novatlantis
Nachhaltigkeit im ETH-Bereich

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

13th Discussion Forum on Life Cycle Assessment

Environmental Impact of Telecommunication System and Services

(plenary presentations)

April 25 2001,
Swiss Federal Institute of Technology, Lausanne, Switzerland

Organizers:

Manuele Margni

Olivier Jolliet

LC Group for sustainable development (EPFL)

Thomas Baumgartner

LCA Fora Coordinator (ETHZ)

Plenary Session presentations

Dipl.Biol. I. Reichart , EMPA SG
“Comparison of the environmental impact of electronic and print media: case study television, internet and newspaper”

Dipl.Ing. M. Spielmann, UNS ETH Zürich and Dipl.Ing. K. Schischke, TU Berlin / Fraunhofer IZM
”Environmental Assessment in Production of Electronic Components - Possibilities and Obstacles of LCA Methodology”

Prof. T. Ebrahimi, EPFL- Signal processing laboratory
”***Future Vision of Telecommunications”***

Jens Malmodin, Ericsson
” LCA of telecom products & systems within Ericsson and use of LCA in the annual environmental report”

Filippo della Croce, EPFL–LC Group and Prof. Greg Norris, Harvard University
”Comparison of Process LCA and Input/Output Analysis: Case studies on Internet and the Role of Retail and Wholesale Trade in the Life Cycle”

“Comparison of the environmental impact of electronic and print media: case study television, internet and newspaper”

Reichart I., Hischier, R., Swiss Federal Laboratories for Material Testing and Research (EMPA), Lerchenfeldstrasse 5; CH-9014 St. Gallen, Switzerland, e-mail: ingeborg.reichart@empa.ch; Tel. 071 - 274 78 52

AIM OF THE STUDY

Print media seem to be environmentally less advantageous compared to electronic media. While the amount of paper consumed is easily perceived as being environmentally harmful this is not so the case with electronic media. Environmental impact through production and use of electronic goods is not as obvious as that.

Aim of the study was an in depth examination of the environmental impact caused by the use of electronic and print media as well as a search for possibilities of improvement. This was accomplished by conducting a Life Cycle Analysis whereby popular examples of use of media were investigated. One of these case studies is the use of television, internet (newspaper) and printed daily newspaper for the purpose of information and entertainment.

METHOD

Life Cycle Analysis is a method to assess and compare the environmental impact of products or services “from cradle to grave”. Data about resource consumption, emissions into air, water and soil as well as waste is gathered along production, use and disposal including transportation. Material flows are then assessed with internationally recognised methods for their environmental impact. Here two assessment methods are used: The Ecological Scarcity method[1] and the Eco-Indicator 99 method[2].

FUNCTIONAL UNIT

The following media are compared with each other by their use for the purpose of information and entertainment:

- Television
- Internet newspaper
- Printed daily newspaper

It is obvious that either of the investigated media offer different ways in which information or entertainment is presented and perceived. While print and online version of a newspaper are dominated by printed language and few pictures, moving pictures and spoken language prevail on television. Even within media there are large differences e.g. the emotional style of a boulevard newspaper (“Blick”) and the rational, analytical style e.g. of a “Neue Zürcher Zeitung”.

Differences in perception between or within media make it hard to meet the demanded functional equality of a LCA comparison between media. This problem was solved by subdividing the case study into three different perspectives whereby each time a partially equal but each time different functional unit is chosen. Media are compared with each other by the following three functional units:

First approach: Perception of a typical news item

Equal information content of a typical news item of at least national importance is taken as the focal point. Media are compared with each other by:

- Listening to the news item during the main evening news broadcast on television
- Reading the article in the internet newspaper
- A cutting of the article in an average printed newspaper

The functional unit is quantified by either length of time for reading or listening to the news item in electronic media and half of the size of the area for the newspaper article, as newspapers are printed double-page (table 1).

Second approach: Consumption of the daily news

Satisfaction of the desire of most individuals to be informed about the daily news is the central point within this perspective. Here media are compared with each other by:

- Watching the main evening news broadcast on television as a sole viewer
- Reading an internet newspaper

---

1 BUWAL (1998)
2 PRé (2000)

- Reading a thin boulevard newspaper ("Blick"), while taking into account the average number of 2.3 readers per paper[3]
- Reading a voluminous newspaper ("Neue Zürcher Zeitung"), while taking account the average number of 2.3 readers per paper[4]

Again the functional unit is quantified by either length of time for reading or listening to the news in electronic media as well as part of both of the printed newspapers (table 1).

Third approach: Average daily media consumption

Average daily use of television, internet and print media in Switzerland is taken as the focus. Here functional equality of media is abandoned and media are compared by:

- Average time of watching television per day
- Average daily internet surfing time of an internet user at home
- Average daily amount of consumed print media per over 6-year olds

Here the average length of time watching television per day and household[5] is shared between the average members of a household. The average daily amount of consumed print media is the sum of either bought or free newspapers, magazines, books etc. (table 1).

Tab. 1: Quantified functional units of the three approaches

Approach	Television	Internet	PRINT MEDIA	Print media
News item	3 min	1.5 min	250 cm^2 average newspaper	-
Daily news	25 min	10 min	43% out of 32 pages "Blick"	43% out of 83 pages "Neue Zürcher Zeitung"
Daily media consumption	110 min	74 min	136 g newsprint paper 156 g coated paper 44 g uncoated paper	-

The user of the media is specified as an adult with average reading skills and interest in the daily news unless mentioned otherwise. This person is living in an average household where tv, computer and newspaper are also used by other members of the household. Media are also used for other purposes than the ones investigated.

The household has a television set and a computer. Both of the electronic media are specified as new electronic appliances with typical features and average life span for the Swiss household. Print media are specified as an average newspaper in the first approach, as the newspapers "Blick" and the "Neue Zürcher Zeitung" in the second approach. The average number of pages is taken for each newspaper. For the third approach total daily consumption of printed paper is taken i.e. (free) newspapers, magazines, books etc.

SYSTEM BOUNDARY

3 Tagblatt (2000)
4 Tagblatt (2000)
5 Jedele (1999)

Media are examined from “cradle to grave”. While use of media is included in the system boundaries, production and disposal are only taken into account proportionally. Furthermore operation of the following infrastructure is also included within the system boundary:

- Data transmission in the internet
- Operation of the telephone network
- Production of tv-shows
- Operation of a satellite receiver

Journalism is not included in the system boundaries.

Geographic boundaries are several European countries for the production of media and Switzerland for use phase and disposal, i.e. the relevant national electricity mix is assumed in each of the mentioned cases.

Results

Results of the three approaches are only shown after assessment with the “Ecological Scarcity” method as impact assessment with “Eco-Indicator 99” leads to similar results.

First approach: A typical news item

Reading a news item in the internet newspaper causes by far the highest environmental impact followed by watching television. The cutting of the printed newspaper causes least environmental impact (figure 1).

