1) may be revealed.

Change in the method of collecting export data in 1993
Data on all external trade of EU Member States was collected by means of the so-called ‚'Single Administrative Document‘ until the end of 1992. With the creation of the single market in January 1993, the Single Administrative Document was, therefore, abolished for the purpose of trade between Member States and was replaced by a new system called 'Intrastat'. Under this system, a large number of enterprises make either a simplified declaration or no declaration at all, depending on the value of their total transactions for one year (Eurostat, 1997).

At national level, the systems have also changed. For example, in Germany, the systematic register of goods used in production statistics was restructured in 1995. There was also a change in the method in ascertaining waste data in 1994, which means that the most recent data available is for 1993. In accordance with the new legislation, data on waste was first collected again for 1996, but has not yet been made public.

Figure 5.1 Example: Sales data for refrigerators from different data sources



5.2.2. Market analysis

It has been found that data collected by market research companies as part of a market analysis reflects more accurately the situation and trends of the EEE market, especially for the dynamic personal computer market. A considerable advantage of using data made available by market research institutes is their knowledge of the area of activity and the expertise in compiling and assessing the results. This was also confirmed in the more extensive studies carried out on Ireland.

5.2.3. Empirical data

The statistical data has also been compared with empirical data gained from pilot projects for collection of WEEE. Pilot projects for collection of WEEE have been carried out in a number of municipalities in various countries. Many types of collection systems have been established during these pilot projects, some of which have become the standard for the collection of WEEE. In some schemes the WEEE was collected directly from the households, but, more often, WEEE had to be delivered to central collection sites. The following table summarises the results of some projects in different countries.

Table 5.1: Quantities of WEEE collected in various regions in Europe

Region and source	Total WEEE	Small items	Large items	TV sets	Fridges	Fridges and freezers	Other (e.g. laundries)	Fluorescent tube lights
(Data in kg/head of population per year)								
Austria								
A1		0.21	0.79	0.22				
A2		0.37	1.01	0.27				
A3		0.92	1.81	1.08	0.92			
A4		0.68		0.69	0.68			
A5		0.08		0.16	0.08			
A6	3.5	0.60		0.51	0.08			
Germany								
D1		0.67	1.94	1.75				
D2		1.4	2.9					
D3		0.57	0.73	0.25	0.47			
D4	5.0	0.65		0.48		1.14	1.55	
D5		1.22						
D6	1.03—1.8							
D7	2.3	0.6	0.8	0.3		0.6		
D8	4	0.6	1.6	0.56		1.18		
D9					1.05			0.02
The Netherlands								
N1				0.43				
France								
F1	5.2			0.7				
F2	2.3			0.3				

Region and source:

A1 Average of collection projects in different districts, 1997. (Großversuch Steiermark, 1998)
A2 Collection project Weiz, 1995. (Großversuch Steiermark, 1998)
A3 Collection project Bregenz, 1996. (IPA, 1997)
A4 Collection project Bürmoos, 1996. (IPA, 1997)
A5 Collection project LAUV, 1996. (IPA, 1997)
A6 Collection project in the district of Flachgau, 1998. (Lohse, 1998)
D1 Collection project Freiberg, 1996. (IPA, 1997)
D2 Collection project Rostock, 1996. (IPA, 1997)
D3 Collection project Berlin, 1996. (IPA, 1997)
D4 Various urban and rural regions in Germany. (INFA, 1997)
D5 Household waste investigation by ARGUS, 1996. (Seddigh, 1996)
D6 Household waste investigation in the city of Dortmund, 1995. (INFA, 1997)
D7 Collection project Hannover, 1995. (Lohse, 1998)
D8 Collection project Bremen, 1995. (Lohse, 1998)
D9 Waste audit 1998 from Baden-Württemberg. The waste audit shows the quantity of waste which the public service waste department had to deal with
N1 Collection project in the district of Eindhoven, the Netherlands, 1997. (Lohse, 1998)
F1 Collection project in the region Rhône-Alpes. (Lohse, 1998)
F2 Collection project in the region Envie-Terra. (Lohse, 1998)

The results show clear differences. One reason for the difference can be the export of second-hand appliances, in particular, goods such as TV sets are collected from waste left for collection or from scrap yards and transported, primarily to Eastern Europe.

5.3. Selection of relevant data sources

With considerable effort, the data collected from the various sources described above was assessed for suitability in the calculation of WEEE according to:

- reliability;
- availability, amount and range of data, completeness;
- relevance in terms of the chosen method of calculation.

The assessment regarding completeness and relevance of the data was product specific due to the fact that the circumstances concerning typical consumer goods such as refrigerators differ considerably from those of products primarily in commercial use, e.g. photocopiers. Incomplete data was supplemented with product specific assumptions.

5.3.1. Refrigerators

For refrigerators, comparatively good data exists because they are a widespread consumer good. It is possible to calculate the sales data for 1993 to 1997 from the statistics available from Eurostat. All the market research data is for 1991 to 1996 and covers all EEA countries with the exception of Iceland, Liechtenstein and Norway. For Austria, Ireland, Germany and Spain, Eurostat data was of good quality and was therefore used for the calculations. For the other countries, data from Euromonitor was used. With this relatively standardised database, a good comparability of information for the different countries was possible.

Concerning the market penetration of refrigerators, the European Marketing Pocket Book was used as an all-round source of information.

5.3.2. Television sets

As for refrigerators, there is good market information on television sets for most European countries. It is possible to calculate the sales for 1993 to 1997 from the data available from Eurostat. All the market research data is for 1991 to 1996 and covers every European country with the exception of Iceland and Liechtenstein.

Data from Euromonitor could be used confidently with the exception of data for Spain where the sales data suggested a fall of 50 % between 1991 and 1996 which did not agree with the other facts. Eurostat data for 1993 to 1996 was used.

Regarding market penetration of television sets, the European Marketing Pocket Book proved to be a comprehensive source of information.

5.3.3. Personal computers (PC)

The market for personal computers in every European country has been characterised by rapid growth over the last few years. For the majority of European countries, the analysis of statistical data showed substantial fluctuations which often made it impossible to see a trend. The annual fluctuations often amounted to more than 100 % contradicting the generally accepted development of this market. As a result, the official statistics were not used in the calculation of waste potential from PCs.

The European PC market is regularly observed and analysed by several market research institutes. However, the resulting processed data is only partly available. The data available from different sources was studied with regard to suitability for waste calculations.

For Ireland, Gartner Group provides sales data for PCs for 1996 to 1999, drawing a distinction between PC sales to private consumers and industry.

Euromonitor provides data for most European countries for 1991 to 1996. This data relates only to the sale of PCs to private consumers and not to industry.

A fully comprehensive and easily available source of information is the European Information Technology Observatory's annual publications (EITO, 2000). The EITO publications include PC sales in Europe from 1993 to 1999 as well as forecasts for 2000 and 2001.

5.3.4. Photocopiers

In Europe the market for photocopiers is saturated, so that for recent years steady sales data can be expected. Data for this is relatively incomplete and includes some uncertainties, which makes the calculation of waste potentially difficult.

The published statistics from Eurostat differ widely so that they can only be partly used in the calculations. Among the other sources of data, the EITO publications contain relevant information, including sales of photocopiers in almost every European country from 1991 to 1999 as well as forecasts for 2000 and 2001.

Since photocopiers are almost exclusively for commercial or industrial use, market penetration in private households is irrelevant in this case. There is no comprehensive data available on the current numbers of photocopiers in industry. A further uncertainty when calculating the waste potential involves the return and reconditioning of used copiers, carried out to differing extents by individual manufacturers (Mahr, Xerox). Reconditioned appliances reduce the waste potential because, after their first use, they are immediately fed back into circulation and subsequently sold as new appliances.

5.3.5. Fluorescent tube lights

There is very little reliable data available on fluorescent tube lights for some countries. If sales data is calculated from official statistics, very different values for individual countries are obtained when they are compared with the corresponding population statistics: a comparison of data from Ireland and Denmark shows that specific sales data for Denmark from 1993 to 1997 is 3.4 to 6.7 times higher than for Ireland. As fluorescent tube lights are a widely used product in private households as well as in commerce and industry and both countries show a similar level of industrialisation, it can be assumed that the actual specific sales are of a similar magnitude. According to one trade organisation in Germany (ZVEI, Lichttechnische Industrie, 1999) the market share is 40 % private household and 60 % commercial use.

5.3.6. Small appliances

Small electrical appliances found in households include power tools, household appliances, entertainment electronic devices and toys. In view of the large number of different products, a quantitative inclusion of production statistics covering the whole spectrum is not possible. Statistics are not available from market research institutes either. However, a comparatively good database exists for toasters as well as for mobile phones and these have therefore been included as examples in the calculation of WEEE.

Toasters

Statistics exist for most European countries thus allowing the calculation of sales data. Of all market research institutes, Euromonitor provides the only comprehensive source of information for most European countries for 1991 to 1996.

The comparison of the sales data for different countries as well as market research results which have been established, make the reliability of the emerging statistical data doubtful. For Germany, for example, sales obtained from statistical data lie between 61 % and 121 % above the values from Euromonitor for 1993 to 1996. Regarding market penetration of toasters, data is only available for Germany (Hausgeräte-Fachverbände im ZVEI, 1999) which shows a steady market penetration of about 87 % between 1990 and 1999. There is no information for the other European countries on market penetration. As a result, a steady market penetration has been assumed for all European countries.

5.3.7. Mobile telephones

The European market for mobile telephones has shown an extraordinary rate of growth over the last few years. Because of this, the availability of possible up-to-date data for this sector is of particular interest. However, the analysis of available statistical data only enables the calculation of sales up to 1997.

Comprehensive data on the distribution of mobile phones as well as the development of the turnover in Euro in recent years up to 1999 for most European countries is available from EITO. In addition, forecasts for 2000 and 2001 are given. Because of the standardised system, the EITO publications are taken as a major source of data in the calculation of mobile phones. Data from market research institutes (Young & Rubicam, 2000) is used to fill in missing data.

5.4. Potential quantities of WEEE

Due to lack of data the results of the potential quantities of WEEE presented here cover only five of the six types of appliances that were chosen (refrigerators, personal computers, TV sets, photocopiers and small household appliances). For the same reason the projections cover only four types of appliances (refrigerators, personal computers, TV sets and photocopiers). Thus, the calculations presented here do not cover total potential quantities of WEEE. They have been made on the basis of the findings of the pilot studies and on existing data.

According to the proposal for the WEEE directive[5], various estimates of the quantity of WEEE indicate that the collection target of 4 kg per inhabitant constitutes only 25 % of the overall annual generation of this waste.

In this section the potential quantities for the appliances are added up in totals, but the quantities for each appliance are presented in Annex II.

5.4.1. Potential of WEEE 1990-99

In table 5.2 the total waste potential of WEEE for the five types of appliances (refrigerators, PCs, TV sets, photocopiers and toasters) are shown for 17 countries and EU15. No data is available for Liechtenstein.

Table 5.2: Total waste potential for five appliances (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
1990	3 568		40 026	3 170	13 452	2 040	30 620	19 720	8
1991	26 358		335 100	10 729	141 754	21 108	215 909	195 673	887
1992	28 495		351 596	10 343	138 734	21 017	221 401	195 013	885
1993	29 279		346 516	11 022	137 537	20 818	221 943	166 402	798
1994	28 411		373 909	12 099	142 435	20 623	233 303	178 241	835
1995	27 950		381 392	13 207	144 298	20 286	222 251	185 345	831
1996	26 530		302 504	12 145	133 481	18 696	201 920	177 273	819
1997	31 818		436 077	12 934	150 779	18 879	221 552	173 406	760
1998	17 829		267 054	15 644	174 362	23 451	180 917	218 332	879
1999	23 593		295 645	22 777	163 113	18 432	232 892	190 518	745

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	EU15	Iceland	Norway
1990	13 961	5 210	2 446	3 801	8 059	34 981	185 343	170	2 100
1991	65 734	31 330	23 617	15 510	36 331	181 604	1 326 698	168	11 567
1992	57 865	31 697	26 114	12 978	33 913	178 962	1 333 237	171	12 253
1993	56 415	30 538	24 934	13 705	32 140	186 562	1 302 820	161	13 210
1994	61 657	31 063	25 038	14 407	35 841	189 507	1 376 704	156	15 970
1995	53 246	29 277	26 329	14 953	30 143	165 370	1 342 447	160	13 690
1996	39 796	24 775	23 276	14 577	18 298	132 956	1 152 831	161	11 049
1997	33 378	24 529	23 113	13 355	25 422	122 722	1 311 511	156	10 567
1998	13 321	25 260	27 149	17 025	29 845	231 628	1 268 488	153	11 992
1999	23 130	26 141	24 297	16 204	33 577	146 683	1 246 463	154	11 040

In general, the data for 1990 is particularly poor and include toasters only, which explains the low values. Furthermore, data for photocopiers only covers the period 1994-99.

For Iceland the data includes toasters only. For Luxembourg there is no data for personal computers and photocopiers. For the Netherlands, the figure for 1998 does not include refrigerators and TV sets.

For 1991-99 it seems as if the potential is declining for several countries. This is especially evident for the Netherlands where the potential seems to have been reduced by 65 % from 66 000 tonnes in 1991 to only 23 000 tonnes in 1999.

The potential for EU15 seems to decline by 8 % from 1.3 million tonnes in 1991 to 1.2 million tonnes in 1999.

Table 5.3 shows the waste potential for the five types of appliances stated in kg per inhabitant.

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5 Proposal for a Directive of the European Parliament and of the Commission on waste from electrical and electronic equipment, COM(2000)347 final, Brussels, 13.6.2002.

Table 5.3: Total waste potential for five appliances (kg per inhabitant)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
1990	0.46	0.83	0.51	0.90	0.35	0.20	0.54	0.35	0.02
1991	3.39	4.87	4.20	3.05	3.65	2.07	3.80	3.45	2.31
1992	3.62	4.69	4.38	2.92	3.56	2.04	3.87	3.44	2.27
1993	3.68	4.67	4.28	3.09	3.52	2.01	3.86	2.92	2.02
1994	3.54	5.64	4.60	3.38	3.64	1.98	4.04	3.12	2.08
1995	3.48	5.29	4.68	3.67	3.68	1.94	3.83	3.24	2.04
1996	3.29	4.91	3.70	3.35	3.40	1.79	3.47	3.09	1.98
1997	3.94	4.32	5.32	3.54	3.84	1.80	3.79	3.02	1.82
1998	2.21	4.87	3.25	4.24	4.43	2.23	3.08	3.79	2.07
1999	2.92	5.40	3.60	6.15	4.14	1.75	3.95	3.31	1.76

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	EU15	Iceland	Norway
1990	0.94	0.52	0.25	0.76	0.95	0.61	0.51	0.67	0.50
1991	4.38	3.14	2.39	3.10	4.23	3.15	3.63	0.66	2.72
1992	3.82	3.16	2.65	2.58	3.92	3.09	3.63	0.66	2.87
1993	3.70	3.03	2.53	2.71	3.70	3.21	3.53	0.61	3.07
1994	4.02	3.08	2.53	2.84	4.10	3.25	3.72	0.59	3.69
1995	3.45	2.89	2.66	2.93	3.42	2.83	3.61	0.60	3.15
1996	2.57	2.44	2.35	2.85	2.07	2.26	3.09	0.60	2.53
1997	2.14	2.41	2.33	2.60	2.87	2.08	3.51	0.58	2.41
1998	0.85	2.48	2.73	3.31	3.37	3.92	3.39	0.56	2.71
1999	1.47	2.56	2.43	3.14	3.79	2.48	3.32	0.56	2.48

The potential quantity of the five types of appliances included in this report is estimated at 3.3 - 3.6 kg per inhabitant for EU15.

Greece, Luxembourg and Portugal seem to have the lowest potentials in kg per inhabitant, but while the potential in Portugal seems to remain fairly constant the potential in Greece and Luxembourg seems to decline.

On the other hand, Denmark, Sweden and France seem to have the highest potentials of WEEE. In Ireland the potential seems to be growing rapidly from 3 to 6 kg per inhabitant.

5.4.2. Projection 2000-10

Table 5.4 shows the projected waste potential for four appliances of WEEE for 2000-10 (refrigerators, TV sets, personal computers and photocopiers).

It is worth noticing that the projections are carried out using linear extrapolation of the trend for sales and stock figures for 2000-2010.

Table 5.4: Total waste potential for four appliances (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
2000	27 954		349 200	24 399	184 988	20 534	242 918	212 231	763
2001	28 915		329 142	26 328	188 504	21 092	239 363	220 062	752
2002	30 176		324 442	29 142	196 723	21 921	244 134	225 806	741
2003	31 441		320 039	31 961	204 903	22 754	248 635	231 381	729
2004	30 131		275 287	32 484	206 059	22 115	231 524	215 918	718
2005	31 316		270 053	35 239	214 212	22 891	235 742	220 764	707
2006	32 502		264 820	37 994	222 365	23 667	239 960	225 610	696
2007	33 687		259 586	40 749	230 518	24 442	244 178	230 456	685
2008	34 872		254 353	43 504	238 672	25 218	248 396	235 303	673
2009	36 058		249 119	46 259	246 825	25 994	252 615	240 149	662
2010	37 243		243 886	49 014	254 978	26 770	256 833	244 995	651

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	EU15	Iceland	Norway
2000	12 073	25 288	27 520	19 384	38 270	187 369	1 475 127		13 925
2001	9 138	24 914	27 602	19 322	39 391	176 467	1 460 133		13 547
2002	9 422	26 097	28 339	20 287	45 318	180 029	1 499 663		14 081
2003	9 701	27 312	29 065	21 245	51 243	183 606	1 539 022		14 613
2004		24 258	27 849	19 271	53 812	167 583	1 437 058		13 345
2005		25 288	28 505	20 102	59 683	170 590	1 472 992		13 841
2006		26 317	29 161	20 932	65 554	173 597	1 508 927		14 338
2007		27 346	29 818	21 763	71 424	176 604	1 544 861		14 834
2008		28 375	30 474	22 594	77 295	179 611	1 580 796		15 331
2009		29 405	31 130	23 425	83 166	182 618	1 616 730		15 827
2010		30 434	31 786	24 256	89 036	185 625	1 652 665		16 324

There are no projections available for Iceland and Liechtenstein. Nor is there any data for refrigerators and TV sets for the Netherlands. For Luxembourg there is no data available for personal computers and photocopiers. For photocopiers projections are only available for 2000-2003.

Furthermore, the results for some countries (TV sets: Greece, Belgium and Sweden; refrigerators: Sweden; PCs: the Netherlands) show negative values. The reason for these obviously inaccurate calculations must be deviations in future market penetration data for televisions, which was obtained by linear extrapolation of developments up to the present. Data sets with negative values are not included in the projections presented in Tables 5.4 and 5.5, but are presented in Annex II.

Despite the negative values and the lack of some data sets, the potential for EU15 seems to increase by 12 % or 200 000 tonnes, to 1.6 million tonnes.

The total potential in Germany, the Netherlands and Luxembourg seems to be declining, while it seems to be increasing in the other countries. The potential seems to rise fastest in Sweden, Ireland, Spain and Denmark.

Table 5.5 shows the potential per inhabitant for four appliances for 2000-10.

Table 5.5: Total waste potential for four appliances (kg per inhabitant)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
2000	3.46	19.18	4.25	6.41	4.69	1.94	4.09	3.65	1.94
2001	3.58	20.48	4.01	6.91	4.78	2.00	4.03	3.78	1.91
2002	3.73	21.97	3.95	7.65	4.98	2.08	4.11	3.88	1.88
2003	3.89	23.45	3.89	8.39	5.19	2.16	4.18	3.98	1.85
2004	3.73	24.40	3.35	8.53	5.22	2.09	3.90	3.71	1.82
2005	3.88	25.45	3.30	8.95	5.40	2.15	3.89	3.81	1.77
2006	4.03	26.90	3.24	9.65	5.60	2.23	3.96	3.89	1.74
2007	4.17	28.35	3.17	10.35	5.81	2.30	4.03	3.98	1.72
2008	4.32	29.80	3.11	11.05	6.01	2.37	4.10	4.06	1.69
2009	4.47	31.25	3.05	11.75	6.22	2.45	4.17	4.14	1.66
2010	4.63	32.18	3.01	12.21	6.41	2.51	4.16	4.29	1.62

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	EU15	Iceland	Norway
2000	0.76	2.47	2.75	3.74	4.32	3.15	3.91		3.12
2001	0.58	2.44	2.75	3.73	4.44	2.97	3.87		3.04
2002	0.59	2.55	2.83	3.92	5.11	3.03	3.98		3.16
2003	0.61	2.67	2.90	4.10	5.78	3.09	4.08		3.28
2004	0.00	2.37	2.78	3.72	6.07	2.82	3.81		2.99
2005	0.00	2.46	2.82	3.85	6.68	2.84	3.88		3.02
2006	0.00	2.56	2.88	4.01	7.33	2.89	3.98		3.13
2007	0.00	2.66	2.95	4.17	7.99	2.94	4.07		3.24
2008	0.00	2.76	3.01	4.33	8.65	2.99	4.17		3.35
2009	0.00	2.86	3.08	4.49	9.30	3.04	4.26		3.46
2010	0.00	2.95	3.12	4.61	9.88	3.05	4.34		3.51

The projected potential for EU15 seems to rise steadily from 3.9 to 4.3 kg per inhabitant. The development is the same for Norway, but at a lower value, from 3.1 to 3.5 kg per inhabitant.

5.5. Conclusions

A general conclusion is that the data necessary to carry out the calculations is rather poor. Especially data regarding sales, market saturation, import and export is lacking. The absence of reliable data implies that the estimated potentials of WEEE are of limited value and should be used only with great caution focusing more on the trend shown and not on the absolute quantities. Furthermore, the appliances selected here only cover a fraction of the total WEEE potential included in the proposal for the WEEE directive.

According to the proposal for the WEEE directive (COM(2000)347 final), various estimates of the quantity of WEEE indicate that the collection target of 4 kg per inhabitant constitutes only 25 % of the overall annual generation of this waste.

One of the objectives of the project was to provide a first insight in the complex waste stream of WEEE, by trying to estimate current and future potentials. For the EU15 the average potential quantity of the five types of appliances shows a downward trend from 3.6 - 3.3 kg per inhabitant. The projected potential quantity for four types of appliances seems to rise steadily from 3.9 to 4.3 kg per inhabitant.

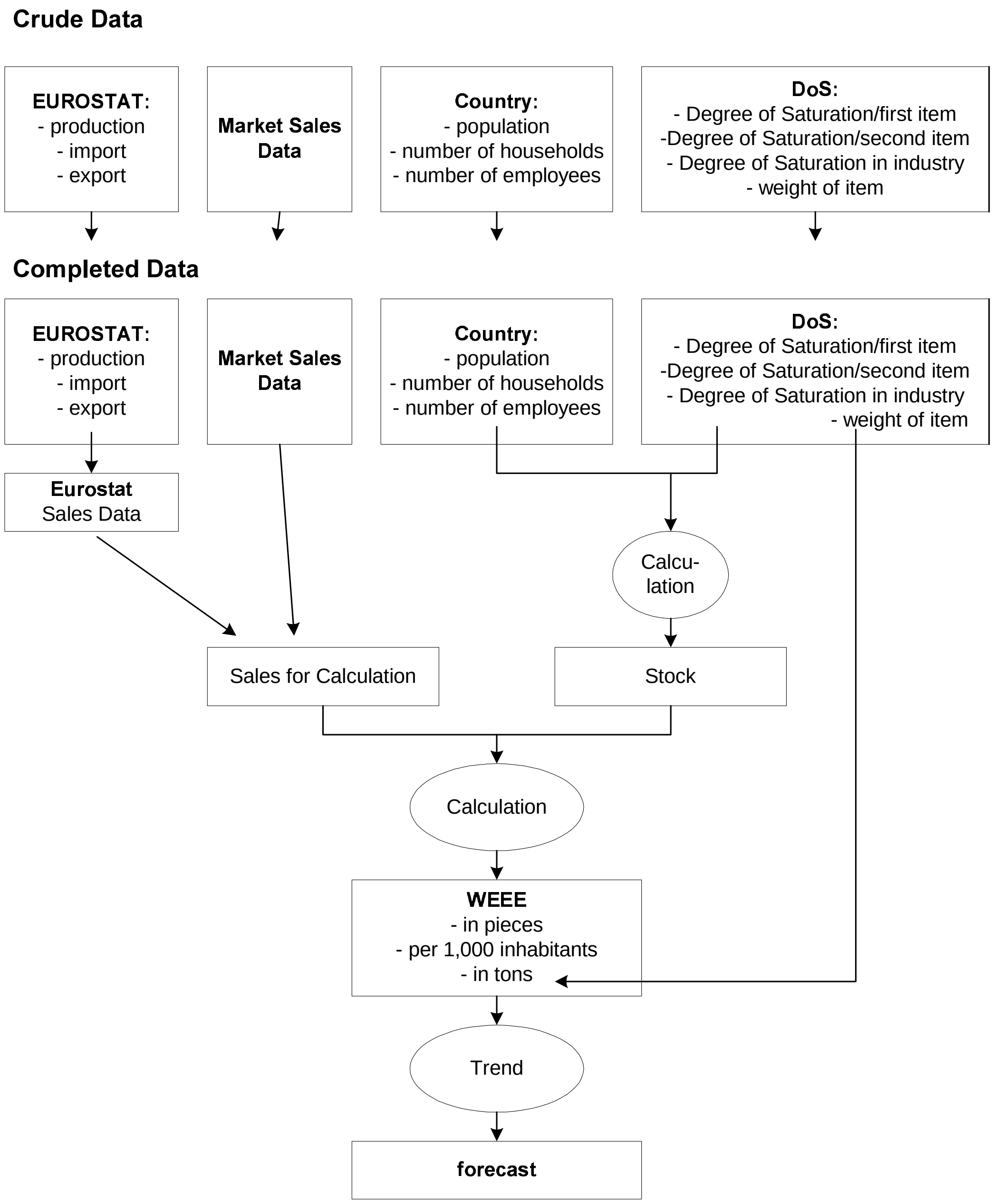
Among the selected appliances, the highest potentials for EU15 are found for TV sets with figures of 1.2 - 1.7 kg and refrigerators with a potential of approximately 1.1 kg per inhabitant.

With respect to the projections, the most interesting factors are trends and tendencies of how each appliance as well as the total potential may develop in the future, as it is considered to be too unreliable to forecast the actual quantities. The projections are estimated by using linear extrapolation which does seem not to work very properly in this case. Instead of using only historic data for sales, market saturation, etc. to estimate the future quantities it might be considered to include other variables such as economic development.

5.6. Data flow

Figure 5.2 schematically summarises the data flow from input and completion of crude data until calculation of WEEE and forecasts.

Figure 5.2: Data flow from input and completion of crude data until calculation of WEEE and forecasts



6. Dangerous substances and emissions

6.1. Introduction

The WEEE stream is treated in various ways. The specific allocation of WEEE to recycling, recovery, treatment and disposal technologies differs from country to country. Allocation is also dependent on the actual prices for treatment and disposal. In recent years, an increasing amount of WEEE is treated in thermal industrial processes.

6.2. Waste composition

According to investigations carried out in Germany, 40 % of total WEEE comes from industrial goods, 40 % from large household appliances and 20 % are electronic consumer goods, including 5 % end-of-life computers.

The composition of WEEE is specific for each appliance. In order to handle this complexity the parts/materials found in WEEE have been divided into six categories:

- iron and steel, used for casings and frames;
- non-ferrous metals, especially copper used in cables, and aluminium;
- glass used for screens, windows;
- plastic used as casing, in cables and for circuit boards;
- electronic devices mounted on circuit boards;
- others (rubber, wood, ceramic etc.).

Table 6.1 provides an overview of the composition of the six appliances selected for the present project.

Table 6.1: Average weight and composition of selected appliances

Appliances	Average weight (kg)	Fe % weight	Non Fe-metal % weight	Glass % weight	Plastic % weight	Electronic components % weight	Others % weight
Refrigerators and freezers	48	64.4	6	1.4	13	-	15.1
Personal computers	29.6	35.3	8.4	15	23.3	17.3	0.7
TV sets	36.2	5.3	5.4	62	22.9	0.9	3.5
Photocopiers		58	8	7	9	2	16 (10 rubber)
Fluorescent tubes	0.2	0.6	1.4	93.9			4.1
Small appliances		38	21	49			

6.3. Dangerous substances in the selected appliances

Dangerous substances are present in all appliances in varying amounts. The appliances selected for further investigation are generally representative of the dangerous substances present in all categories of WEEE. The most important parts that may contain dangerous substances are considered as follows:

Ferrous metals

- Steel is used for frames. The hazardous potential of iron and steel for the environment is low.

Non-ferrous metals

- Copper and its alloys are used for wires, conductors for electricity and heat, and as pigments in plastic. The toxicological risk for human health is not considered to be significant. It may leach from landfills.
- Aluminium is used for frames. Its hazardous potential is low.

Glass in screens (cathode ray tubes)

- Screens containing lead components.

- Fluorescent material in screens (Cd in old screens, Y, Eu, Se, Zn), the average amount of fluorescent material is about 6 g per screen.
- Various components hindering recycling.

Electronic components/circuit boards

- Solders containing Sn, Pb.
- Semi-conductors (B, Ga, In, As).
- Flame retardants; up to 5-10 % by weight.
- Mercury in batteries, switches.

Plastic

- Plastic containing pigments and stabilisers (Cd, Pb, Ni, Cr, Sb, Sn, Ba).
- The relative quantity of plastic with flame retardants (FR) depends on the appliance category and, within the category, on the type of the appliance. Circuit boards as well as thermoplastics are treated with flame retardants. FR includes organic halogenated compounds (esp. brominated flame retardants (BFR) such as deca bidiphenylether (10-BDE)), antimony oxide (as a synergist), phosphorous organic compounds and other materials. Due to environmental problems, particularly in relation to 10-BDE, industry has taken steps to minimise FR contents or to substitute 10-BDE with tetrabrombisphenol A, which has a lower dioxin generation potential. Nevertheless, WEEE still contains significant quantities of BFR.

PCBs

- PCB capacitors have been used in electric motors for white goods and in fluorescent tubes (average capacitor weight: 100-300 g, 30-90 g PCB).

Others

Special problems are related to the following.

- Freezers and refrigerators containing CFCs in the cooling circuit and in the insulation foam. CFCs contribute to global warming.
- Fluorescent tubes contain mercury (modern tubes 3-20 mg, others 15-30 mg), energy efficient compact fluorescent tubes about 6 mg.
- Small appliances (coffee grinders, irons, hair dryers): An investigation[6] carried out in Germany showed that the amount of small EEE, which is disposed of together with municipal waste in the rubbish bin is about 1 % by weight (see Figure 6.1). The group ‘others’ also includes single parts such as pumps, small motors and components that cannot be assigned to a specific appliance. Small appliances have differing amounts of components with dangerous substances. For instance, in certain cases, batteries/accumulators are not removed. Appliances with a high percentage of electronic components, with plastic containing flame retardants and with heavy metals should also be considered as potentially harmful.

6.4. Emissions from treatment of WEEE

At present, most WEEE is collected as part of municipal waste and is therefore disposed of at landfill sites or in incineration plants depending on the local/national practices. In some countries or regions, certain products such as refrigerators and freezers are collected separately, but this is not a widespread practice. Where WEEE is separately collected, special treatment processes tend to be used for the different WEEE subgroups. An overview of the various treatment schemes for WEEE is provided in Annex IV.

The following sections consider typical emissions resulting from:

- Landfilling or incineration of WEEE together with municipal waste;
- Recycling/recovery processes;
- Disposal of residues from recycling/recovery processes.

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6 Kommission der Niedersächsischen Landesregierung zur Vermeidung und Verwertung von Abfällen, Abschlußbericht des Arbeitskreises 13, Elektronikschrott, 1997.

6.4.1. Landfilling and incineration

Landfilling and incineration are the predominant practices in waste management with major differences between countries.

Landfilling

The degradation processes in landfills are very complicated and run over a wide time span. At present it is not possible to quantify environmental impacts from WEEE in landfills for the following reasons:

- Landfills contain mixtures of various waste streams;
- Emission of pollutants from landfills can be delayed for many years;
- According to climatic conditions and technologies applied in landfills (e.g. leachate collection and treatment, impermeable bottom layers, gas collection), data on the concentration of substances in leachate and landfill gas from municipal waste landfill sites differs with a factor 2-3.

As a study states[7], the environmental risks from landfilling of WEEE cannot be neglected because the conditions in a landfill site are different from a native soil, particularly concerning the leaching behaviour of metals. In addition it is known that cadmium and mercury are emitted in diffuse form or via the landfill gas combustion plant.

Although the risks cannot be quantified and traced back to WEEE, landfilling is not an environmentally sound treatment method for substances which are volatile and not biologically degradable (Cd, Hg, CFC), persistent (PCB) or with unknown behaviour in a landfill site (brominated flame retardants). As a consequence of the complex material mixture in WEEE it is not possible to exclude environmental (long-term) risks even in controlled landfilling.