Production and use phase of both of the electronic media are large contributors to the environmental burden. Use phase of the internet newspaper is dominated by the electricity demand for the operation of the telephone network followed by data transfer via router and running the computer itself.

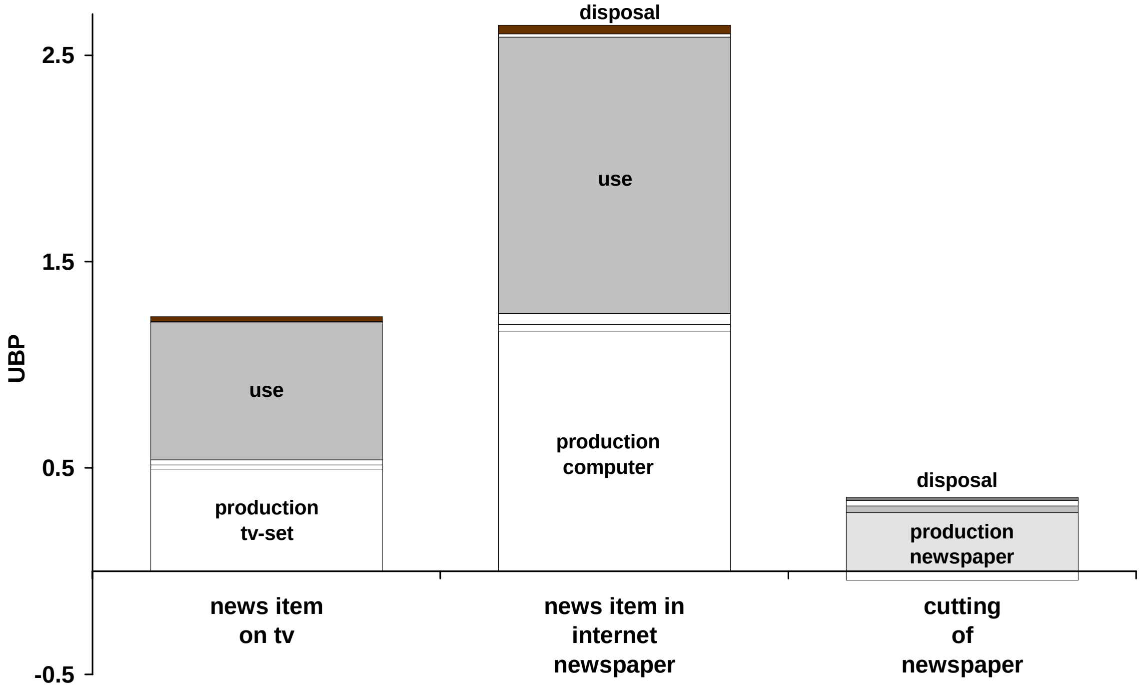


Fig. 1: Environmental impact of the consumption of a single news item

Second approach: The daily news

In contrast to the previous approach print media are causing more environmental impact when compared with electronic media irrespective whether a thin or voluminous newspaper is read (figure 2). Main cause of the high environmental impact of both of the newspapers is the production of paper and in particular energy consumption to produce pulp and paper.

Sensitivity of the results of the second approach is tested by varying several parameters.

Length of time for reading or listening to the daily news has a major influence on the result (figure 3). Environmental impact of both of the newspapers is constant because it depends on the physical existence of the paper and not on the time needed for reading.

Watching television is environmentally the most favourable option as long as watching does not take more than 80 minutes. Using the internet newspaper is only advantageous compared to a printed newspaper if it does not last more than 20 minutes. If however, a newspaper is read only by a single person environmental impact rises proportionally.

The environmental impact of internet use easily succeeds that of a (thin) newspaper when internet information is printed. This is the case when for example internet is used for 10 minutes and 3 pages are printed. Most of the environmental burden is caused here by the production of graphical papers.