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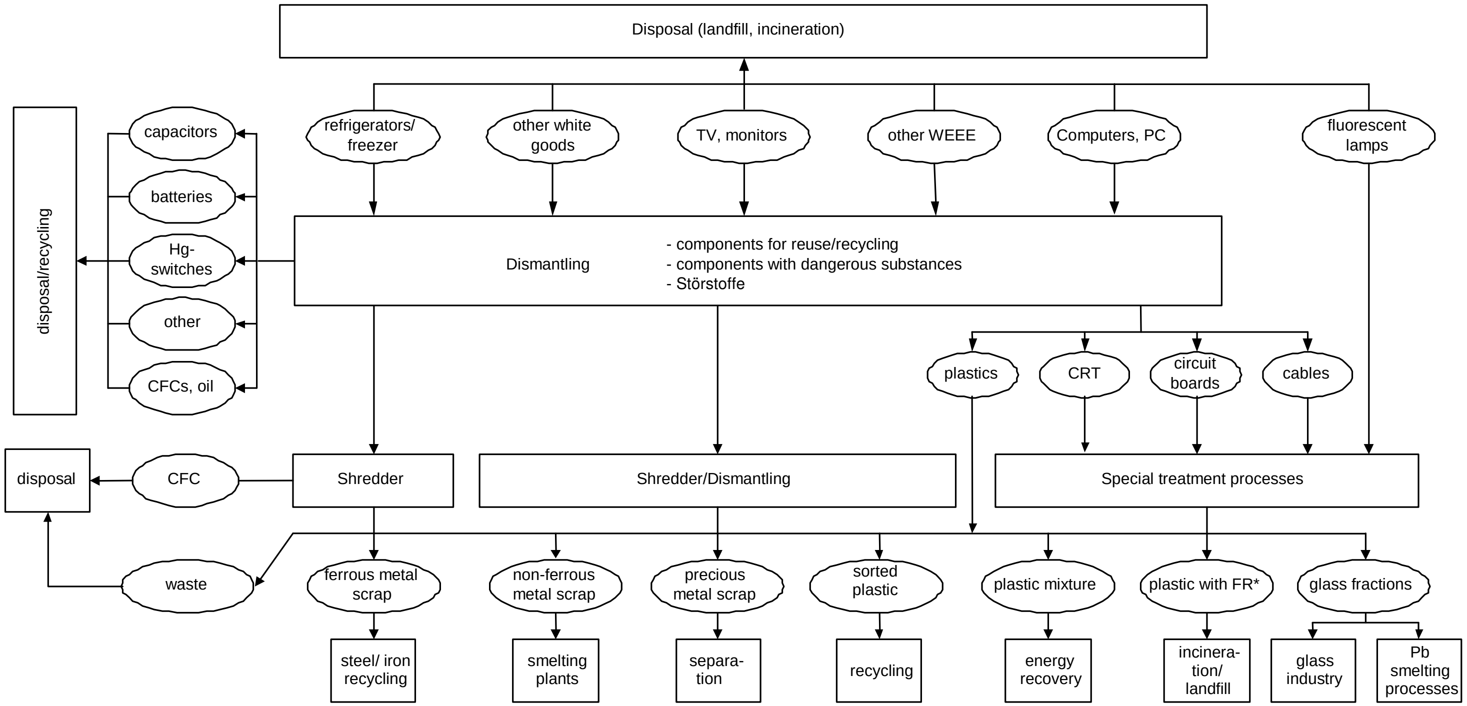
7 Tema Nord 1995:555, Environmental consequences of incineration and landfilling of waste electrical and electronic equipment, Nordic Council of Ministers, Copenhagen, 1995.

Figure 6.1: Treatment schemes for WEEE



* FR = flame retardant
CFC = chlorofluorocarbon

Zeichnun

Incineration
Advantages of incineration of WEEE are the reduction of waste volume and the utilisation of the energy content of combustible materials. Some plants remove iron from the slag for recycling. By incineration some environmentally hazardous organic substances are converted into less hazardous compounds. Disadvantages are the emission to air of substances escaping flue gas cleaning and the large amount of residues from gas cleaning and combustion.

There is no comparable data indicating the impact of WEEE emissions into the overall performance of municipal waste incineration plants. Waste incineration plants contribute significantly to the annual emissions of cadmium and mercury. In addition, heavy metals not emitted into the atmosphere are transferred to slag and exhaust gas residues and can re-enter the environment on disposal. It is inevitable that WEEE incineration will increase these emissions, if no reduction measures are taken.

6.4.2. Recycling and recovery
Overall, recycling/treatment schemes are similar for all kinds of WEEE.

- *Dismantling*: Removal of parts containing dangerous substances (CFCs, Hg switches, PCB); removal of easily accessible parts containing valuable substances (cables containing copper, steel, iron, precious metal containing parts, e.g. contacts).

  Potential emission to the environment: There is a risk for contamination of the soil through improper storage of WEEE, removed parts or improper handling of liquids (e.g. oil). There is also a risk of emission of CFC to the atmosphere.

- *Segregation of ferrous metal, non-ferrous metal and plastic*: This separation is normally done in a shredder process.

  Potential emission to the environment: This depends on the input, but there is a risk for emission of a number of volatile components.

- *Recycling/recovery of valuable materials*: Ferrous metals in electrical arc furnaces, non-ferrous metals in smelting plants, precious metals in separating works.

  Potential emission to the environment:
  At steel/iron recovery there is a risk of emission of dioxins from electric furnace steel plants, depending strongly on operation conditions; if scrap preheating is applied, dioxin emissions are up to five times higher[8]. Electric arc furnaces also contribute to the emission of Cd (13 % of the total Cd Emission in the 15 EU countries)[9].

  At copper recovery plants there is a risk for emission of a number of heavy metals, as well as volatile metals and their oxides. Also secondary copper production contributes significant to PCDD/F emissions in Europe.

  At aluminium recovery plants there is a risk for emissions of PCDD/F and fluorides, SO_2 and NO_x.

- *Treatment/disposal of dangerous materials and waste*: Shredder light fraction is disposed of in landfill sites or sometimes incinerated (expensive), CFCs are treated thermally, PCB is incinerated or disposed of in underground storages, Hg is often recycled or disposed of in underground landfill sites.

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8 *The European dioxin inventory*, Final Report, LUA NRW, 1997.

9 *The European atmospheric emission inventory of heavy metals and persistent organic pollutants for 1990*, published by German EPA (Umweltbundesamt)

6.5. A study on dangerous substances and emissions

In the following, a study prepared by the Topic Centre on estimation of emissions of dangerous substances from a number of appliances is described.

6.5.1. Objective

The objective of this survey is to provide a computer-based method to calculate emissions of dangerous substances and materials from WEEE treatment. The substances are limited to: Hg, Pb, Cd and POPs contained within five selected appliances: refrigerators, PCs, TV sets, fluorescent tubes and small household appliances. The survey focused on information from five countries: Austria, Denmark, Germany, Ireland and Spain.

6.5.2. Method

The model is based on substance and material flows analysis. Substance flow analysis tracks the flow of a substance through a technical system. At its simplest, it is an input-output balance, where the distribution of a specific input stream on several output streams is determined. For inorganic substances the input mass is equal to the output (mass conservation), in the case of organic substances, material can be destroyed or new material generated. A comprehensive description of the model is found in Annex V. The method consists of four steps:

The first step in conducting a substance flow analysis is to define the system boundaries. The system starts with the treatment of WEEE and ends when treatment is completed.
In this system all emissions to air, water and waste related to the treatment of specific WEEE appliances are considered. Emissions from 'unauthorised' treatment of waste are not considered. (The system boundaries for this step are illustrated in Annex V)

The second step is to define the unit operations within the system boundaries. This means that a specific treatment scheme is designed for each of the selected appliances. The unit operations are technical processes such as dismantling, shredding or metallurgical treatment. A system can be very simple e.g. in the case of disposal technologies it is limited to a single process. In the case of recycling the system can be complex and may comprise several unit processes. (The system boundaries for this step are illustrated in Annex IV).

The third step is to describe the transfer of substances in the various unit operations. Assigning transfer factors for each substance and each unit operation does this. They are defined as follows:

$$t_i = \frac{m_{out,i}}{m_{,in}}$$

i = index for output paths (e.g. air); out = output; in = input
m = mass

The input vector for a particular substance also includes input of the substance from sources other than the appliance, such as process materials that are required to run the process.

The fourth step is to carry out the calculations. This was done using a commercial computer software package UMBERTO[10].

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[10] Umberto has been developed by ifu, Institut für Umweltinformatik Hamburg GmbH and ifeu, Institut für Energie- und Umweltforschung Heidelberg GmbH, Heidelberg/Germany.

6.5.3. Definition of factors

Various factors are defined that allow comparison of emissions from the different treatment schemes. In Annex V all factors used in the estimation are defined. Below are given the definitions of recycling factors and air emission chosen for the presentation of some of the results.

The **recycling factors** (f_r) are calculated as the ratio of kg recovered material (e.g. metals and plastic) per 1000 t input of appliance (e.g. refrigerator, PC etc).

$$f_r = \frac{kg_{recycl.}}{1000 t_{input}}$$

In addition, for the state-of-the-art treatment schemes the **recycling quota** is calculated using the EU definition from the proposed WEEE directive as the ratio of kg recycled material per average weight of appliance. For each appliance this quota is compared with the targets set by the EU in the proposed directive.

Air emission factors (f_e) are calculated as the ratio of kg emitted dangerous substance per 1000 t input of appliance.

$$f_e = \frac{kg_{ds}}{1000 t_{input}}$$

To assess and compare the emissions generated by the state-of-the-art treatment, various scenarios were set up. The emissions from state-of-the-art treatment are compared with emissions from the incineration of 1000 t of the appliance and the incineration of 1000 t municipal waste.

6.5.4. Required data and availability

To calculate the emissions, various data is necessary:

1. The amount of WEEE as input to treatment.
2. The composition of the input stream and location of dangerous substances.
3. National treatment schemes - The same treatment scheme was used for each appliance for all countries and is regarded as the state-of-the-art at present.
4. Emission and transfer factors for waste treatment facilities.

For further information see Annex IV.

6.5.5. Calculations and results

The following presents the results estimated by using the developed substance flow model. The presented results focus on the recycled quota and the fraction of emission of a number of dangerous substances. All results are from the five selected appliances.

Table 6.2 illustrates the recycling quotas for the five appliances. The **recycling quota** is calculated using the EU definition from the proposed WEEE directive as the ratio of kg recycled material per average weight of appliance. For each appliance this quota is compared with the targets set by the EU in the proposed Directive.

Table 6.2. Recycling quota for selected appliances using state-of-the-art recycling schemes

	Refrigerators % weight	**TV % weight**	**Fluorescent tubes % weight**	**PC % weight**	**Small appliances % weight**
Metals	45 % (Al, Cu, steel)	14 % (Al, Cu, Fe (steel), Pb)	1.6 % (steel, Al/Cu + Hg)	40 % (Al, Cu, Steel, Pb)	54 % (Fe, Al, Cu)
Plastic	18 % (PS, PU, PVC)	1,4 % (PVC)		3.3 % (PVC)	1.7 %
Glass	1,8 %	41 % (screen glass) 18 % (cone glass, without Pb)	88 %	9.7 % (screen glass) 3.8 % (cone glass)	
Compressor	10 % (reuse) 10 % (recyc.)				
Batteries					0.2 %
Sum	85 %	75 %	90 %	57 %	56 %
EU minimum rate of component, material and substance reuse and recycling[11]	75 %	65 %	80 %	65 %	50 %

The table shows that the EU minimum rate of component, material and substance reuse and recycling is achieved by using the so-called 'state of the art' recycling schemes for all selected appliances except for PCs.

It should be noted that the recycling rate for plastics is rather low due to problems with the recycling of plastic. This problem is likely to increase due to increased use of plastic in the production of EEE.

[11] According to proposal for directive on WEEE

7. Recommendations on reduction of waste amounts and emissions from WEEE

In order to reduce the amounts of WEEE and emissions of dangerous substances resulting from the disposal of such waste and in order to reintegrate valuable materials into the economy, ecological efficiency (not recycling at any price), economic aspects and social acceptability must be considered. Measures to minimise environmental impacts can focus on effective treatment and final disposal of reduced WEEE amounts and on long-term measures such as eco-design of EEE and changed consumer behaviour.

7.1. Waste management oriented measures

Collection infrastructure
Collection systems are one of the key issues concerning WEEE management. In Europe most WEEE is collected and disposed of together with municipal waste, especially small appliances and electronic goods. Refrigerators and freezers appear to be the exception, although their separate collection does not always lead to appropriate treatment. For waste management purposes it is important to collect and separate different types of WEEE according to the subsequent waste treatment and recycling processes.

For recycling purposes collection systems for categories of WEEE should be created:
- refrigerators/freezers to enable separate treatment of CFC;
- TV sets, monitors to enable special treatment of circuit boards and parts containing flame retardant;
- lighting equipment for mercury recovery;
- large white goods. After removal of capacitor that might contain PCB the ferrous, non-ferrous and plastic fraction can be recycled directly.

Dismantling and separation
Dismantling and separation constitute the important first step for reducing amounts of WEEE and emissions from WEEE treatment.

To improve the current situation several measures can be taken:
- Tools for dismantling should be developed and improved, in order to automate the dismantling process and to increase the segregation of materials in this first step.
- Information for the recyclers about the location of parts containing dangerous substance and how they can be recognised should be provided.
- The shredder process is the most problematic step in the pre-treatment chain, particularly when the input is not dismantled. Although this process is designed to facilitate material separation (ferrous material, non-ferrous and plastic) no pure fractions are obtained so that significant quantities of dangerous substances are dispersed to all fractions. This causes problems in the subsequent recycling facilities. Therefore efforts should be made to improve the process technology and to develop alternatives to this process.
- The shredder residues are not recyclable so this fraction should be incinerated in well-controlled plants or used after further treatment for energy recovery in plants with high standard flue gas cleaning systems.
- In order to reduce the amount of shredder residues, easily accessible parts should be removed before shredding.

Improvement of treatment processes
State-of-the-art incineration plants for hazardous waste are equipped with efficient abatement technologies, so that major environmental problems are not caused during

operation. Residues containing heavy metals have to be disposed of in properly operated landfills to avoid leaching of heavy metals.

A high percentage of WEEE is still treated in municipal waste incinerators and an increasing amount is processed in industrial facilities for recycling purposes. These facilities should be equipped with appropriate abatement technologies. Another way could be to improve the quality of the input materials. To realise this, the collection and separation systems should be improved to reduce the amount of dangerous substances transferred to thermal processes.

7.2. Product-oriented measures

Source-oriented measures are the most efficient way in the long term to reduce environmental problems by treatment of WEEE. Product design plays an important role because it can phase out dangerous substances such as heavy metals and halogenated organic compounds and improve the recyclability of the product. However, innovative product design is not a solution to the current problems, but an investment for the future.

Design
The trend towards increased recyclability of products has led to the concept of design for recyclability (DFR) and disassembly (DFD). The product design determines to a large extent how easily a product can be recycled. Intelligent design can therefore significantly improve the suitability of a product for disassembly and recycling.

Design for disassembly (DFD) and design for recyclability (DFR)
Dismantling of WEEE is the first and the most important step in the recycling chain. Currently, this process is very labour intensive. As a result only easily accessible parts, containing dangerous substances and precious metals are removed in this first step and various valuable and dangerous materials are transferred further on to the subsequent processes.

Because most electrical and electronic goods have a high value, computer-aided design (CAD) tools are used in the design process, so data on materials and rules for DFD and DFR should be incorporated into the CAD-software to enable the designers to take environmental aspects into consideration.

Material substitution
Examples of possible substitution of materials used in EEE manufacture are listed below:

- PCB-containing capacitors are no longer in use in Europe, so problems related to these dangerous substances will disappear over the next ten years;
- Hg switches are being phased out. The main sources of Hg and Cd are accumulators in electronic equipment and on circuit boards;
- a substitute for brominated flame retardants is currently being developed. Flame retardants for plastic can be avoided by using alternative construction measures, such as metal chassis and capsulated power supply;
- substitutes for lead in solders are currently being developed, but are not yet applicable;
- specifications of electronic devices have to be adapted to withstand higher temperatures.

7.3. Consumer-oriented measures

Eco-efficient services
A new approach to saving raw materials and resources is product leasing or selling services (the so-called eco-efficient service) instead of selling products.

The leasing approach is realised by producers of copiers, for example, Xerox and Kodak. The copier in use remains the property of the producer. It is therefore in the producers' interest to extend the life span of the product. End-of-life products are returned to the producer thus encouraging him to develop efficient re-use and recycling strategies. Xerox re-uses up to 60 % of end-of-life copiers in the production of new machines. Other parts of the old equipment are recycled so that the remaining waste from end-of-life copiers is reduced by 90 %. This could be expanded to other products.

Changing consumption patterns
Consumers represent the demand side in the market system. They can influence product design, increase the demand for eco-efficient services, buy long-life products or stop buying useless products.

First of all, consumers should be informed about the environmental impacts they cause by using and discarding EEE. They also should be informed about possibilities of reducing these impacts, such as existing take-back systems. Therefore information campaigns are useful and can be launched in cooperation with consumer associations and NGOs. Industry can support these activities by publishing product information about the environmental performance. Eco-labelling systems can be implemented to increase transparency on the market, that is, provide a common standard to compare eco-performance of products. Information on sustainable consumption patterns can be integrated in the education system.

8. Conclusions

8.1. WEEE potentials

A general conclusion is that the necessary data in order to carry out the calculations is rather poor. Especially data regarding sales, market saturation, import and export is lacking. The absence of reliable data implies that the estimated potentials of WEEE are of limited value and should be used only with great caution.

Furthermore, the appliances selected here only cover a fraction of the total WEEE potential included in the proposal for the WEEE directive. According to the proposal for the WEEE directive (COM(2000)347 final), various estimates of the quantity of WEEE indicate that the collection target of 4 kg per inhabitant constitutes only 25 % of the overall annual generation of this waste.

One of the objectives was to provide a first insight into the complex waste stream of WEEE, by trying to estimate current and future potentials. A large recycling potential exists, which, if thoroughly explored, can significantly contribute to a reduction of the amounts of dangerous substances emitted as well as the recovery of considerable quantities of valuable materials. This is in line with the proposal for the WEEE directive where targets have been established for recovery and component, material and substance reuse and recycling.

For EU15 the potential quantity of the five types of appliances shows a downward trend for 1990-99 from 3.6 - 3.3 kg per inhabitant. The projected potential for four types of appliances seems to rise steadily from 3.9 in 2000 to 4.3 kg per inhabitant in 2010. However, it is not possible to explain why the potential suddenly should be rising from 2000 and onwards.