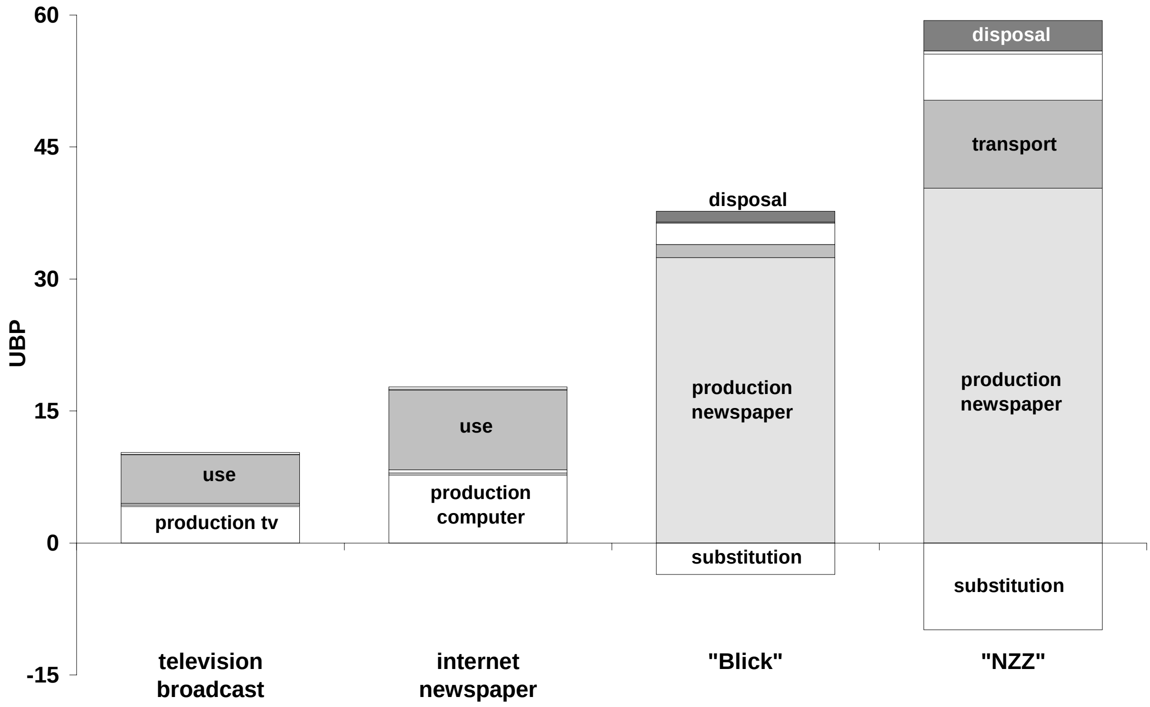


Fig. 2: Environmental impact of the consumption of the daily news

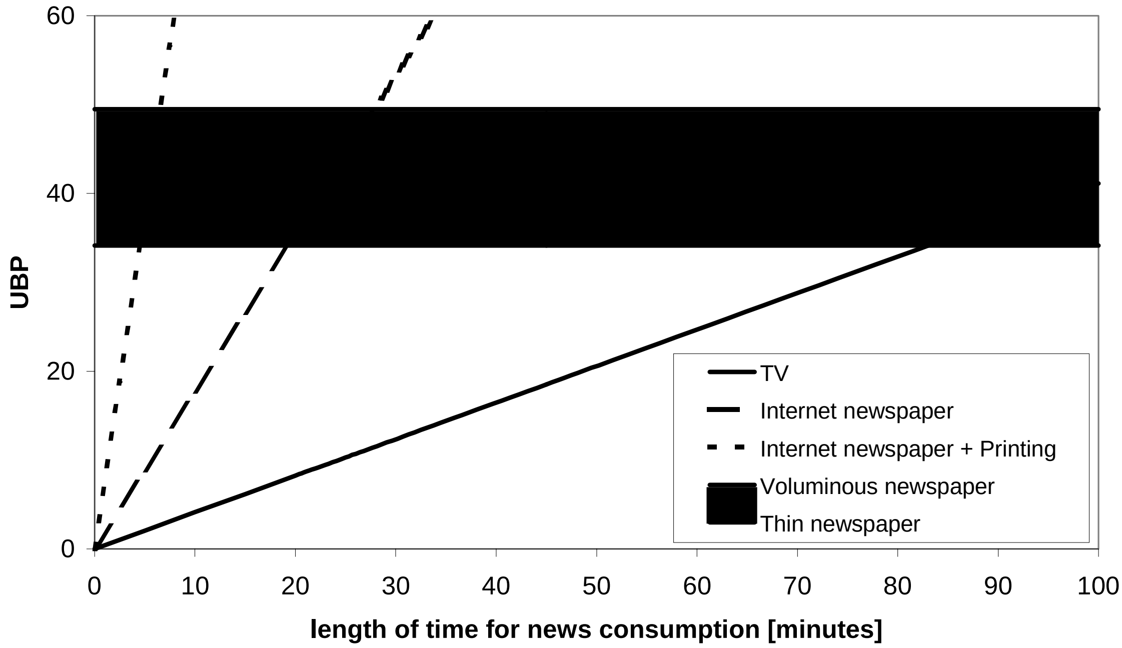


Fig. 3: Influence on the environmental impact by the length of time spent for news consumption

In a further sensitivity analysis the Swiss national electricity mix which was assumed for use phase of electronic media is replaced by the average European electricity mix. This scenario shall represent media use in places like Germany or other places in Europe where a much larger proportion of electricity is generated from fossil fuel and not by using as much hydropower as in Switzerland. Results change dramatically. In this case environmental impact of 10 minutes internet use is in the same range than a newspaper while watching television is only very slightly better than reading a thin newspaper (not shown).

Third approach: Average daily media consumption

Results of this approach do not lead to very different results compared to the second approach - only magnitude changes.

CONCLUSION

Summarising the results electronic media cause less environmental impact than print media but only under specific conditions. The advantage exists only if:

1. Electronic media and in particular internet is used in a selective manner meaning use is directed towards a specific goal and is not very time-consuming.
2. Internet information is read on the monitor and is not printed.
3. Use of electronic media takes place in places like Switzerland where electricity is generated mainly from renewable energy sources and not fossil fuel.

The environmental advantage of print media seen in the approach single “news item” is hypothetical up to now as parts of a newspaper cannot be bought. “Printing on demand” may offer such an environmentally sensible option in the future as long as newspaper extracts are printed on newsprint paper and not on graphical paper.

REFERENCES

BUWAL (1998) Brand G., Braunschweig A., Scheidegger A., Schwank O.,: Bewertung in Ökobilanzen mit der Methode der ökologischen Knappheit – Ökofaktoren 1997. Bundeamt für Umwelt, Wald, Landschaft,, Schriftenreihe Umwelt Nr. 297, Bern 1998

Jedele (1999) Personal communications Mr. Jedele, publidata of SRG, 25.6.1999

PRé (2000) The Eco-indicator 99. A damage oriented method for Life Cycle Impact Assessment. Methodology Report. Published electronically under URL: http://www.pre.nl

Reichart (2001) Reichart I., Hischier R., Vergleich der Umweltbelastungen bei Benutzung elektronischer und gedruckter Medien. EMPA-Bericht, St. Gallen 2001 (full report is still in press)

Tagblatt (2000) Zeitungslandschaft in der Schweiz. Härtere und eurokompatible Leserschaft der „MACH Basic 2000“. St. Galler Tagblatt. 13th September 2000, p. 3

WEMF (2000) MA Comis 2000. Published electronically under URL: http://www.wemf.ch/de/produkte/comis.html

"Environmental Assessment in Production of Electronic Components - Possibilities and Obstacles of LCA Methodology"

Dipl.Ing. M. Spielmann, UNS ETH Zürich and Dipl.Ing. K. Schischke, TU Berlin / Fraunhofer IZM

1 INTRODUCTION

The growing importance of new means of telecommunication in all parts of economy and society has resulted in an enormous growth in the underlying technology sectors, in particular in the electronic sector.

However, beside the potential of telecommunication technologies for environmental relieve, the required hardware for the application of these technologies is characterized by severe environmental impacts in manufacturing and end of life.

Thus, it is crucial to link further technology developments with the guiding principal of sustainable development.

In recent years, LCA as an environmental assessment tool, designed to support the concept of sustainable development, have been frequently applied in various sectors of industry to introduce the concept of environmental sustainability in the design of new products.

In this paper, an overview of the possibilities and the obstacles that occur when applying Life Cycle Assessment methods in the electronic sector and hence the telecommunication sector is presented. This overview is based on own experiences made when applying LCA methodology in the field of semiconductor production. Literature data is cited in addition to give an extended survey of this topic.

1.1 State of the Art: Environmental assessment and LCAs for Electronics Production

In the last decade several case studies in the field of LCA have been undertaken. One of the first case studies has been the Life Cycle Environmental Assessment of a Computer Workstation of The Microelectronics and Computer Technology Corporation (MCC) in 1993 [1]. Further studies investigated single components or materials in electronics manufacturing in depth [e.g.: 2] as well as Life Cycle Assessment of Electronics in general [e.g.: 3]. According to recent case studies only few generic LCA data is available, most of the projects are for internal and B2B-purposes as well as summarized for the presentation of the environmental performance of products [4, 5]. Some case studies are also focussing on the methodology of LCA for the production of electronic components [6, 7].

1.2 Process Chain of Electronics Production

A finished electronic product comprises various components each characterized by certain manufacturing steps such as the production of printed circuit boards, active and passive compounds, solders and/or adhesives for assembly as well as housings, displays, energy supply etc (fig. 1). Electronics specific processes in this supply chain are mainly the manufacturing of printed circuit boards and of integrated circuits (ICs).