Among the selected appliances, the highest potential amounts for EU15 are found for TV sets with figures of 1.2 - 1.7 kg and refrigerators with a potential of approximately 1.1 kg per inhabitant.

With respect to the projections, the most interesting factors are trends and tendencies of how each appliance as well as the total potential may develop in the future, as it is considered to be too unreliable to forecast the actual quantities.

8.2. Emissions of dangerous substances

The Topic Centre has calculated emissions from a number of dangerous substances from treatment of selected appliances with use of the state-of-art treatment methods present. The results of the calculation were:

The recycling quota (ratio of kg recycled material per average weight of appliance) is calculated for the selected appliances. This recycling quota shows that the EU minimum rate of component, material and substance reuse and recycling in the proposed WEEE directive has been achieved by using the so-called “state of the art” recycling schemes for all selected appliances except for PCs.

The air emission fraction (ratio of kg emitted dangerous substance per 1000 t input of appliance) is calculated for the selected appliances and shows that the lead emissions from recycling of PCs and TVs are the highest in comparison with the other appliances. Main contributors to these emissions are the copper and lead recycling plants. Given the fact that TVs and PCs account for approximately 55 % of the overall waste potential of these appliances, lead emissions from the treatment of TVs and PCs must be considered to be potentially significant. Among persistent organic pollutants the emission of PCB is highest. Incineration and metallurgical plants emit

PCBs. Relatively high emissions of PCBs result from the shredding of small appliances.

Additionally the study included a comparison between emissions produced by state-of-the-art recycling and emissions produced by incineration of a similar quantity of appliance. In most cases, emissions from incineration were lower than emissions from recycling. However, it is important to note that incineration means that resources such as metals are permanently removed from the economic cycle. Therefore, a comprehensive comparison of recycling and incineration must also take into account the emissions resulting from the primary production of materials destroyed by incineration.

To reduce the amount of WEEE and the emissions from the treatment of such waste, focus may be waste management oriented, product oriented and consumer-oriented.

Waste management oriented measures:
- Collection systems are one of the key issues concerning management and minimisation of WEEE. Separate collection of WEEE is the first and very important step to enable appropriate treatment.
- Dismantling and separation at pre-treatment facilities, where removal of parts containing dangerous substances takes place.
- Improvement of recycling technologies.

Product oriented measures:
- Product design plays an important role. The trend towards increased recyclability of products has led to the concept of design for recyclability (DFR) and disassembly (DFD). The product design determines to a large extent how easily a product can be recycled.
- Substitution of dangerous substances, especially brominated flame retardants, Cd, Hg, Pb and PCB is very important.

Consumer-oriented measures:
- A new approach to saving raw materials and resources is product leasing or selling service - the so-called eco-efficient services.

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Annex I. Methodology for potentials

For the calculations of waste potential of WEEE, various methods can be used. Table I.1 shows the methods of calculation used in the present report. The time step method is described in chapter 5. The other methods are described in this annex. The method in the last column - estimation - is simple estimations.

Table I.1: Methods of calculation used in the project

Appliance	Method of calculation				
	Time step	**Market supply**	**Approx. 1**	**Approx. 2**	**Estimation**
Refrigerators	X				
TV-sets	X				
PCs	X				
Photo copiers		X			
Fluorescent lamps				X	
Toasters				X	
Mobile phones			X		
Small appliances					X

I.1. The time step method

With this method the calculation of WEEE is made on the basis of private and industrial stock and sales data. The waste potential in phase III at time t is calculated from the difference in stock levels of private and industrial equipment (phase II), in the period between two points in time t, plus sales in that period (phase I) minus the annual waste produced in that time period up to time t-1. In a Fraunhofer ISI material flow study[12], this method was termed „the time step method“.

The time step method

WEEE generation (t) =

$$[\text{Stock}(t_1) - \text{Stock}(t)]_{private} + [\text{Stock}(t_1) - \text{Stock}(t)]_{industry} + \bullet_{n=t_1+1 \text{ to } t-1} \text{Sales}(n) - \bullet_{n=t_1+1 \text{ to } t} \text{WEEE}(n)$$

with $t_1 < t$

$\text{Stock}_{private}$ = Number of households *saturation level of households / 100
= Population / average size of household *saturation level of households / 100

$\text{Stock}_{industry}$ = number of work places *saturation level in the industry / 100
= number of employees / number of users per appliance

Information about domestic sales required for this calculation can be obtained from production and export statistics. Domestic sales are the sum of domestic production and imports minus the number of exported appliances.

Appliance stock levels can be taken from ascertained saturation levels in the household. This information is available for some selected appliances in private households. Industrial stock levels however are rarely available and require assumptions.

The required input data are sales and stock data of appliance.

I.2. The market supply method

With this method the calculation of WEEE is made on from sales data, together with typical lifetimes. The waste potential in phase III at time t is calculated from sales figures from phase I and information about consumption patterns from phase II (see section 5.1). Disposal is seen as the

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12 Nathani, Carsten; *Materialfluß spezifischer Abfallarten und Abfallkennziffern bedeutender Bereiche*, Fraunhofer-Institut für Systemtechnik und Innovationsforschung, Mai 1998.

opposite to the acquisition of appliances, but with a certain time delay in the subsequent process. In a study for DG ENV[13] this method, 'market supply method', was termed 'Phase method' in a Fraunhofer ISI[14] material flow study.

The market supply method

WEEE generation (t) = sales ($t - d_N$) + reuse ($t - d_S$)

with d_N - average lifetime of new items
d_S - average lifetime of second-hand items

Similar methods of calculation were also used in the so-called Toepfer study[15] and in Fraunhofer IPA[16] calculations. It should be pointed out that the average lifetime of new goods and second-hand appliances is different.

Information about domestic sales required for this calculation can be obtained from production and export statistics.

The phase difference corresponds to the average lifetime of the appliance. Assessing the average lifetime is to a large extent subjective, when one considers that EEE is often replaced and disposed of before it reaches its technical end-of-life, and WEEE is often stored for years in cellars or garages. For simplification purposes, it is assumed as a rule that all appliances produced in the same year will be in line for disposal after exactly the average lifetime. Closer to reality would be to assume a lifetime as a normal distribution with the average lifetime as average value and a certain variance. However, as the availability of data does not permit establishing distribution curves, the simplified method will be employed here.

Required input data: Sales data and assumptions about average lifetime of appliance.

The advantage of this method is that the necessary data need not be so wide-ranging and the calculation, using a simple formula, can be carried out without any great assistance.

Sales data is derived from official statistics from market research institutes or trade organisations and are of good quality and available for a large number of products. The assumption of an average lifetime, however, seems to be a problem and we will demonstrate this by taking the PC market as an example.

The assumption that a product has a fixed lifetime or period of use over a longer period of time, presupposes constant customer behaviour over this period. But there are several reasons to suggest that customer behaviour can change. Sudden events, such as changes in technology, may result in a temporary increase (or decrease) in discarded equipment. For example, in years of rapidly increasing sales, more PCs become obsolete before the average lifetime period assumed is over, because they are replaced with new ones. However, in this case, the market supply method predicts no increase in waste generation for this year, but x years (x = average lifetime) later.

It comes to an analogous conclusion for the example of a year showing weak sales corresponding with a prolongation of first use, i.e. reduction of waste generation, which is not predicted by the market supply method.

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[13] Lohse, Dr J. *et al.*; *Collection targets for waste from electrical and electronic equipment (WEEE)* - Report compiled for EC DG ENV; Ökopol - Institut für Ökologie und Politik GmbH, Hamburg/Germany, 1998.

[14] Nathani, Carsten; *Materialfluß spezifischer Abfallarten und Abfallkennziffern bedeutender Bereiche*, Fraunhofer-Institut für Systemtechnik und Innovationsforschung, Mai 1998.

[15] Töpfer, P.; *Elektronikschrott - Entsorgung /* Recycling. Impuls-Stiftung (VDMA), Juni 1993.

[16] IPA Expertenforum 'Entsorgungslogistik und Produktrecycling'; Institut Produktionstechnik und Automatisierung (IPA), 23 April 1997.

Conclusion
The market supply method makes the assumption that the average variance in lifetime of items of EEE does not change very much, whereas, in reality, lifetimes may become shorter in the future. This means that this method is not especially useful in the calculation of WEEE for a dynamic market such as for PCs where technology and lifetimes are changing rapidly. The market supply-method, however, produces good results regarding saturated markets with no extreme changes in sales volume.

I.3. The Carnegie Mellon method

With this method the calculation of WEEE is made from sales data, assumptions about typical lifetimes, recycling and storage.

In 1997, the Green Design Initiative at Carnegie Mellon University[17] used a model which is a variation on the Market Supply method outlined above. The model attempts to examine further and take into consideration consumer behaviour when disposing of an end-of-life PC. The model may be applicable to other items of EEE as well.

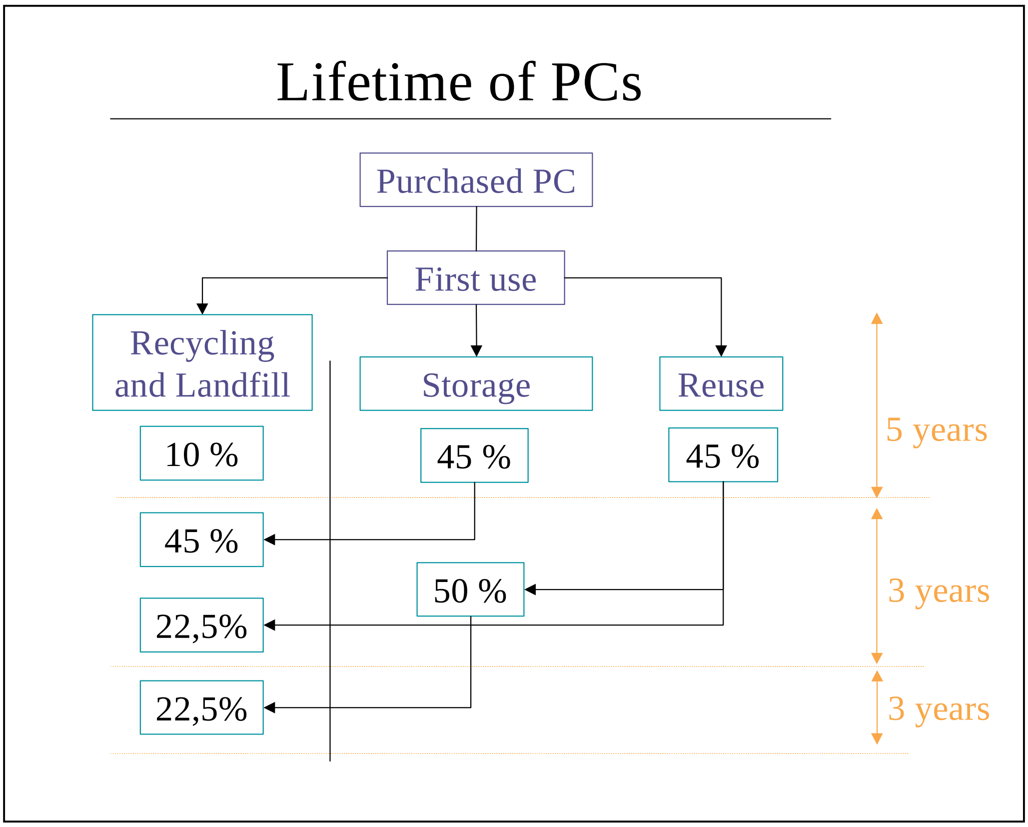
The model used in the Carnegie Mellon study defines the pathways of computers from purchase to end-of-life. A new computer is purchased and eventually becomes obsolete. At this point there are four options available to the owner

- Reuse: Possibly resold or reassigned to another user without extensive modification.
- Storage: Not used.
- Recycled: Defined as the product being taken apart and individual materials or subassemblies being sold for scrap.
- Landfilled.

The model therefore allows for a computer to be purchased, reused, stored and finally recycled or landfilled. Some assumptions are made regarding the pathways and these are applied to the model. This model also requires a full coverage of sales data from as early as possible.

[17] Carnegie Mellon University, *Green design initiative*, 2000.

Figure I.1: Pathways of PCs from purchase to end-of-life



Required input data: Sales data and assumptions about average lifetime of appliance, reuse, storage, recycling and landfill.

Conclusion
The Carnegie Mellon method presents a refinement of the market supply method by carrying out a sophisticated examination of a product's total lifetime. For the possible options - reuse, storage, recycling, landfill - facing a product at the end of its first life, there are additional assumptions to be made regarding the probability of an option and, where necessary, the subsequent phase. These assumptions are both product and country specific and therefore demand a good knowledge of consumer behaviour and the disposal position. The Carnegie Mellon method is, in the first place, ideal for more extensive examination of individual products. Because of the larger amount of input data, the calculation of WEEE is clearly more extensively structured.

I.4. Approximate formula

Two methods are possible here: approximation 1 and approximation 2.

Approximation 1
The calculation of WEEE is estimated on the basis of stock and average lifetime data. This method has also been referred to as the 'Consumption and Use' method[18]. The same method was used to calculate WEEE in the Netherlands and was also used by NGS for WEEE estimations for the German Federal State of Lower Saxony. The method is represented by the following equation;

[18] Lohse, Dr J. *et al.*; *Collection targets for waste from electrical and electronic equipment (WEEE)* - Report compiled for EC DG XI; Ökopol - Institut für Ökologie und Politik GmbH, Hamburg/Germany, 1998.

Approximation 1

WEEE generation (t) = [Stock $_{private}$ (t) + Stock $_{industry}$ (t)] / average lifetime

Stock$_{private}$ = Number of households *saturation level of the households / 100
= Population / average size of household
*saturation level of the households / 100
Stock$_{industry}$ = number of work places *saturation level in the industry / 100
= number of employees/number of users per appliance

The method uses stock levels together with an assumption regarding the average lifetime of the appliance. As with the time step-method, stock levels are obtained by multiplying the number of households and work places by the degree of penetration for the appliance (i.e. percentage of households containing the particular appliance). Stock is then divided by the average lifetime to calculate the WEEE potential.

The required input data is: Stock data and assumptions about average lifetime of appliance.

Similar to the market supply-method, this method of calculation is based on the assumption of a product's constant mean lifetime. It is therefore suitable for estimating WEEE in widely saturated markets, where no great deviations from the mean lifetime are to be expected. This method is particularly sensitive to alterations in the average lifetime of the item being considered, and this is a somewhat subjective variable in the equation.

This method is particularly useful when reliable stock data for an appliance is available, but there is only limited information regarding sales figures.

Approximation 2
The calculation of WEEE is estimated on the basis of sales statistics assuming a saturated market. This method is based on the assumption, that with the sale of a new appliance, an old appliance has to be disposed of. It is represented by a very simple equation:

Approximation 2

WEEE generation (t) = sales (t)

The required input data is: Sales data.
This method is only suitable in a fully saturated market where the purchase of a product leads to the same quantity of waste from the old product. This method is therefore not sensibly deployed in dynamic, developing markets, as in these markets a larger part of the sales serves to increase stock and does not initially contribute to waste. In addition, this method should not be deployed if the temporary storage or second use of old appliances plays a significant role in consumer behaviour as this leads to a time delay in the emergence of waste.

One advantage of this method is the limited range of input data required. In contrast to the market supply method, no historical data is required, only sales figures for the period of time in question. This method is, therefore, suitable for carrying out an initial assessment requiring little data collection or calculation time.

I.5. Conclusion

The choice of a suitable method of calculation for WEEE is dependent on several factors. Leading questions have been formulated to make the classification of the appropriate method of calculation easier.

Character of the market segment to be considered
Are we concerned with a largely saturated statistical market or with a dynamic market, which is characterised by radical change and growth?

Behaviour of the product users
Are we dealing with product users from industry and the commercial sector or with private consumers?

- Which type of behaviour predominates with the users after the first use (continued use, storage, recycling, disposal)?
- To what extent is information on the product under investigation readily available, and how good is the quality of this data?

In Table I.2, the respective conditions for deployment of different methods of calculation and their characteristics are presented in summary form.

Table I.2: Demands and suitability for different methods of calculation of WEEE

Calculation method	Required database			Applicable to		Time consuming
	Sales	Stock	Average lifetime	Saturated markets	Dynamic markets	
Time step	X	X		X	X	high
Market supply	X [1]		X	X		medium
Carnegie Mellon	X [1]		X	X	(X)	high
Approximation 1		X	X	X		low
Approximation 2	X			X		low

[1] Sales data for previous years in accordance with assumed duration of use

The choice of a particular method of calculation requires a careful consideration of the aspects identified above and demands expertise. In every case, good results can only be achieved with a good quality database. This is especially true for the highly time-consuming calculations connected with the time step-method and the Carnegie Mellon method, which demand a more extensive database than the other methods of calculation.

If there were uncertainties concerning estimations about the market or quality of the database, the thing to do would be to implement several possible methods in parallel and then compare the results. The required values will most probably lie within the range of the results obtained.

Annex II. WEEE in the EEA member countries

II.1. Refrigerators

With regard to refrigerators, there is a saturated market determined by private consumers. The sales data from Euromonitor shows that these are, exclusively, sales to private households. An additional 10 % was added here to take the sales to industry and commerce into consideration.

For all EEA member countries, a value of between 97 and 99 % was reported for equipping households with a refrigerator. As the only information available regarding a second appliance in households was for Germany with 17 %, this value was taken as an approximation for the other countries. The specific waste potential varied between 20 and 40 units per 1 000 inhabitants for most countries.