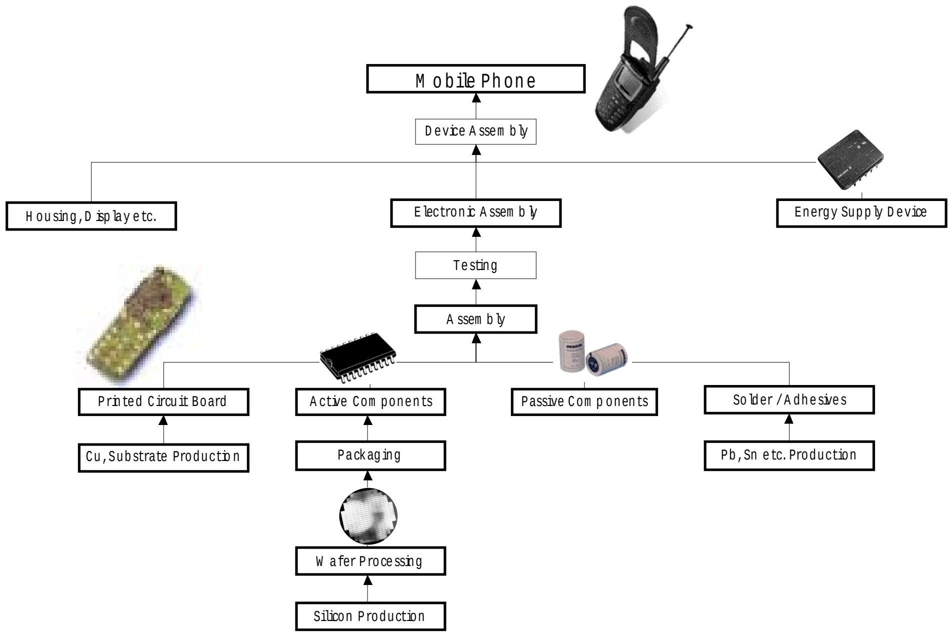


Fig. 1: Survey - Production of Mobile Phones

2 Environmental Assessment - Data Survey

The extent of published LCA data for electronics in general and especially telecommunication products is fairly limited. To give an impression of the

significance of certain aspects in the life cycle of electronics, exemplary data for mobile phones (see chapter 2.1) and printed circuit boards in particular (chapter 2.2) are given.

2.1 Energy Consumption of Mobile Telecommunication

The energy consumption of mobile phones within its phases of the life cycle according to Nokia data (fig. 2) show a rather high impact of the production [4]. A study of Ericsson (fig. 3) includes also the mobile network of the network operator and states a main contribution of energy consumption of the use phase, mainly for base stations and operator activities [5, 8].

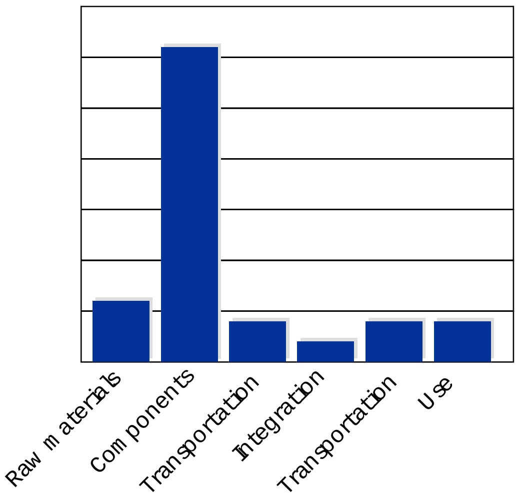


Fig. 2: Energy Burden of a Mobile Phone [4]

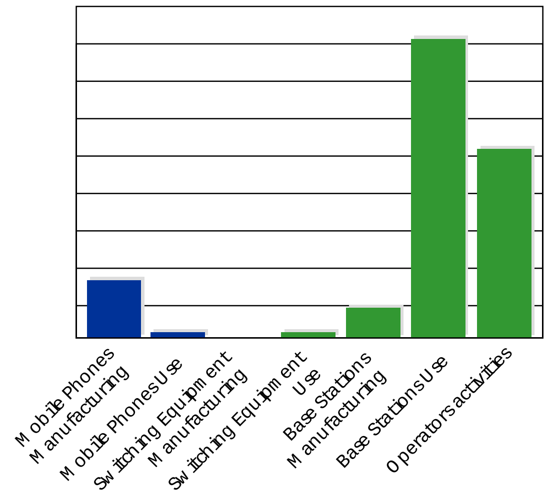


Fig. 3: Energy Burden of Mobile Telecommunication [5, 8]

2.2 Key Data: Printed Circuit Board Manufacturing

AT&S as one main producer of PCBs for the telecommunications market publishes inventory data within the environmental management system. These data (fig. 4) gives an impression on the environmental significance of PCB manufacturing [9, 10]. For 1 m² of PCB with an average number of 5.5 layers energy consumption is in the range of 40 kWh and the consumption of ultrapure water slightly lower than 1 m³. The amount of waste according to AT&S is at about 4.6 kg per m² PCB.

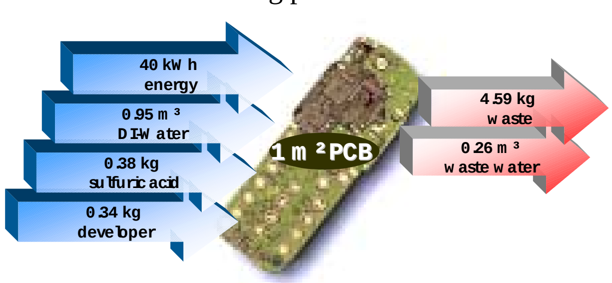


Fig. 4: Environmental Key Data: Printed Circuit Board Manufacturing [9, 10]

3 Scope Definition - Example Wafer Processing

In the following chapters possibilities and selected obstacles of LCA are discussed referring to the example of wafer processing as a main part within semiconductor manufacturing - and a highly environmentally critical one as well.

3.1 The Production Process - System Boundaries

The production of monocrystal slices of silicon (wafers) is followed by wafer processing to apply electronic structures onto the silicon. Wafer processing includes several hundred process steps within a wafer fab, and needs a highly clean production environment (manufacturing in cleanrooms). Each wafer finally contains up to several hundred integrated circuits (ICs, dies) to be separated. Within the next production steps after processing the ICs are encapsulated (plastic packages) and Printed

Wiring Boards are assembled with these packages.

3.2 Significance of Yield

The yield in semiconductor manufacturing is a highly critical parameter and needs special attention in an LCA. The raging development of increasing integration and decreasing geometries results in die yield of significantly less than 100%. To give an impression of the dynamics of the yield improvement, e.g. the initial yield of a wafer fab may be at 50% and increases within months (ramp time) up to 95%, which is a very high yield for a fab. A similar "learning yield" occurs with the introduction of new sophisticated ICs with minimized geometries. Thus, the overall yield of a fab is always changing, and ideally must be reflected in the functional / reference unit.

However, the yield is one of the most secret data of a wafer fab and consequently, access to yield data is fairly restricted. In addition, the yield is a product and process specific variable and is not transferable to other products or wafer fabs. Thus, when trying to generate generic LCI data, the yield could be variability between sources and objects and thus be addressed by probabilistic simulation similar to the procedure for operationalizing parameter uncertainty [18].

3.3 Reference Unit

ICs are highly complex products with mostly a broad variety of functions, which has to be taken into account for the definition of a suitable, comparable reference unit. The area and the complexity of the processing steps determine the functionality of ICs. Thus, besides the minimum geometry, the number of mask-layers is a suitable indicator for the functionality. A preferable reference unit is 1 m² wafer area processed error-free with a single mask-step. To calculate all inventory data for this reference unit the number of Production Units (PU) is introduced as:

$$\textbf{\textit{PUs = wafer area [m}}^2\textbf{\textit{] x average no. of mask layers x yield}}$$

The wafer area is defined as number of wafers multiplied by the area of a single wafer. The number of wafers is the actual number of processed wafers in a defined period of time.

3.4 Dynamics of Technological Development in Electronics

A significant characteristic of electronics industry is the raging development of electronic components. In 1965 Gordon Moore stated, that the data density on a chip doubles approximately every 18 months - a statement still valid today and known as Moore’s law. This raging development is unique and means new functionalities for electronics products within short cycles. For Life Cycle Assessment this development has several conclusions:

Inventory data has to be very up-to-date, otherwise the LCA bases on data for products which are already out of date; e.g. the MCC LCA data for a Computer Workstation of 1993 bases on a product which isn’t suitable for today’s software applications

A rapidly increasing performance affects the functionality of electronic devices - thus, the definition of a functional unit for e.g. a mobile phone is difficult, due to the fact, that new functionalities of mobile phones are introduced within months

LCA results have to be gained within very short periods to be suitable to support a Design for Environment process

4 INVENTORY DATA AND ANALYSIS

The generation as well as the application of generic inventory data reveals several sever problems which will be outlined in this chapter.

4.1 Electronic Production Specific Chemicals

The production of semiconductors uses a variety of chemicals which are mostly specific to the electronics industry, e.g. WF_6 for thin films, H_2SiCl_2, $HSiCl_3$, and $SiCl_4$ for thin films and epitaxy, PH_3, AsH_3, and BF_3 for epitaxy and ion implant, GeH_4, and $Al(CH_3)_3$ for ion implant, $POCl_3$ for oxidation. For these and many more electronic specific input materials no generic LCI data is available by now. Additionally cut of criteria for the assessment of these input materials are critical: Mostly the mass input of these substances is in the range of promille and much less compared to the bulk input flows, but many of these substances are highly toxic and thus assumed to be of an environmental relevance. A generic LCI database for the production of these chemicals is a precondition for future LCAs within reasonable time frames - or the relevance of these pretty small input flows has to be neglected based on a detailed LCA of these chemicals.

4.2 Quality Levels of Bulk Chemicals hinder application of generic LCA data

The bulk chemicals in electronics manufacturing are chemicals well known from other industries, such as sulfuric, nitric and hydrofluoric acid, hydrogen peroxide, isopropyl alcohol, and ammonium hydroxide (fig. 5).

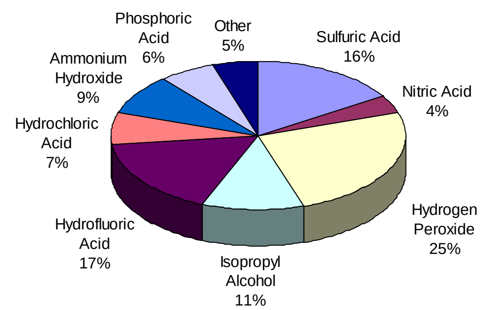


Fig. 5: Electronics Chemicals Usage [12]

Nevertheless, generic LCA data available for these chemicals are not applicable for the chemicals used in electronics manufacturing: According to the introduction of new products with microstructures of rapidly decreasing geometries the requirements for chemicals with lowest contaminations are required. In the 1990s quality levels of 10 ppb (ULSI standard - ultra large scale integration), 1 ppb (SLSI standard - super large scale integration), and 100 ppt (XLSI standard - extra large scale integration) have been implemented (fig. 6) [12]. These high quality level products demand specific production and cleaning processes as well as specific transportation and packaging requirements, which not have been a subject of Life Cycle Inventory by now. Thus, the differences of environmental impacts between “standard” chemicals and these ultra pure chemicals has not been quantified.

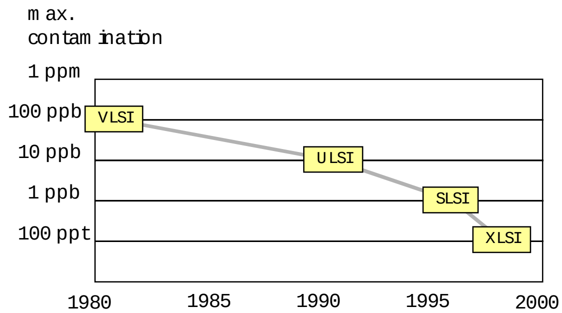


Fig. 6: Implementation of Quality Levels [12]

4.3 Downstream Processes

Another critical point for an life cycle inventory of electronic products is the inventory of disposal. Due to the fact, that in an complex electronic product e.g. at least 30-40 elements are contained, the releases of environmentally critical substances into the environment from landfills, incinerators and metal refinery have to be simulated. Generic data is partly available, but not to a sufficient extend for electronic products. Furthermore the waste management of electronics in the future is rather uncertain, because proposals for legislation have been presented several times - to be changed again within months. Thus, the legal frame for electronics waste, the future real disposal of electronic products just introduced into the market and the unknown behavior of electronic waste in landfills etc. represent a large field of uncertainty for LCAs.

On the other hand, addressing these uncertainties due to knowledge and data gaps, are a matter of scientific work to be done in the future, as expressed e.g. in the actual proposal of the "Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment" [11]:

Article 4

(1) ...from 1 January 2008 the use of lead, mercury, cadmium ... is substituted by other substances.

Article 5

(1, b) exempting materials and components ... from Article 4 (1) ... where the negative environmental and/or health impacts caused by substitutions are likely to outweigh the environmental benefits thereof...

In the above parts some severe uncertainties and variability in currently available data as well as for the prediction of relevant future issues (e.g. the future end of life treatment of electronic products) have been outlined. Thus, further data and knowledge generation is one approach to address these uncertainties. However,this is a necessary but not sufficient approach. In addition it is important to integrate approaches for uncertainty management within the framework of LCA. In particular there is a need for integrating and applying scenario analysis and participation in LCA studies for complex electronic products [19].

4.4 Exemplary Inventory Data for Wafer Processing

The exemplary inventory data (gate-to-gate) for an R&D laboratory processing line at the Technical University of Berlin (fig. 7) gives an impression of wafer processing related energy and material flows [13]. The data refers to the processing of a single wafer (diameter 4”, 100 mm; processed by 11 mask-steps; yield not taken into account). The number of integrated circuits (ICs, chips) per wafer is in the range of several hundreds. The energy consumption is extremely high - in this example also caused by high stand-by times at low throughputs -, as well as the water consumption. Additionally the amount of chemicals and gases is in the range of a few kilograms compared to a weight of about 7 g of a 4”-wafer.