II.1.1 Potential of WEEE 1990-99

Table II.1: Waste potential of refrigerators (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
1990									
1991	10 907	9 123	78 613	3 894	48 129	12 985	62 419	76 567	440
1992	11 504	9 013	108 756	3 477	49277	13 369	65 157	77 286	449
1993	11 611	8 989	110 795	3 645	51 067	13 436	64 050	64 194	410
1994	9 651	11 279	120 838	4 180	56 803	13 776	69 916	67 062	462
1995	10 123	10 933	128 436	5 094	56 021	13 934	68 414	74 815	476
1996	10 711	11 399	102 833	5 524	53 516	14 178	69 594	79 184	446
1997	13 767	12 001	170 006	5 899	61 474	14 919	72 514	73 595	438
1998	6 371	13 095	59 102	5 324	67 559	16 203	37 798	87 249	523
1999	7 954	13 735	84 483	9 521	64 623	15 151	75 601	82 677	463

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
1990									
1991	15 454	10 719	5 001	4 039	9 028	29 267			2 117
1992	15 122	10 804	7 389	3 771	7 651	28 631			1 998
1993	15 539	10 419	5 590	3 544	6 274	29 121			2 159
1994	16 008	10 840	6 269	3 335	6 164	29 319			2 349
1995	15 565	11 102	6 515	3 943	6 503	30 748			2 100
1996	14 023	10 784	6 747	6 125	5 746	33 685			2 113
1997	13 913	10 624	6 324	5 169	5 150	33 638			2 225
1998		8 242	6 915	5 496	4 494	71 210			2 215
1999	13 262	10 905	6 865	6 564	4 619	38 702			2 197

II.1.2 Forecast 2000-10

Table II.2: Waste potential of refrigerators (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
2000	8 469	14 133	105 007	7 998	68 026	15 928	63 989	82 952	486
2001	8 105	14 746	104 589	8 563	70 332	16 271	63 777	84 373	492
2002	7 741	15 360	104 172	9 128	72 637	16 613	63 565	85 794	498
2003	7 377	15 974	103 754	9 693	74 943	16 955	63 352	87 215	504
2004	7 013	16 588	103 336	10 258	77 249	17 298	63 140	88 635	510
2005	6 649	17 202	102 918	10 823	79 555	17 640	62 927	90 056	515
2006	6 285	17 816	102 501	11 389	81 861	17 982	62 715	91 477	521
2007	5 921	18 430	102 083	11 954	84 167	18 325	62 503	92 898	527
2008	5 558	19 044	101 665	12 519	86 472	18 667	62 290	94 319	533
2009	5 194	19 658	101 247	13 084	88 778	19 009	62 078	95 740	539
2010	4 830	20 272	100 830	13 649	91 084	19 352	61 865	97 161	545

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
2000		9 944	7 067	6 442	3 700	50 942			2 236
2001		9 834	7 200	6 797	3 204	53 923			2 250
2002		9 725	7 333	7 152	2 708	56 904			2 264
2003		9 615	7 466	7 508	2 211	59 885			2 279
2004		9 505	7 599	7 863	1 715	62 867			2 293
2005		9 395	7 732	8 218	1 219	65 848			2 308
2006		9 285	7 865	8 573	723	68 829			2 322
2007		9 175	7 998	8 929	227	71 810			2 336
2008		9 066	8 131	9 284	- 270	74 792			2 351
2009		8 956	8 264	9 639	- 766	77 773			2 365
2010		8 846	8 397	9 995	- 1 262	80 754			2 380

II.2. Television sets

It was possible to use the sales data from Euromonitor for most EEA member countries. The missing values for 1991 as well as 1997-99 were added using the 'trend' linear function. For Ireland, for 1998 and 1999, data supplied by CEDA were used. For Spain, the sales data from Euromonitor did not seem consistent since they showed a dramatic fall from 1993-96, which did not correspond with an increasing degree of equipment in households. For this reason, an assumed annual rate of growth of 3 % was added for Spain for 1993-99.

The market penetration for equipping households with a first television set was taken to be 98 or 99 % over the whole period. In contrast, equipping with a second appliance had increased rapidly over the previous years, which was obvious from available values for Germany and Ireland. For example, the value for Germany more than doubled from 23 % in 1993 to 48 % in 1999 and in Ireland the increase from 27 % in 1994 to 46 % in 1999 was equally high. For every other country, values for only one year - normally 1998 - were available, so an approximate steady growth was assumed for 1990-99. The annual rate of growth was set individually for each country by taking the market penetration values for 1998 into consideration.

For most countries, the specific waste potential for 1990-99 showed a slight downward trend. In forecasts for 2000-10, this trend became stronger leading to values of around zero for some countries (e.g. Luxembourg) and in some cases negative values (Greece, Sweden, Belgium). The reason for these obviously inaccurate calculations must be deviations in future market penetration data for televisions, which were obtained by linear extrapolation of developments up to the present.

II.2.1 Potential of WEEE 1990-99

Table II.3: Waste potential of television sets (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
1990									
1991	9 594	9 461	175 102	3 400	67 366	5 660	96 876	83 054	440
1992	10 970	8 365	155 846	3 291	62 248	5 064	97 055	80 264	428
1993	10 974	7 765	134 464	3 484	62 666	4 520	100 649	69 196	380
1994	10 216	8 179	133 074	3 836	62 877	4 056	100 267	77 311	365
1995	10 348	8 728	138 159	3 783	62 840	3 628	100 446	78 622	348
1996	10 224	9 233	128 802	4 625	62 510	3 017	99 348	78 248	364
1997	13 595	8 461	180 069	4 417	62 378	2 184	99 413	73 537	314
1998	6 500	8 773	78 223	3 064	61 344	3 010	68 092	82 256	349
1999	7 291	8 906	120 474	6 580	58 048	598	94 272	73 524	276

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
1990									
1991	25 873	9 785	14 574	4 447	13 706	86 166			4 094
1992	17 975	9 475	14 563	2 286	11 922	82 938			4 370
1993	17 322	8 604	14 638	3 382	10 066	79 567			4 547
1994	16 485	7 935	14 021	3 706	9 879	74 206			5 391
1995	14 578	7 918	14 804	4 793	8 372	66 462			4 587
1996	13 162	7 846	13 476	5 413	6 584	58 540			4 229
1997	9 658	6 851	13 457	5 063	4 978	49 879			4 564
1998		4 221	13 825	5 684	3 436	76 398			4 321
1999	5 749	5 697	12 327	6 202	1 651	59 963			3 964

II.2.2 Forecast 2000-10

Table II.4: Waste potential of television sets (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
2000	8 521	8 773	107 876	5 278	59 065	849	86 766	75 458	277
2001	8 231	8 798	101 802	5 523	58 383	314	85 088	75 083	260
2002	7 942	8 822	95 728	5 768	57 701	- 221	83 410	74 707	243
2003	7 652	8 846	89 654	6 012	57 019	- 757	81 731	74 332	226
2004	7 363	8 870	83 580	6 257	56 337	- 1 292	80 053	73 957	209
2005	7 073	8 894	77 506	6 502	55 655	- 1 827	78 375	73 581	192
2006	6 784	8 919	71 432	6 747	54 973	- 2 363	76 696	73 206	174
2007	6 494	8 943	65 358	6 992	54 291	- 2 898	75 018	72 831	157
2008	6 205	8 967	59 284	7 237	53 609	- 3 434	73 340	72 455	140
2009	5 915	8 991	53 210	7 482	52 927	- 3 969	71 661	72 080	123
2010	5 626	9 015	47 136	7 727	52 245	- 4 504	69 983	71 704	106

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
2000		4 617	12 789	6 409	582	53 834			4 302
2001		4 021	12 554	6 781	- 871	50 510			4 272
2002		3 426	12 319	7 152	- 2 323	47 185			4 242
2003		2 831	12 083	7 523	- 3 776	43 861			4 212
2004		2 236	11 848	7 895	- 5 228	40 536			4 182
2005		1 641	11 613	8 266	- 6 681	37 211			4 153
2006		1 046	11 378	8 637	- 8 133	33 887			4 123
2007		451	11 142	9 009	- 9 586	30 562			4 093
2008		- 145	10 907	9 380	- 11 038	27 238			4 063
2009		- 740	10 672	9 751	- 12 491	23 913			4 033
2010		- 1 335	10 437	10 123	- 13 943	20 588			4 003

II.3. Personal computers (PCs)

The sales data for personal computers provided by EITO (European Information Technology Observatory) was used in calculations for every country with the exception of Ireland. For Ireland, values from Gartner Group were used due to the fact that the scale and chronology seemed consistent. The missing values for 1990-95 assumed a steady growth rate of 25 %. The missing values for 1990-92 for Greece and Portugal were supplied by assuming exponential growth. Regarding market penetration of personal computers in private households, research results are available for most EEA member countries. These are, however, of only limited use, as there is no data available regarding the penetration in industry and, therefore, the total stock of personal computers cannot be deduced from the market penetration in private households. For a few countries, information on the ratio of the stock of privately used PCs to commercially used PCs is available. However, these ratios vary from one to four and therefore seem to be unreliable. To obtain the total stock of PCs, it was therefore necessary to fall back on market penetration data obtained from EITO, which does not differentiate between private and commercial use. This information is available for most EEA member countries for 1992-94 as well as 1998 and shows rapid growth. The missing information was supplied by using the assumption of exponential growth. As expected, a significant increase in waste potential from personal computers for the majority of EEA member countries was found.

For some countries, for example the Netherlands, a clear fall in the quantity of waste was seen which could not be explained. This demonstrates the problem of the rapidly growing number of appliances, which cannot be determined accurately enough for this method of calculation. Because deviations in the stock of appliances effect the resulting waste data over proportionally, dramatic deviations in the quantity of waste for individual years may even produce contradictory results.

II.3.1 Potential of WEEE 1990-99

Table II.5: Waste potential of personal computers (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
1990									
1991	2 345	1 865	40 146	267	12 092	427	24 983	16 344	
1992	2 676	1 697	41 767	405	12 749	536	26 030	17 153	
1993	3 955	4 433	43 232	589	12 097	689	29 766	15 201	
1994	5 773	6 644	63 905	901	11 223	887	35 093	17 195	
1995	4 675	4 382	58 949	1 251	13 678	1 058	24 537	15 630	
1996	5 356	5 063	68 309	1 835	16 986	1 452	31 484	19 439	
1997	4 165	2 230	83 317	2 463	26 456	1 727	48 006	25 888	
1998	2 155	683	73 312	4 077	33 918	2 331	46 808	32 189	
1999	7 843	5 895	85 834	6 353	39 515	2 594	60 223	33 489	

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
1990									
1991	10 656	5 358	1 591	3 074	5 353	30 663			3 171
1992	11 241	5 668	1 706	2 582	5 950	31 174			3 598
1993	12 005	6 619	2 000	3 437	7 770	47 244			4 120
1994	17 197	7 215	2 339	3 990	11 893	54 409			5 774
1995	10 897	5 068	2 537	2 740	7 201	35 216			4 430
1996	12 164	5 949	2 765	2 920	5 692	38 317			4 626
1997	9 367	6 868	3 032	3 000	15 018	36 679			3 688
1998	1 356	7 741	3 976	2 457	13 988	52 176			2 989
1999	3 218	9 146	4 549	3 208	26 760	43 380			4 712

II.3.2 Forecast 2000-10

Table II.6: Waste potential of personal computers (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
2000	8 399	75 736	83 338	8 188	46 355	3 084	63 897	38 123	
2001	10 238	82 949	84 596	10 133	52 884	3 517	70 005	41 924	
2002	12 077	90 163	85 854	12 078	59 414	3 951	76 114	45 725	
2003	13 916	97 377	87 112	14 023	65 943	4 384	82 223	49 525	
2004	15 755	104 590	88 371	15 968	72 473	4 818	88 331	53 326	
2005	17 594	111 804	89 629	17 913	79 002	5 251	94 440	57 127	
2006	19 432	119 017	90 887	19 859	85 532	5 685	100 549	60 927	
2007	21 271	126 231	92 146	21 804	92 061	6 118	106 658	64 728	
2008	23 110	133 444	93 404	23 749	98 591	6 551	112 766	68 529	
2009	24 949	140 658	94 662	25 694	105 120	6 985	118 875	72 329	
2010	26 788	147 872	95 920	27 639	111 649	7 418	124 984	76 130	

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
2000	- 1 501	10 197	5 369	3 097	30 330	50 779			4 821
2001	- 4 576	11 336	6 127	3 201	36 201	54 129			5 333
2002	- 7 650	12 475	6 886	3 305	42 071	57 480			5 845
2003	- 10 724	13 614	7 644	3 409	47 942	60 830			6 357
2004	- 13 798	14 753	8 402	3 513	53 812	64 180			6 869
2005	- 16 873	15 892	9 161	3 617	59 683	67 531			7 381
2006	- 19 947	17 032	9 919	3 722	65 554	70 881			7 893
2007	- 23 021	18 171	10 677	3 826	71 424	74 231			8 405
2008	- 26 095	19 310	11 436	3 930	77 295	77 582			8 917
2009	- 29 169	20 449	12 194	4 034	83 166	80 932			9 429
2010	- 32 244	21 588	12 952	4 138	89 036	84 282			9 942

II.4. Photocopiers

There are comprehensive sales data on photocopiers available; however, there is no reliable information to allow the calculation of stock. Because of this, a calculation of waste potential was carried out using the market supply method. A mean appliance lifetime of four years was assumed. Using the available data, the waste potential for 1994-99 was calculated as well as a forecast to 2003. For almost every EEA member country, a falling emergence was revealed, which reflects the slight fall in sales over the last few years.

II.4.1 Potential of WEEE 1990-99

Table II.7: Waste potential of photocopiers (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
1994	3 350	4 200	38 000	3 000	13 000	2 000	29 500	19 258	
1995	3 288	4 522	39 182	3 000	13 720	2 000	30 556	19 258	
1996	3 114	5 064	42 967	3 000	13 987	2 000	31 819	19 865	
1997	2 502	2 934	55 686	3 143	11 252	2 127	26 071	17 379	
1998	2 526	3 146	53 671	3 024	11 072	1 860	26 592	16 263	
1999	2 552	3 436	53 354	2 920	11 293	1 624	27 390	15 872	
2000	2 565	3 594	52 980	2 935	11 542	1 522	28 266	15 698	
2001	2 341	2 648	38 155	2 109	6 905	1 304	20 493	18 683	
2002	2 416	2 741	38 689	2 168	6 971	1 357	21 046	19 580	
2003	2 496	2 810	39 519	2 232	6 998	1 414	21 329	20 309	

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
1994	13 500	5 000	2 200	3 700	7 800	33 000			2.022
1995	13 289	5 258	2 200	3 845	7 964	33 458			2.111
1996	13 070	5 549	2 200	4 231	8 150	34 108			2.201
1997	11 103	4 697	2 428	3 231	7 764	28 393			2.295
1998	11 525	4 871	2 126	3 261	7 640	29 245			2.380
1999	11 756	5 007	2 190	3 359	7 792	30 561			2.475
2000	12 073	5 147	2 295	3 436	7 940	31 814			2.566
2001	9 138	3 744	1 721	2 543	3 190	17 905			1.692
2002	9 422	3 897	1 802	2 678	3 247	18 460			1.729
2003	9 701	4 083	1 872	2 805	3 301	19 030			1.765

II.5. Fluorescent tube lights

Since sales data was only available for five countries, approximate values for the other countries were calculated. This was carried out as follows:

As 60 % of fluorescent tube lights are used in commerce and industry, the gross domestic product was taken as the basis for other countries. For the five countries for which sales data is available, ratios s, which were averaged out over the year, were calculated (s = number of sales/GDP). These lie between 40 and 83 and so seem fairly plausible. A mean value was created from these ratios and used for the other countries. This gives an annual emergence of fluorescent tube lights for EEA member countries of approximately 400 million pieces or 96 000 tonnes.

Table II.8: Calculation of waste, fluorescent tube lights in EEA member countries

a) Calculation sales average 1993-98 (units)

	Austria	Denmark	Germany	Ireland	Spain
1993		7 100 000		1 382 252	
1994		7 500 000		1 486 546	
1995	7 018 134	12 000 000		1 867 315	
1996	8 062 995	12 400 000		1 895 276	
1997	6 966 255	10 800 000		1 093 610	
1998			90 000 000	2 486 671	41 000 000
Average 1993-98	7 349 128	9 960 000	90 000 000	1 701 945	41 000 000

b) Calculation average sales / GDP 1997 (units / Euro)

	Austria	Denmark	Germany	Ireland	Spain
Sales	40.28	66.89	48.22	24.55	83.16

c) Calculation average sales / GDP 1997 (units / Euro)

Five countries
52.62

d) Calculation WEEE, EEA member countries

	mio units	tonnes
1997	399.6	95.892

II.6. Small appliances

II.6.1 Overall assessment

A survey carried out by Bundesverband Sekundärrohstoffe und Entsorgung[19] gives a total amount of 130 000 tonnes/year for Germany for 1998. Included in this are the following types of appliances: vacuum cleaners, power tools, kitchen appliances, electric heating appliances (toasters etc), electric lawn mowers, ironing machines, sewing machines, hairdryers, razors, hot-water appliances. This quantity represents an emergence of 1.6 kg per capita per year. When this value is compared with the empirical data provided by various pilot projects from the collection of end-of-life appliances (compare Table 5.1), the empirical data values with a range of 0.57 to 1.4 kg per capita per year lies clearly lower. This corresponds with the experience that only a small portion of the total waste potential can be collected by waste collection systems.