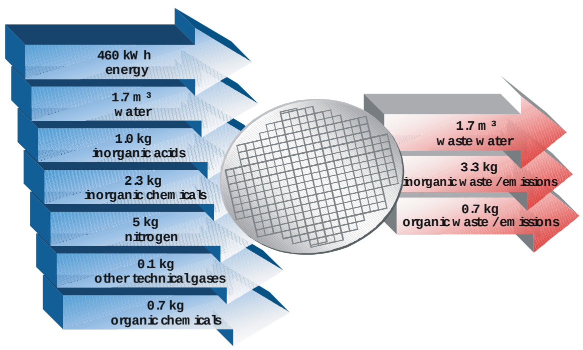


Fig. 7: Exemplary Inventory Data for Wafer Processing (per 4”-wafer)

4.5 Basis for Improvements: Process Clusters in Wafer Processing

In case that an inventory analysis or an complete LCA is performed in order to improve the production processes, an amount of several hundred of single processes in a wafer fab is to handle. Furthermore, to apply the different mask-layers, the wafer is processed in loops, treated several times in the same process chain.

To structure the inventory data process clusters have to be defined [7]. The clusters were divided into infrastructure and fab process modules. Infrastructure processes in semiconductor manufacturing are worth to be evaluated separately due to the high energy consumption to guarantee well controlled cleanroom conditions, the demand for process cooling water and the high throughput of ultrapure water for the key processes, especially wet bench processes. The energy consumption of infrastructure is in the same range as the energy consumption of the tools. Infrastructure process modules are supply of make up air, recirculating air, and ultrapure water, the process cooling water supply, nitrogen supply, generation of compressed dry air as well as central plant facilities and the process exhaust (scrubber, oxidizer), and wastewater treatment.

The key process clusters for which data has to be aggregated are:

Lithography

The photolithography processes create device patterns by use of UV sensitive resists, exposure via photomasks and development of exposed structures. During developing, exposed parts of positive resist are removed leaving an image of the mask pattern on the surface of the wafer for following deposition, etching or implant processes.

Ion Implant

Diffusion and ion implanting processes introduce precise amounts of donor and acceptor elements, e.g. phosphorus, arsenic, or boron, into silicon by magnetically focused high-energy ion bombardment.

Dry Etch

The dry etch process is using a reactive ionized gas plasma to remove surface material from a wafer.

Thin Films

Thin films processes include epitaxy and other physical and chemical vapor deposition processes (PVD, CVD). Epitaxy is the growth of an ultrapure layer of cristalline silicon as a high quality, low doped surface for the subsequent construction of transistors. Sputtering as the most common form of PVD is a method of depositing a metal layer onto a wafer by bombarding a target (e.g. aluminum or gold) with an argon plasma. The deposition of dielectrics/insulators on wafers is usually performed by placing the wafers in a mixture of gases which react at the surface of the wafers (CVD).

Thermal

The main thermal process in wafer processing is thermal oxidation by creating silicon dioxide when silicon reacts in a furnace with oxygen at about 1000°C. Furthermore thermal processes are used to redistribute an applied layer of dopant into the surface.

Wafer Cleaning / Wet Benches

Wafer cleaning and wet benches include all workstations for handling acid, base and caustic solutions for cleaning and wet etch purposes.

Chemical-Mechanical Polish (CMP)

For CMP a slurry compound and reactive chemical agents are used to microscopically polish the surface of a wafer prior to its use as a substrate and of deposited metals and oxides.

As a result of the above process clustering, the number of processes to be evaluated is reduced from several hundred to 16.

4.6 Cluster Related Mass Flow Analysis

Relating the mass and energy flows to process clusters supports the identification of environmentally significant aspects. A sankey diagram (fig. 8) shows the process clusters which contribute mainly to the overall mass flow. For a wafer fab mass flows for water and nitrogen dominate the mass throughput by far. Hence, the figure shows data for input of chemicals only.

Based on a mass and energy flow analysis a benchmarking of manufacturing sites and thus best-practice-sharing is possible. Combining this inventory with economic aspects is sensible, because 25-30% of processing costs of wafer fabs are materials, energy, and parts [14

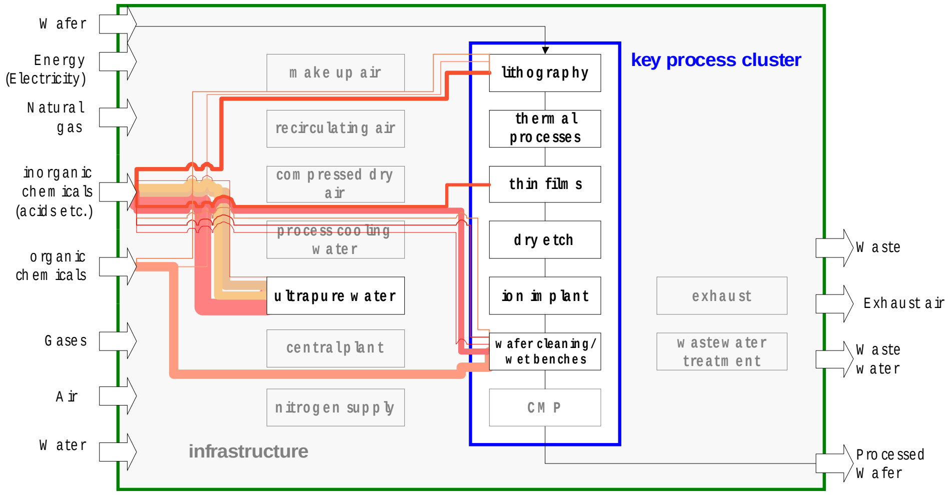


Fig. 8: Mass Flow Analysis – Input of chemicals (width of lines corresponds to mass flows in kg/a)

5 Impact Assessment for Electronics Manufacturing

5.1 Current Problems

A serious problem for the performance of an impact assessment is the variability and uncertainty in the environmental interventions in available inventory data bases, e.g. due to missing upstream process data for electronics specific chemicals and high quality level bulk chemicals, and data for emissions as well as downstream data for the disposal of electronic products.

Furthermore, for electronic products an assessment of very specific emissions is necessary which do not occur in the life cycle of many other product categories already evaluated by LCAs. In consequence, characterisation factors for the impact assessment, especially concerning toxicity is not yet available. For instance for the above mentioned chemicals WF_6, AsH_3, BF_3, GeH_4, $Al(CH_3)_3$, $POCl_3$ no characterization factors are available for Eco-Indicator 99 calculations [15], nevertheless most of these chemicals have a highly toxic potential.

5.2 Screening Assessment of Processes: ProTox

Due to the severe problems to employ in-depth Life Cycle Inventories and Impact Assessments for electronic products the screening methodology ProTox has been established by the Fraunhofer IZM [7, 16, 17].