The value of 1.6 kg per capita per year given above is therefore acceptable and will also be used for estimating waste potential of small electrical appliances for the remaining European countries. With these assumptions there is an overall waste potential of small appliances in the EEA member countries of 593 000 tonnes/year. A backdated calculation of emergence in previous years as well as projections for the future will not be made due to the limited range of data.

Table II.9: Calculation of waste potential of small appliances in the EEA member countries

	WEEE (tonnes)	WEEE (kg/person/year)
Estimation BVSE Germany	130 000	1.6
Estimation EEA member countries	593 000	1.6

II.6.2 Toasters

The results for most of the EEA member countries show a nearly constant or slightly increasing waste potential between 1990 and 1999.

Table II.10: Waste potential of toasters (tonnes)

	Austria	Denmark	Germany	Ireland	Spain	Greece	France	Italy	Luxem-bourg
1990	218	81	2 026	170	452	40	1 120	462	8
1991	224	81	2 057	168	447	36	1 075	450	8
1992	231	86	2 261	171	473	48	1 340	445	8
1993	238	88	2 340	161	455	47	1 407	432	8
1994	245	89	2 421	158	460	44	1 435	410	8
1995	252	90	2 493	160	465	42	1 464	406	7
1996	240	92	2 560	161	469	49	1 494	402	8
1997	290	94	2 685	156	471	49	1 619	386	8
1998	277	95	2 745	154	469	47	1 628	375	7
1999	286	97	2 829	154	475	49	1 676	366	7

[19] BVSE - Bundesverband Sekundärrohstoffe und Entsorgung e.V., 1998.

	Nether-lands	Belgium	Portugal	Finland	Sweden	UK	Iceland	Liechten-stein	Norway
1990	461	210	246	101	259	1 981	170		78
1991	462	210	251	105	280	2 050	168		74
1992	457	200	256	108	240	2 111	171		86
1993	447	200	278	111	265	2 238	161		88
1994	442	202	282	114	265	2 328	156		76
1995	450	182	283	118	275	2 383	160		98
1996	447	197	288	120	275	2 414	161		81
1997	441	187	300	123	275	2 527	156		90
1998	440	185	306	126	287	2 600	153		88
1999	440	182	310	129	288	2 658	154		89

II.6.3 Mobile telephones

The available data on mobile telephones represents the total market well, but as there is no sales data for every EEA member country, a comprehensive calculation of waste potential using the calculation tool is not possible. For France, Germany, Italy, Spain and the UK, EITO provides data on market penetration for several years which, assuming a constant rate of growth in these countries, is supplemented for 1990-98. The growth in the stock of mobile telephones in each country can be calculated from this data and is identified as being dramatic (Table II.11).

The use of the calculation tool to create forecasts is not possible because of the data situation described. Besides, the market research carried out for EITO can be used for this[20]. The following illustrations show forecast values provided by EITO for market penetration and the associated rate of growth of stock of mobile telephones in Western Europe for 1995-2005. When one accepts this forecast, the market is seen to approach saturation in 2005. When this value is applied to all EEA member countries, it produces a total stock of approximately 230 million appliances in 2005. From this, an estimation of waste potential can be made for 2005. Taking into consideration the assumption that at that time there will be a relatively saturated market, the 'approximation 1' method is used. The average lifetime of an appliance is assumed to be four years. From this, a waste potential of approximately 57.6 million units or 14 400 tonnes of mobile phones is projected for 2005 for the EEA member countries.

Table II.11: Mobile phones, calculated data, stock total (units)

	Germany	Spain	France	Italy	UK
1990	824 101	143 407	297 412	758 665	1 193 405
1991	1 075 172	186 598	389 961	994 746	1 564 768
1992	1 415 325	242 796	511 309	1 304 292	2 051 693
1993	1 867 238	315 920	670 418	1 710 161	2 690 139
1994	2 458 565	411 067	879 039	2 242 329	3 527 256
1995	3 915 428	955 987	1 341 265	3 842 741	5 408 499
1996	5 405 745	1 598 784	2 201 166	5 349 395	7 200 616
1997	8 447 816	3 341 459	4 928 613	10 413 122	9 680 967
1998	13 999 436	7 000 736	11 332 134	20 115 680	12 693 120

[20] EITO - European Information Technology Observatory 2000, European Economic Interest Group, 2000.

Annex III. Material flow in the recycling/recovery of WEEE

In the following, typical recycling and recovery processes for WEEE are described, stating input/output and environmental problems for each step.

III.1. Dismantling

Dismantling is an important step in the recycling/recovery chain. The main purpose is to remove parts containing dangerous substances that are hazardous in the subsequent processes and to segregate valuable parts in accordance with the material-specific recycle chains.

Dismantling is labour-intensive, so its extent is usually a compromise between ecological and economic aspects. It should be considered to remove parts and substances that might contain Hg, PCB, CFC, Cd and Pb.

Outputs

Material for recovery/recycling	• Steel, iron, plastic, copper, aluminium, printed circuit boards, cathode ray tubes
Waste	• PCB containing capacitors, Hg-switches, CFC
Environmental risks	• Contamination of soil through improper storage of WEEE, removed parts or improper handling of liquids (e.g. oil) • Emission of CFC to the atmosphere.

III.2. Separation by shredder process

Shredder processes are applied to separate ferrous metal, non-ferrous metal and plastic. The fractions obtained are not pure, all fractions contain a low percentage of the other substances, and dangerous substances in the input material are spread over all fractions. The ferrous and non-ferrous fraction can be recycled in smelting plants, whereas the shredder residue is a mixture of different plastics, ceramic, glass etc. and cannot be recycled.

White goods (refrigerators, etc.) are normally treated in large shredders together with cars. The environmental impacts from shredder residues depend on the input material, which means whether components containing dangerous substances were dismantled and the dangerous substances removed/recycled before shredding. In white goods such components are large capacitors with PCBs for refrigerators/freezers and in addition mercury switches, CFC and oil from the cooling circuit and the insulating foam if the shredder is not encapsulated. For other WEEE, it should be considered to remove batteries and accumulators before shredding.

Input	• White goods (often together with cars and other scrap)
Output	• Ferrous fraction • Non-ferrous fraction • Shredder light fraction • Filter dust
Environmental problems	• Shredder light fraction (large quantities and dangerous substances) • Volatile emissions

Ferrous metal fraction
The scrap metal after shredding has a 95-98 % iron content. Problems for steel production processes are caused by contamination with copper (app. 2 g/kg ferrous fraction).

Non-ferrous metal fraction
According to information from shredder operators the metal yield is about 50 %, the other half being plastic, rubber, stones etc. For non-ferrous metal recycling this fraction is treated in several further separation processes (for example, sink-float processes) and the separated non-metallic fraction is landfilled.

Shredder residues
The filter dust is, in most cases, disposed of together with the light fraction. The shredder light fraction is a mixture of plastics, rubber, wood, textiles, foam, glass, ferrous and non-ferrous metals and wires. The amount of shredder residues lies between 20 and 30 % of the input and depends on:

- the type and proportion of the input materials (cars, white goods, other scrap);
- the extent of dismantling;
- the operating conditions.

The calculated amount of shredder light fraction is 11-49 % by weight for washing machines, 23-51 % for dishwashers and 39 % for cooling appliances[21]. The percentage depends on type and year of production.

Disposal of shredder residues
Except for pilot projects there are currently no recycling/recovery treatment processes for shredder residues available. Normally the shredder residues are disposed of in landfill sites for municipal waste. From experiments on mono-landfilling of shredder residues the following conclusions were drawn:

- Despite their composition shredder residues are microbiologically degradable[22].
- The self-generated heat (up to 70°C) leads to emissions of light volatile compounds[23].

To reduce the volume of the shredder residues (and the disposal costs) extruders are used, reducing the volume by up to one seventh.

Pilot projects on minimising shredder residues (input: cars, white goods, other scrap) demonstrated that by mechanical treatment this fraction can be separated further: a plastic fraction which can be used for energy recovery, a metal fraction which can be recycled and a fraction consisting of glass, ceramics, metal containing dust which has to landfilled[24]. The method is not commonly used, because direct landfilling of shredder residues is cheaper.

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[21] Institut für Siedlungswasserwirtschaft und Abfalltechnik, Universität Hannover, *Untersuchungen zur Herkunft, Zusammensetzung und zum Deponieverhalten von Shredderrückständen*, 2. Korr. Auflage, 1992.

[22] Institut für Siedlungswasserwirtschaft und Abfalltechnik, Universität Hannover, *Untersuchungen zur Herkunft, Zusammensetzung und zum Deponieverhalten von Shredderrückständen*, 2. Korr. Auflage, 1992, Annex 1.

[23] Institut für Siedlungswasserwirtschaft und Abfalltechnik, Universität Hannover, *Untersuchungen zur Herkunft, Zusammensetzung und zum Deponieverhalten von Shredderrückständen*, 2. Korr. Auflage, 1992, p. 117.

[24] K.-U. Rudolph, T. Passvoss, H. Gotthelf, H.-F. Wilms, 'Stand der Behandlung und Verwertung von Shredderrückständen aus Altautos', *Müll und Abfall*, Volume 12, 1997, p. 745.

III.3. Recycling/recovery

Steel / iron recovery
Scrap is melted in electric arc, the waste gases are passed through a cooler which can also serve to recover heat. Gases are then dedusted by filters. In some cases the dust can contain considerable quantities of heavy metals such as zinc and lead, which can be recovered.

Input	• Scrap
Output	• Steel • Slag, dust from steel mill process, sludge contaminated with Pb, Cd, Hg, PCDD/F
Environmental problems	• Dioxin emission factors for electric arc steel plants depend strongly on operation conditions; if scrap preheating is applied, dioxin emissions are up to five times higher[25] • Electric arc furnaces contribute to the emission of Cd (13 % of the total Cd Emission in the 15 EU countries)[26].

Copper recovery
Most of the copper comes from printed circuit boards, cables and the non-ferrous fraction from shredder processes.

Printed circuit boards
All copper recycling processes require pre-treatment of the boards. Components for re-use and components containing dangerous substances (Ni/Cd, Li batteries, NiMH accumulators, PCB capacitors, mercury switches, Se-containing parts) are manually dismantled. Subsequently, the boards are crushed and copper can be recovered in (hydro-) metallurgic processes. Printed circuit boards with a high Au, Pd, Pt content are recycled separately.

The mechanical treatment (crushing, sifting, sieving magnetic and electrostatic separation) of printed circuit boards leads in the case of non-assembled boards to a copper fraction with about 95 % purity and to plastic fractions.

Input	• Printed circuit boards assembled without dangerous components
Output	• Al fraction (->Al recycling) • Ferrous metal fraction (->steel recycling) • Shredder residues (plastic, metal content 3 %): light fraction • Filter dust (->landfill) • Metal mixture • (Precious metal content > 0.02 % -> separating works; • < 0.02 %: -> copper recycling)
Environmental problems	• Dangerous substances are spread over all fractions • Crushing leads (depending on the plant and operation modus) to a thermal strain, which can cause emissions of dangerous substances • Filter dust is breathable and contains heavy metals (for industrial safety good exhausters are necessary).

Another mechanical process ('kryo recycling') uses liquid nitrogen to cool the circuit boards. Inputs and outputs are the same as in the conventional mechanical process, but the low temperature excludes the emission/generation of several dangerous substances.

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25 *The European dioxin inventory*, Final Report, LUA NRW, 1997.

26 *The European atmospheric emission inventory of heavy metals and persistent organic pollutants for 1990*, published by German EPA (Umweltbundesamt)

Metal reclamation from cables
Cable burning is a process in which copper and lead are recovered through burning of the insulating material. The gases are incinerated in a thermal afterburner and emitted into the atmosphere after wet scrubbing.

While these facilities have been shut down in Germany and the Netherlands, no information is available for other countries[27].

Environmental problems:
- All ingredients for the generation of PCDD/F are present;
- occasionally high flue gas concentrations and soil contamination at former plants were found.

Copper smelting plants
Copper can be recycled by pyrometallurgical or hydrometallurgical processes. It is recovered from copper scrap and copper alloy scrap, and substances containing oxidised copper. Pyrometallurgical treatment with a blast furnace and converter is preferred.

Primary copper smelting process
Circuit boards are often treated in the copper ore process. Plastic is burned, metals more precious than copper are transferred to the copper phase, less precious metals are transferred to the slag. The process requires flue gas cleaning.

Input	• copper ore, circuit boards
Output	• slag (contains Fe, Cr, Al, Mn, ceramic, glass) ->used for construction purposes • copper • anode sludge (Ag, after further treatment: Au, Pt, Pd recovery) • electrolyte (-> Ni recovery) • residues from exhaust gas cleaning (if applied) containing Hg, Pb, Cd (-> Pb recovery)
Environmental problems	• high temperature destroys organic hazardous compounds; • it is assumed that the 'de novo' synthesis (i.e. new generation) of PCDD/F is low because of the high SO_2 concentration • release of volatile heavy metals if flue gas cleaning not applied

Secondary copper production
Copper scrap is melted in small converters with coke and iron scrap during air blowing. Crude copper in the converter contains impurities and must be refined. The copper rich slag is processed by reducing blast furnace smelting to yield black copper.

Environmental problems	• volatile metals or their oxides are transferred to the exhaust gas and - if abatement technologies are present - in the gas cleaning residues • secondary copper production contributes significantly to the PCDD/F air emissions in Europe. In the case of printed circuit boards all ingredients for dioxin formation are present

Aluminium recovery
Secondary aluminium production in rotary furnaces:

27 *The European dioxin inventory*, Final Report, LUA NRW, 1997.

After preparation, such as milling, materials containing aluminium are melted and treated in converters for refinement. In rotary drum furnaces the re-melting process is carried out under a salt layer. Most of the contaminants are transferred to the slag.

Secondary aluminium production in open-hearth smelting furnaces:
In modern multi-chamber open-hearth smelting furnaces, clean grade materials such as wrought alloys are melted down without salt. Waste gas is post burnt.

The secondary aluminium production uses only 5 % of the energy used for primary aluminium production.

The most widespread method for waste gas cleaning is the dry sorption technique. Emissions of organic substances are low when the input contains low amounts of organic matters (paint, grease, oil).

Input	• Al scrap • (salt)
Output	• Al • Salt slag • Exhaust gas • Residues from gas cleaning
Environmental problems	• Salt slag • Emissions of PCDD/F • Emission of fluorides, SO_2, NO_x

Annex IV. Background information to study on dangerous substances and emissions

Annex IV contains background information to the study carried out by the Topic Centre on emission of dangerous substances and materials from treatment of WEEE. This background information consists of a description of the substance Flow Methods, data required and availability as well as a detailed description of the five appliances and the state-of-the-art treatment operation used in methods to calculate the results.

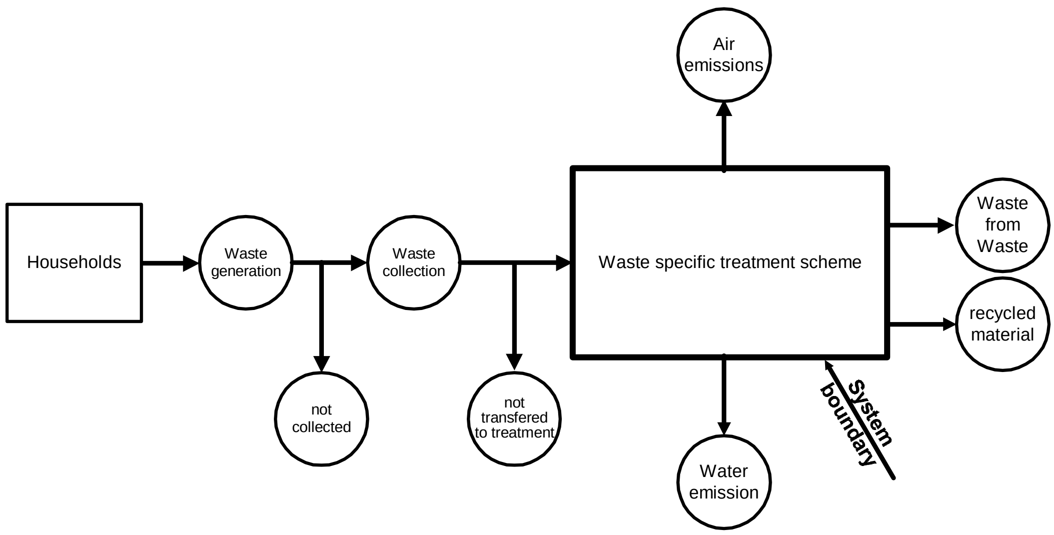
IV.1. Description of the substance flow method

Substance flow analysis
Substance flow analysis tracks the flow of a substance through a technical system. At its simplest, it is an input-output balance, where the distribution of a specific input stream on several output streams is determined. For inorganic substances the input mass is equal to the output (mass conservation), in the case of organic substances material can be destroyed or new material generated.

The first step in conducting a substance flow analysis is to define the system boundaries. The system boundaries for this study are illustrated in Figure IV.1. The system starts with the treatment of WEEE and ends when treatment has concluded.