5.2.1 Methodology

ProTox has been developed facing especially the problems of missing generic data for upstream processes, the fast development cycles of the electronics industry and the demand for an environmental assessment tool for product design and process improvement. On the other hand an assessment tool adapted to the electronics industry has to take into account the high throughput of hazardous chemicals, the legal requirement to have access to material safety data sheets and a transparent screening of (potential) environmental impacts.

The screening methodology ProTox is based on the Hazardous Substances Declaration (R-values), Allowable Workplace Concentration (MAK) and the Water Pollution Classification (WGK), which have to be declared on material saftey data sheets (MSDS) for all chemicals distributed in Germany. Thus, the preconditions for the ProTox assessment is knowledge about the mass flows and access to the MSDS. Knowledge about the specific composition of inputs is not demanded, if the MSDS is accessible.

For each substance a single value, the Toxic Potential Indicator (TPI per mg, on a scale from 0 to 100), is generated from the above mentioned classifications (fig. 9). The mathematical aggregation bases on equal weights for human toxicity, damage to aquatic systems and declared hazardous properties.

The input mass flows are multiplied by the TPI of each substance. Combining the TPI with the process input flows a TPI for process clusters is calculated. Thus, process clusters are compared taking the hazardous potential of materials into account.

Weak points of the ProTox methodology are:

only potential impacts considered based on legal / political / scientific determinations

upstream processes not considered in terms of LCA methodology

weighting of potential impacts to gain a single measure

Non hazardous flows as water and energy which contribute significantly to the environmental performance of electronics production have to be assessed separately.

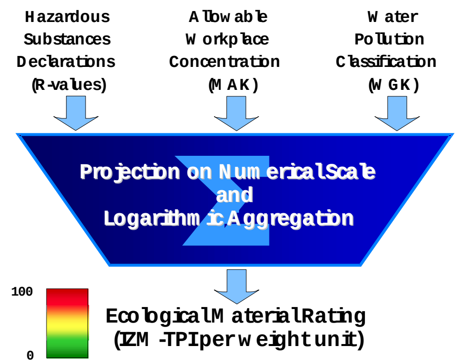


Fig. 9: Calculation Sceme for Toxic Potential Indicators (TPI)

5.2.2 Exemplary ProTox Assessment for Wafer Processing

The calculation of Toxic Potential Indicators for wafer processing reduces the confusing number of mass flows to a single measure. Thus, looking at the exemplary calculation for the R&D laboratory processing line the process clusters Thin Films and Wafer Cleaning / Wet Benches are identified to contribute predominately to the overall TPI of wafer processing (fig. 10). The ultrapure water process in this assessment is less important due to the fact, that the UPW process has a high throughput of regeneration agents but much less hazardous substances compared to the process clusters Thin Films and Wafer Cleaning / Wet Benches.

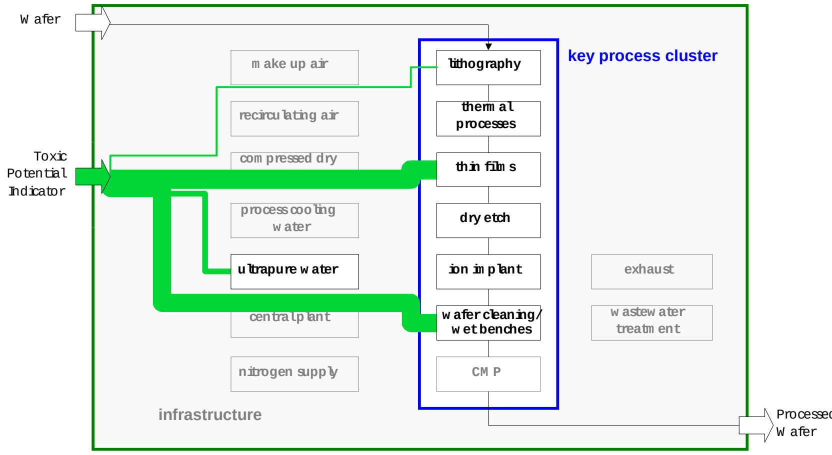


Fig. 10: ProTox Assessment for Chemicals Input (width of lines corresponds to TPI)

6 Conclusions

Life Cycle Assessment for the production of electronics has to focus on

evaluation of generic data for supplies in electronics, taking the requirements for high quality level chemicals into account,

furtheron a modularisation of infrastructure processes in semiconductor manufacturing seems to be managable, but has to consider the specific technological circumstances at the production site(s) as variables

frequent up-to-date evaluation of semiconductor processes, due to raging development in electronics, by employing a "lean" LCA (process clusters, functional unit applicable for future product generations), prepared by further case studies to gain experiences in effectively conducting LCAs for electronics and knowledge exchange between experts, how to make the methodology even leaner

By now, LCAs for complex electronic products, such as telecommunication products, are only applicable with serious restrictions due to severe data gaps in available data bases and doubtful reliability and appropriateness of available data sets. LCAs with reliable results within sensible time frames in electronics are only applicable for defined, small systems, e.g. the evaluation of single components, or solder types, or interconnection technologies. Thus, the Fraunhofer IZM employs the screening methodology ProTox to go a step forward into the direction of LCAs for electronics until the LCA methodology is effictively applicable for the Design for Environment process and keeps pace with the development cycles in electronics.

In order to assess complex system such as telecommunication applications which are characterized by comprehensive electronic hardware and unpredictable behavior of consumers, application specific environmental assessments which integrate LCA methodology with other methods of knowledge integration, such as scenario analysis and participation are essential.

References

[1] The Microelectronics and Computer Technology Corporation (MCC): Environmental Consciousness: A Strategic Competitiveness Issue for the Electronics and Computer Industry, March 1993

[2] Segerberg, T.: Life Cycle Assessment of Tin-lead Solder and Conductive Adhesive in Surface Mount Technology, IVF Report 95051, Mölndal 1995

[3] Siemens AG, Fraunhofer IVV et al.: Verbundprojekt Ökobilanzierung in der Elektroindustrie, funded by the Federal Ministry of Education and Research, 1995-1999

[4] Nokia and the Environment 1998, www.nokia.com

[5] Weidman, E.; Lundberg, S.: Life cycle assessment of Ericsson third generation systems, Int. Symp. on Electronics and the Environment 2000, San Francisco

[6] Nagel, M.H.: Environmental-Economic Assessment Methods in the Supply Chain Management Approach of an Original Equipment Manufacturer (OEM) of Telecommunication Products: an

Overview, Electronics Goes Green 2000+, Berlin, September 11-13, 2000

[7] Schischke, K., Stutz, M. et al.: Life Cycle Inventory Analysis and Identification of Environmentally Significant Aspects in Semiconductor Manufacturing, Int. Symp. on Electronics and the Environment 2001, Denver, May 7-9, 2001

[8] Ericsson: Environmental Report 1999

[9] Zeman, F.: Der Kreis schließt sich, AT&S Mitarbeiterzeitung, Ausgabe 12, April 2000

[10] Zeman, F.: e-mail correspondence February 28, 2001

[11] Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment, proposal 13.6.2000

[12] Sievert, W.J.: A European Perspective on Electronic Chemicals, Semiconductor Fabtech, 10th Edition, 2000