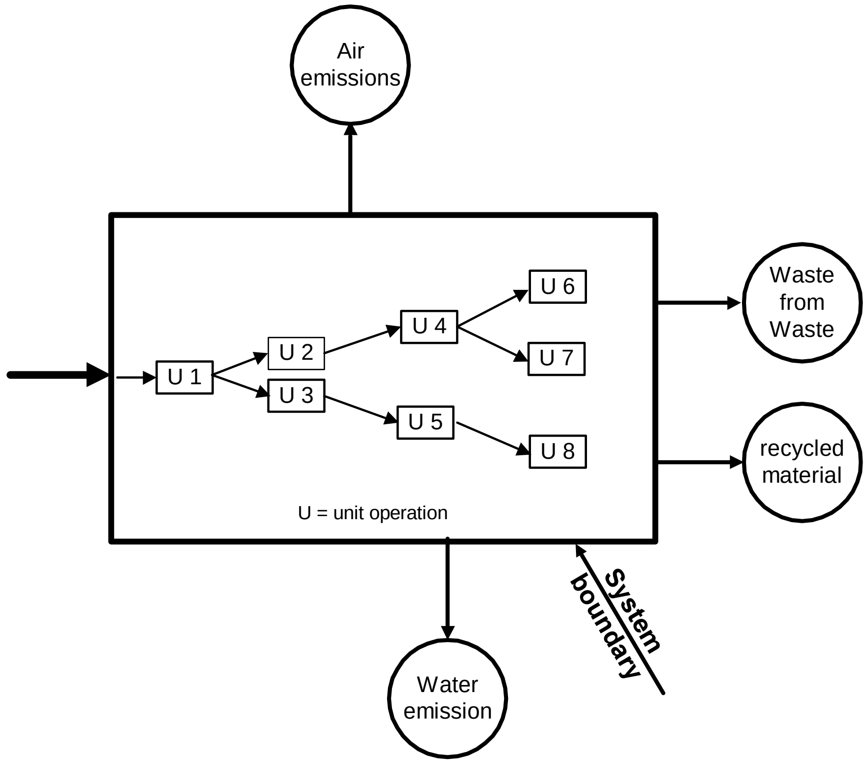
In this system all emissions to air, water and waste, that are related to the treatment of specific WEEE appliances are considered. Emissions from "unauthorised" treatment of waste are not considered.

Figure IV.1: System boundary



The second step is to define the unit operations within the system boundaries. This means that a specific treatment scheme is designed for each of the selected appliances. The unit operations are technical processes such as dismantling, shredding or metallurgical treatment. A system can be very simple e.g. in the case of disposal technologies it is limited to a single process. In the case of recycling the system can be complex and may comprise several unit processes.

Figure IV.2: Definition of technical system



The third step is to describe the transfer of the substances in the various unit operations. This is done by assigning transfer factors for each substance and each unit operation. They are defined as follows:

$$t_i = \frac{m_{out,i}}{m_{,in}}$$

i = index for output paths (e.g. air); out = output; in = input
m = mass

The input vector for a particular substance also includes input of the substance from sources other than the appliance, such as process materials that are required to run the process.

The fourth step is to carry out the calculations. This was done using a commercial computer software package UMBERTO.

IV.2. Definition of factors

Various factors are defined that allow emissions from the different treatment schemes to be compared.

The **recycling factors** (f_r) are calculated as the ratio of kg recovered material (e.g. metals and plastic) per 1000 t input of appliance (e.g. fridge, pc etc).

$$f_r = \frac{kg_{recycl.}}{1000 t_{input}}$$

In addition, for the state-of-the-art treatment schemes the **recycling quota** is calculated using the EU definition[28] as the ratio of kg of recycled material per

[28] Proposal for a Directive on Waste Electrical and Electronic Equipment, 13.06.2000

average weight of appliance. For each appliance this quota is compared with the targets set by the EU in the WEEE directive.

The **waste for disposal factors** (f_{wfd}) are calculated as the ratio of kg of secondary waste per 1000 t input of appliance.

$$f_{wfd} = \frac{kg_{\sec.waste}}{1000t_{input}}$$

The **waste for recycling factors** (f_{wfr}) are calculated as the ratio of kg of recycled waste per 1000 t input of appliance. This 'waste for recycling' results mainly from the additional process materials and is a couple product of the recycling process such as metal containing flue dusts or slags.

$$f_{wfr} = \frac{kg_{recycl.waste}}{1000t_{input}}$$

Air emission factors (f_e) are calculated as the ratio of kg of emitted dangerous substance per 1000 t input of appliance.

$$f_e = \frac{kg_{ds}}{1000t_{input}}$$

To assess and compare the emissions generated by the state-of-the-art treatment, various scenarios were set up. The emissions from state-of-the-art treatment are compared with emissions from the incineration of 1000 t of the appliance and the incineration of 1000 t municipal waste.

IV.3. Required data and availability

To calculate the emissions, several data sources are necessary:

1. The amount of WEEE as input to treatment
2. The composition of the input stream and location of dangerous substances
3. National treatment schemes
4. Emission and transfer factors for waste treatment facilities.

Amounts of WEEE
In the countries investigated statistical data on WEEE amounts is not available. Figures for collected WEEE are scarce and only available for some regions in Germany and Austria. To calculate the emissions from WEEE treatment at national level, estimated WEEE arisings data is used. This data is calculated from production, sales, lifetime and market saturation statistics and provide an upper limit for the WEEE amount entering the specific treatment scheme. This is because a certain percentage of the calculated end-of-life appliances are either stored in households, officially or unofficially exported or removed from the bulky waste stream.

Composition of WEEE and location of dangerous substances
The composition of WEEE is, generally, the same as that of the original appliance. Producers provide very limited information on product composition, especially on the content and location of dangerous substances. In the last year, however, several studies on product composition were published. Therefore data from literature and direct information from recyclers was used for this report. This information is quite reliable for appliances that currently enter the waste stream. For further investigations, especially projections of future emissions, changes in composition would have to be considered.

National treatment schemes

All of the five countries considered have regulations or rules for the treatment of WEEE, either as part of the general waste management system or specifically relating to the waste stream. Recycling facilities for the waste stream also exist, to differing extents, in the countries considered. None of the countries, however, have established monitoring systems that provide sufficient information to describe a representative 'treatment scheme' for the country or region. Therefore the same treatment scheme was used for each appliance for all countries. This treatment scheme is regarded as the state-of-the-art at present.

Emission and transfer factors for waste treatment facilities
For most of the processes used in the treatment scheme, data is available or could be obtained by direct contact to companies or from literature sources.

However, problems arose in relation to the link between input concentration and the emission of dangerous substances from metallurgical works. The Sevilla papers [29]and other scientific literature provide emission data in relation to the product output (emissions per t steel, copper produced etc).

Input related emission factors (emissions per t WEEE input) were obtained by recalculating the literature values. The emission data given in literature differs in a wide range.

For heavy metals this problem was addressed by making the assumption that dangerous substances are removed, to a large extent, by state-of-the-art treatment. Therefore minimum emission factors were used. Emission factors also account for emissions caused by process materials (e.g. limestone).

For POPs especially Dioxins this problem is more severe. POPs and Dioxins are generated during thermal processes. At present, there is insufficient scientific knowledge about mechanisms that lead to the generation of POPs from incineration and metallurgical works The average values for the emissions as stated in the Sevilla papers were therefore used.

Emission data available for metallurgical processes is listed in Table IV.1

Table IV.1: Data availability for metallurgical processes

Metallurgical process	Cd	Hg	Pb	PCDD/F	PCB
Aluminium Recycling				X	
Steel recycling	X	X	X	X	X
Copper recycling	X		X	X	
Copper recycling / printed circuit boards	X		X	X	
Copper recycling / printed circuit boards	X		X	X	
Lead recycling	X		X		
Incineration	X	X	X	X	X

X = data available

Detailed description of the five appliances and the state-of-the-art treatment for the appliances used to calculate the results.

Refrigerators
Refrigerators are of environmental significance because they contain chlorofluorohydrocarbons (CFCs). Refrigerators that were produced between 1990 and 1995 contain over 90 % R12 in the circulating coolant. By optimising the circulating coolant, it was possible to reduce the quantity of R12 that needed to be added. The change to isobutane as coolant followed in the mid-1990s. As well as R12 filled

[29] The European IPPC Bureau (Sevilla) exists to catalyse an exchange of technical information on best available techniques under the IPPC Directive 96/61/EC and to create reference documents (BREFs) which must be taken into account when the competent authorities of Member States determine conditions for IPPC permits (http://eippcb.jrc.es/).

appliances, there are still smaller numbers of very large coolers which are normally used for commercial purposes and which are filled with R22 (CFC). About 2 to 5 percent of all refrigerators are adsorption appliances that are filled with an ammonia - water mixture to which chromium has been added for corrosion protection purposes. In insulation foam - polyurethane - R11 is to be found. This was replaced in the mid-1990s with n-pentane or c-pentane. Refrigerators being disposed of today are between fifteen and twenty years old and therefore contain both R12 and R11. The collection and treatment of appliances containing CFCs - even if in decreasing quantities - has therefore to be planned for at least up to the year 2010.

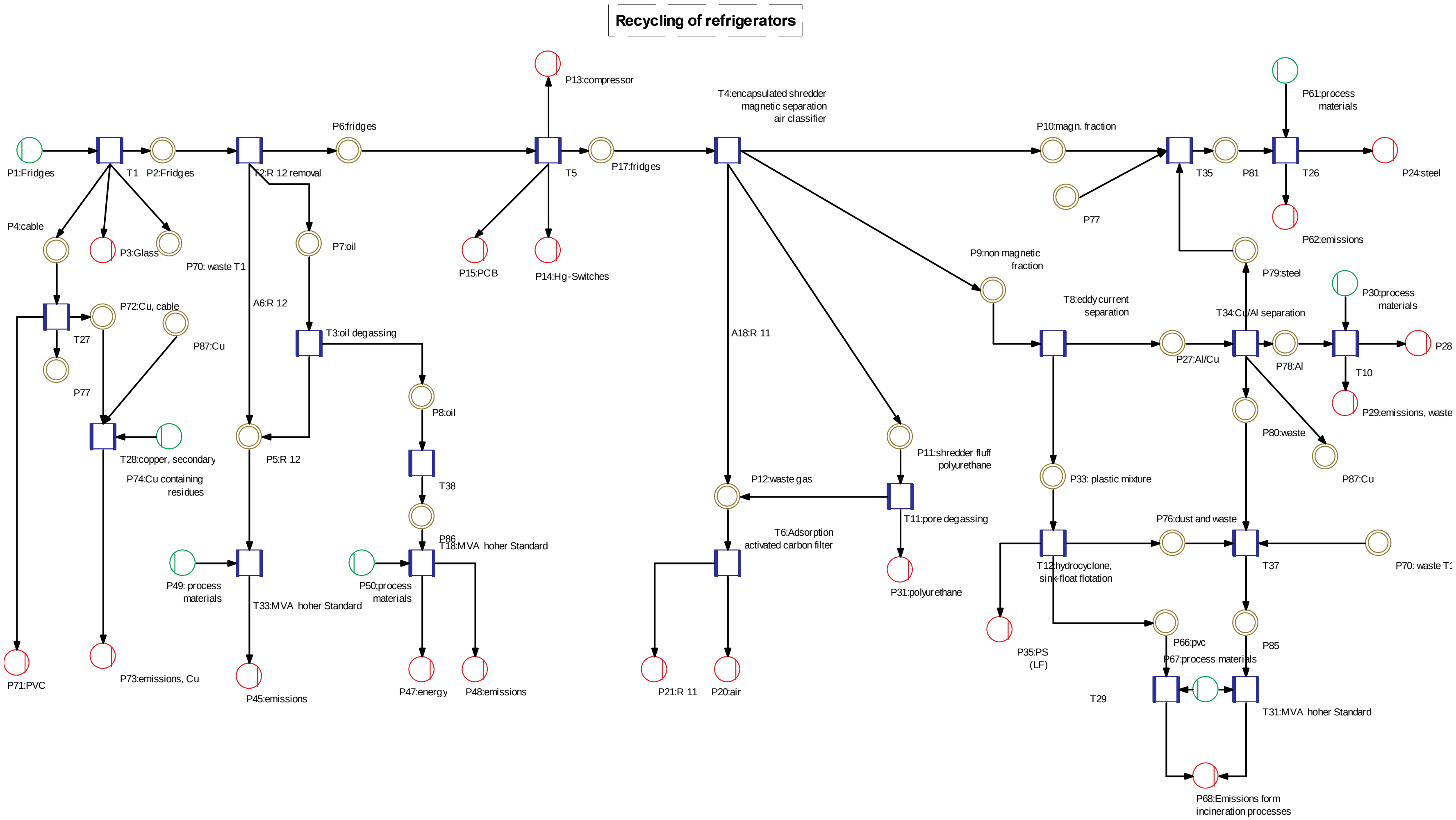
Information that refrigerators are collected separately and brought to special plants is available for the partner countries Austria, Spain (Catalonia) and Germany. However, details regarding the collection quota and method of disposal are missing. It is still the practice that refrigerators, for example, are shredded in unsealed plants and that insulation polyurethane foam from which gas has not been completely removed, is dumped or incinerated in household waste incineration plants. A leakage of R11 during transportation as well as from the dump has to be reckoned with. There is no data available regarding the practice for disposal in Ireland and Denmark

State-of-the-art treatment
The state-of-the-art treatment for refrigerators is illustrated in Figure IV.3: State-of-the-art treatment scheme for refrigerators. The calculations are based on an input of 1000t undamaged refrigerators, where the coolant circulation and insulation CFCs (R12, R11) are still intact[30]. Initially, all the loose interior parts such as glass shelves, racks and plastic parts are removed from the coolers and the electric cable is cut off. Following that, the cooling system is pierced and the coolant and compressor oil sucked out. Coolant and compressor oil yield depend on the size of the appliance and the duration of the suction. The best current achievable values were used. Having removed the compressors and dismantled further components containing dangerous substances (such as capacitors containing PCB, mercury switches), the appliance is shredded in a sealed shredder.

The magnetic fraction is sent directly to an electro-steel works. In other plants, the shredder heavy fraction is separated into aluminium, copper and polystyrene, which can be reused. The shredder light fraction, which consists mainly of polyurethane, is repeatedly ground to press out bound R11. Residual CFC in the polyurethane powder is approximately 1 %. Recovered polyurethane can be used as an oil binder. R11 is removed from the process air by passing it through an activated carbon filter. R11 is cracked in a high temperature plant to form hydrochloric acid and hydrofluoric acid.

[30] Between 20 and 30 % of refrigerators arriving at recycling plants are defective. As a rule, this means that the coolant circulation system has been damaged. We are assuming no damage prior to treatment for the state-of-the-art treatment. It should also be noted that precise data on the quantities of CFCs used in appliances was not readily available from cooler manufacturers, so the theoretical input values are based on average values.

Figure IV.3: State-of-the-art treatment scheme for refrigerators



TV
Televisions (TVs) contain a number of dangerous substances and traditional disposal at either landfill or incineration can lead to environmental problems. Disposal to landfill can result in increased concentrations of heavy metals in landfill leachate. Disposal at waste-to-energy facilities can result in the concentration of heavy metals in the ash, limiting disposal or reuse options.

For some time there has been a trend towards dismantling used TVs into several fractions, which can then be directed to either material recycling or energy recovery. This will be described below under state-of-the-art treatment.

State-of-the-art treatment
The state-of-the-art treatment for televisions is illustrated in Figure IV.4. The collected TV-sets are sent to a 'rough dismantling' process where they are manually dismantled. The components that are separated out are restricted to picture tubes, housing, cables and circuit boards.

The picture tubes are recycled in the 'picture tube recycling process'. Using a separating oven, cone glass and screen glass are separated from each other. Steel components from inside the picture tube are recycled in electro-steel works. Cone glass is reprocessed into working lead in lead works. Lead is used in solders (40 g/TV) and as oxide in the picture tubes. Colour picture tubes utilise leaded frit seals between the funnel and the face[31]. It was found that most of the investigated colour picture tubes exceeded the mandatory limit for leachable lead to be characterised as a hazardous waste, but none of the monochrome picture tubes did. The major contributor to leachable lead in monochrome picture tubes is the neck glass between the electron gun and funnel glass. Because cone glass contains silicon-oxide which is a slag-binding material (replacement for sand), it can be utilised in lead smelters. The coating on the screen glass is washed off in the 'light material removal' process. The coatings are disposed of in special waste depots while the screen glass is dumped.

Plastic housing and backs containing flame retardants are used for energy production after being broken up. Occasionally, pure sorted plastics, the quantities of which are not known, are recycled in special industries.

Dangerous substances are removed from the circuit boards. In this process, round cell batteries, and capacitors that are large or contain PCB are removed from the circuit boards and disposed of appropriately. The circuit boards are then sent to a copper works.

The cables are separated into different fractions. Fractions of iron, copper and plastic are formed and each sent for further processing. The magnetic fraction goes into the production of electro-steel in electro-steel works. The copper fraction is used to produce cathode copper in copper works. The PVC fraction is passed on to the plastic processing industry.

The remaining fractions from 'rough dismantling' are passed to the shredder in order to separate out the iron, copper, aluminium and plastic fractions. The iron fraction goes to electro-steel works, the copper fraction is passed to the copper works while the aluminium fraction is processed to form metallic aluminium in secondary aluminium works. The plastic fraction is converted into energy in a household waste incinerator.

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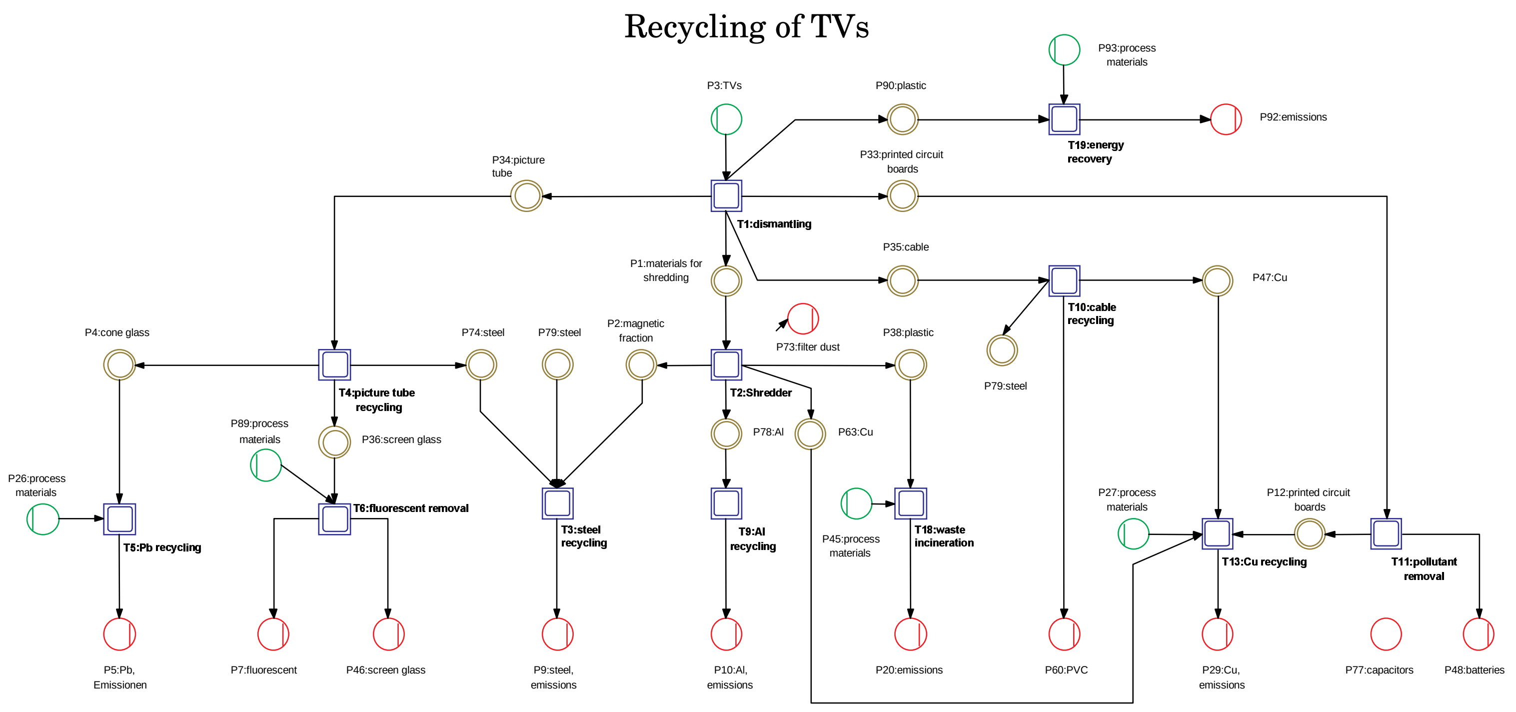
[31] Townsend, T. G. *et al.*, Characterisation of lead leachability from cathode ray tubes using the toxicity characteristic leaching procedure, Florida center for solid and hazardous waste management, Gainesville/Florida, Report 99-5.

Figure IV.4: State-of-the-art treatment scheme for television sets



Fluorescent tubes
Light sources are divided into two classes: incandescent lamps, where the light is generated by electrically heating a filament (not part of this report) and gas discharge lamps, where the light is generated from an electrical discharge of a gas or gas mixture which contains a small amount of mercury. About 25 % of the light sources installed in Europe are gas discharge lamps. They provide 70 % of all artificial light generated in Europe. The remaining 30 % is mainly produced by incandescent lamps which are predominantly installed in private homes. Approximately 350 million gas discharge lamps are sold each year in Europe. More than 90 % of these are fluorescent lamps of which less than 10 % are being used in domestic applications [32]. In private households it is expected that in the future incandescent lamps will be replaced by compact (single ended) fluorescent lamps. Single-ended fluorescent lamps currently represent about 3 % of lamps sold in Europe.

At present there is no substitute for the mercury contained in the lamps. Mercury is consumed in various mechanisms taking place in the lamp between the phosphorus and the inner glass bulb. The consumption rate depends on the type of phosphorus which is used to convert UV into visible light. The mercury consumption can be reduced by applying a barrier coating between the phosphorus layer and the inner glass bulb.

State-of-the-art treatment
The state-of-the-art treatment for fluorescent lamps is illustrated in Figure IV.5. Different recycling processes have been developed and are at present in commercial use. Most of them involve dismantling or shredding (wet or dry) at a mobile or stationary plant. In the following, the dry process is described. Equipment containing PCB was not taken into consideration.

In the cap separating machine the lamps are aerated with a spot burner. The end caps are broken off by heating and cooling. The fluorescent powder and the mercury are blown out of the glass tube. The process air is cleaned using cyclone and fine dust filters. Mercury is absorbed by an activated carbon filter, which is subsequently sent for mercury recovery. The glass tube is crushed and treated in a vibrating fluid bed. The remaining mercury and fluorescents are carried away by hot air, which flows through the bed. The end caps are crushed and passed through a vibrating fluid bed, which removes mercury, fluorescents and other fine grained particles (base cement, glass). In a separator the magnetic fraction is removed. The aluminium/brass fraction is removed via eddy current separation.

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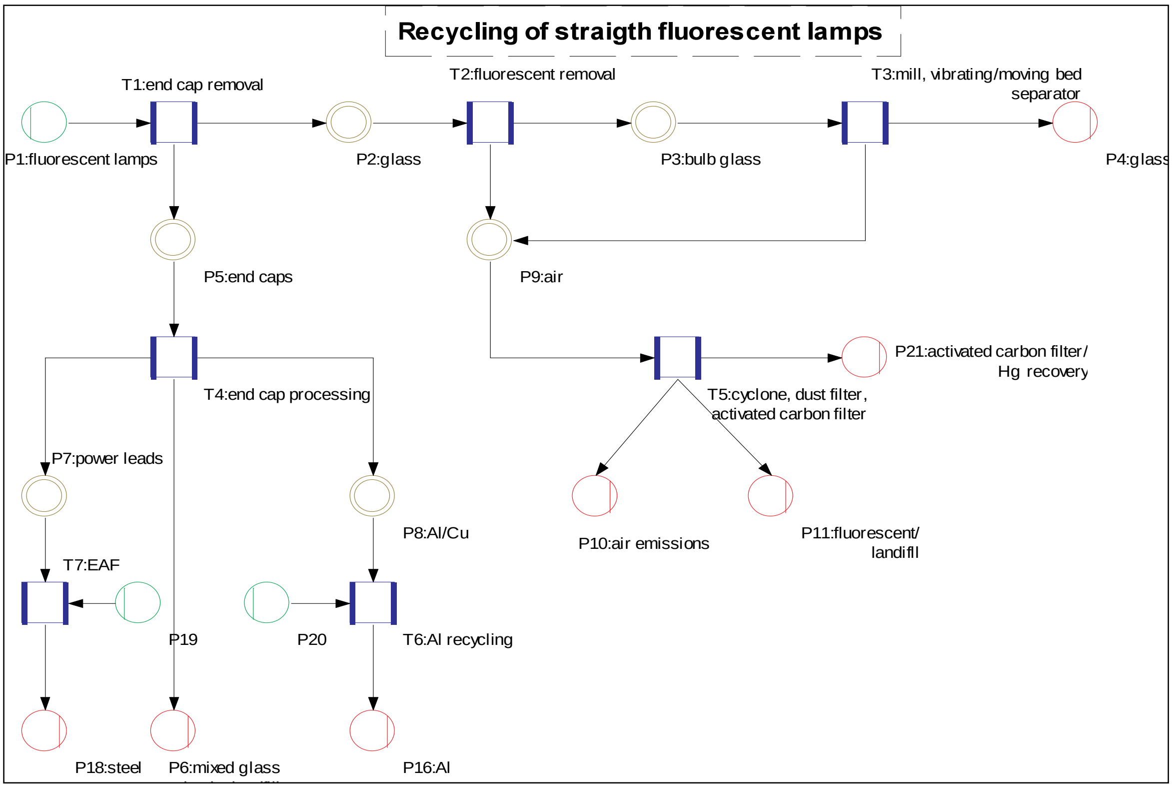
[32] European Lighting Companies Federation ELC, Collection and Recycling of End-of-life Light Sources, Brussels, June 1998.

Figure IV.5: State-of-the-art treatment scheme for fluorescent lamps



PCs
Personal computers are of environmental significance because they contain both heavy metals and halogen-containing flame retardant.

Most of the heavy metals in PCs are to be found in the cone and screen glass in the picture tube, and in fully-furnished circuit boards. In cone glass, approximately 16 % PbO is added on average and in screen glass about 7 % BaO.

So-called flame retardants made from halogenated compounds are predominantly found in PC plastic parts. They account for about 15 % of the weight of plastic. According to one computer manufacturer, PBDE (poly-bromide-diphenyl-ether) was used until 1985 with TBB-A (tetra-bromide-biphenal A) or phosphoric-acid-ester together with antimony-oxide mainly used since then.

Up to forty different plastics are used in PCs, making recycling often impossible and leaving only energy utilisation as a realistic option. Since the 1990s steel parts have been increasingly substituted by plastic parts. As a result, there has automatically been an increase in the amount of flame retardants used in each PC. This trend is predicted to continue into the future and so the plastic parts used in PCs will play an ever greater role in PC recycling.

State-of-the-art treatment
The state-of-the-art treatment for PCs is illustrated in Figure IV.6. The collected PCs are sent to a ‘rough dismantling’ process where they are manually dismantled. The components which are separated out are restricted to picture tubes, cables and circuit boards.

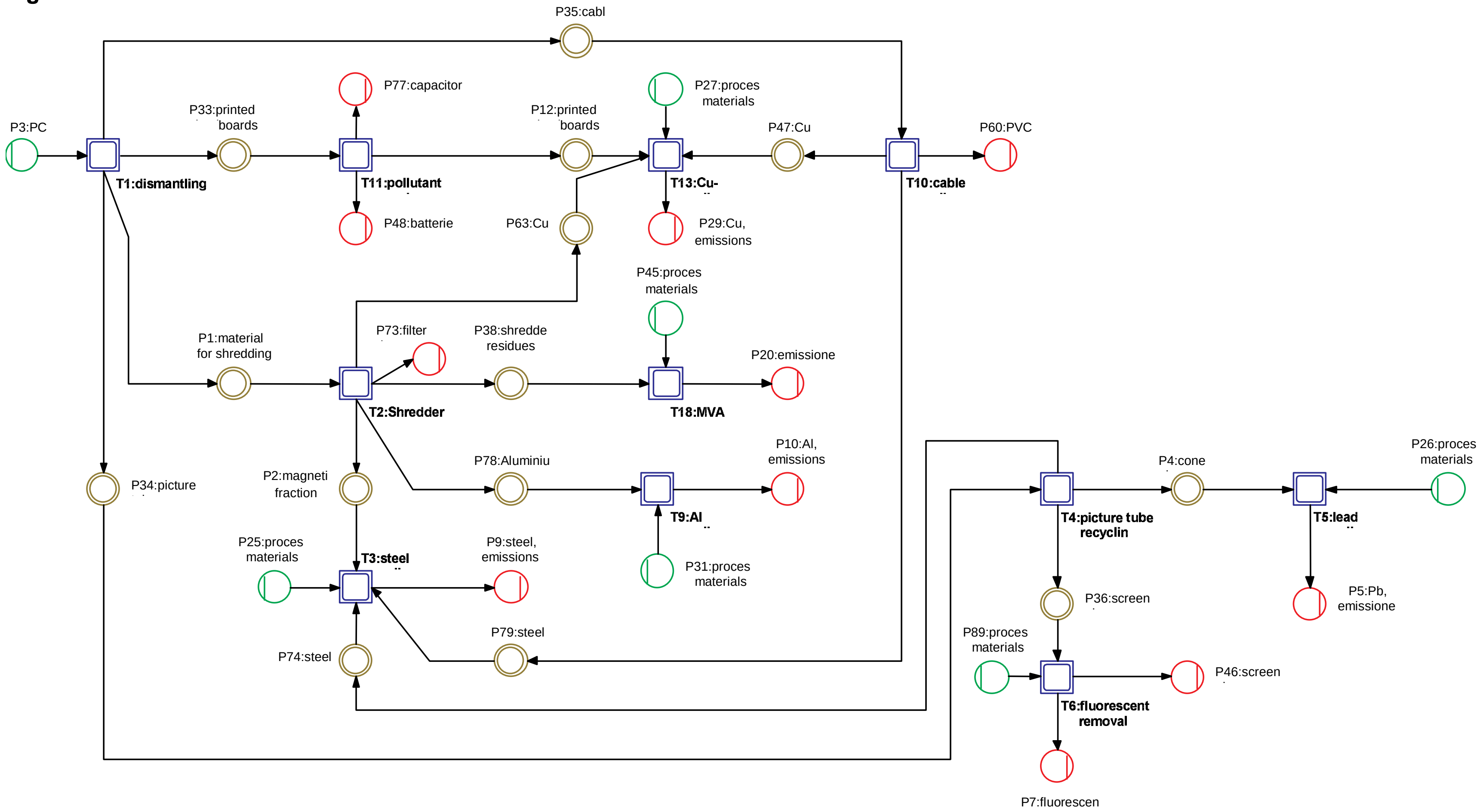
The picture tubes are recycled in the ‘picture tube recycling process’. Using a separating oven, cone glass and screen glass are separated from each other. Steel components from inside the picture tube are recycled in electro-steel works. Cone glass is reprocessed into factory lead in lead works. The coating on the screen glass is washed off in the 'light material removal' process. The coatings are disposed of in special waste depots while the screen glass is stored in old mines.

Dangerous substances are removed from the circuit boards. In this process, round cell batteries, and capacitors that are large or contain PCB are removed from the circuit boards and disposed of appropriately. The circuit boards are then sent to a copper works.

The cables are separated into different fractions. Fractions of iron, copper and plastic are formed and each sent for further processing. The magnetic fraction goes into the production in electro-steel works. The copper fraction is used to produce cathode copper in copper works. The PVC fraction is passed on to the plastic processing industry.

The remaining fractions from 'rough dismantling' are passed to the shredder in order to separate out the iron, copper, aluminium and plastic fractions. The iron fraction goes to electro-steel works, the copper fraction is passed to the copper works while the aluminium fraction is processed to form metallic aluminium in secondary aluminium works. The plastic fraction is converted into energy in a household waste incinerator.

Figure IV.6: State-of-the-art treatment scheme for PCs



Small appliances

The term small appliances includes appliances that are normally disposed of with household waste and subsequently landfilled or incinerated depending on regional practices. Included in these appliances are small kitchen and household appliances, health and beauty appliances, clocks, power tools, toys, IT and telecommunications equipment, entertainment equipment and lighting. In accordance with the EU directive, they belong to categories 2-4,6 and 7. Household waste analysis provides the following weights:

Table IV.2: Quantities of small appliances in household waste

Category	% per weight
small household appliances	40
IT and telecommunication equipment	8
toys, clocks	1
consumer equipment	25
lighting equipment	4
electrical and electronic tools	2
other electrical and electronic scrap	20

The different appliances have different dangerous substance potential in terms of both type and quantity of dangerous substances. Dangerous substance components include:

- Mercury containing components: tube lights, batteries, round cell batteries, printed circuit boards, mercury temperature regulators (e.g. in heating and hot water appliances), irons;
- Ni-Cd-rechargeable batteries;
- Capacitors (PCB) e.g. in salon hairdryers, tube lights, parts containing asbestos (e.g. in toasters, irons, hair dryers);
- Printed circuit boards;
- Plastics with polybrominated diphenylethers (up to 15 % by weight).

State-of-the-art treatment

The state-of-the-art treatment for small appliances is illustrated in Figure IV.7. Once the appliances have been removed from the general waste stream, batteries, rechargeable batteries, cables and large steel parts are manually separated out. Capacitors which are clearly labelled as containing PCB and capacitors above a certain volume are separated out. After the manual dismantling, the remaining plastic, elastomer, glass, wood mix is incinerated. The other appliances, those not initially dismantled and those considered not to contain dangerous substances, are shredded in order to reclaim iron, copper and aluminium. The shredder residue, a mixture of light shredder fraction and filter dust is landfilled or incinerated. This fraction consists mainly of different plastics (with and without flame retardants) elastomers, textiles, wood and glass[33].

[33] Kommission der Niedersächischen Landesregierung zur Verwertung und Vermeidung von Abfällen, Abschlußbericht des Arbeitskreises 13 „Elektronikschrott“, Umweltministerium Hannover, 1997.

Figure IV.7: State-of-the-art treatment scheme for small appliances