[13] Hermanns, S.: Abschätzung von Art, Menge und Herkunft der Umweltbelastungen der Produktion von Halbleiterbauelementen, Berlin, 1997

[14] Tsai, N.-S.: SEMI/TSIA Industry Strategy Symposium, December 6, 2000, Hsinchu, Taiwan

[15] Goedkoop, M., Spriensma, R.: The Eco-indicator 99 - A damage oriented method for Life Cycle Impact Assessment, Methodology Report, 2nd edition, 17 April 2000, Amersfoort

[16] Nissen, N.F. et al.: Environmental Assessment Using the IZM/EE Toolbox; Proceedings Electronics Goes Green 2000+, Sept. 11-13, 2000, Berlin, Germany

[17] Nissen, N.F. et al.: EE-Toolbox – A Modular Assessment System for the Environmental Optimization of Electronics; Proceedings IEEE International Symposium on Electronics and the Environment, May 8-10, 2000, San Francisco, USA

[18] Huijbregts MA: Application of Uncertainty and Variability in LCA, International Journal of LCA, Vol. 3, No. 5. 1998

Spielmann, M. & Tietje, O.: A conceptual framework for Scenario Analysis in Life Cycle Invento

“Future Vision of Telecommunications”

Prof. T. Ebrahimi, EPFL- Signal processing laboratory, Touradj.Ebrahimi@epfl.ch

Communication - definition 1

- Communication has always been about sharing experience (real or imaginary) with others
- It all started with story telling and wall drawing around the fire in the caves of early men
- Modern communication systems are mostly evolved versions of the good old story telling and wall drawing, but offering a richer set of experience

Evolutions versus Revolutions in communication 3

- Evolution: Each modality of communication improves itself in terms of quality of experience:
  - B&W TV
  - Color TV
  - Stereo and CD quality audio TV
  - HDTV
- Revolution: New modalities of communication and expression are introduced bringing new dimensions in quality of experience
  - Photography
  - Cinema
  - Internet

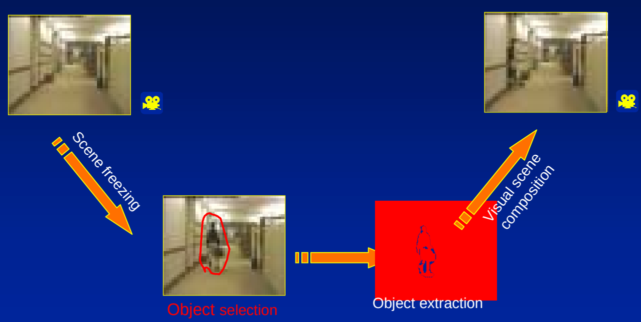
Some of the major evolutions and revolutions in communication modalities 4

- Story telling and cave drawing
- Books and written press
- Photography
- Telegraph
- Telephone
- Radio and music recording
- Cinema
- Television and video recording
- Internet
- Mobile communication
- (What is next?)

New types are media are emerging… 5

New media and experiences with it… 6

- Interactive scene composition



New types of media …Enhanced reality 7

New types of media … Virtual presence

8

New types of media … Avatar

9

Today’s challenges in mobile communication

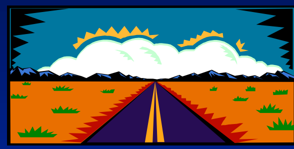
10

- How to provide more than speech and text in a mobile environment?
- How to make sure that the quality of experience becomes rich despite shrinking form factors of mobile devices?
- How to achieve convergence in a multimedia rich environment with a single device (Swiss Army Knife Syndrom)?

Today’s trends in mobile communication

11

- Extend the mobile communication by offering new modalities such as still images, music, video, ...
- No major obstacle is foreseen
- How long will this growth last until rich multimedia mobile communication becomes as routine as speech and SMS today?



What about tomorrow?

12

- The next frontier in extending the experience will be in reality/virtuality continuum
  - Virtual reality technologies are becoming mature
  - Image processing and Computer graphics convergence (Natural, Synthetic)

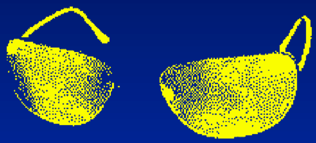
The key to future is in quality of experience through advanced interface design

13

- Connectivity between machines
  - A classical approach that is working and paying
  - Connect machines together to connect people together (network centric design)
  - Lot of technological investments in this area
- Interface between man and machine
  - Mostly ergonomics
  - Much less technological investment in this area

What will tomorrow reserve for us? 14

- Let me introduce your favorite mobile communication device of tomorrow!



Environmental Impact ofTelecommunicationSystem and Services
Lausanne, Apr. 25th, 2001 T. Ebrahimi

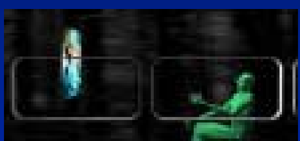
Science fiction or science fact? 15

- Semi-transparent display capable of overlays
- Stereoscopic cameras
- Network enabled
- Powerful processor
- A good amount of memory
- A good autonomy

Environmental Impact ofTelecommunicationSystem and Services
Lausanne, Apr. 25th, 2001 T. Ebrahimi

What if these challenges are answered 16

- No more any restrictions on the quality of multimedia content in a mobile environment
- Truly mobile; with no weight, no size!
- Always available and accessible
- Various truly innovative applications with real use



Environmental Impact ofTelecommunicationSystem and Services
Lausanne, Apr. 25th, 2001 T. Ebrahimi

Some interesting application scenarios 17

- Virtual everything!
  - Virtual teleconferencing
  - Virtual PDA
  - Virtual Laptop
  - Virual Presentation devices
  - Virtual object sharing
  - Virtual advertisement
  - Virtual decoration
  - …

Environmental Impact ofTelecommunicationSystem and Services
Lausanne, Apr. 25th, 2001 T. Ebrahimi

Is that all? 18

- This is just the beginning of a new era where personal communication will be extended to new modalities where a far richer and more realistic experience can be achieved
- Other modalities such as touch, smell, taste, and even emotions will start appearing through the use of bio-interfaces to augmente further the quality of experience
- Quality metrics for these modalities are needed…as well as their combinations
- But let's talk about it another time…

Environmental Impact ofTelecommunicationSystem and Services
Lausanne, Apr. 25th, 2001 T. Ebrahimi

Where are we heading to? 19

- Let me finish by the following quote from Murray Gell-Mann, Nobel Prize and founder of Santa Fe institute:

" One day, for the good or for the bad of it, such interconnections will be possible. Human beings will be able to connect to computers, without need to go through the interface of spoken language or a display, and through these computers to one or more other human beings. There will be a total sharing of thoughts and feelings, without any of the limitations of the language."

Environmental Impact ofTelecommunicationSystem and Services
Lausanne, Apr. 25th, 2001 T. Ebrahimi

"LCA of telecom products & systems within Ericsson and use of LCA in the annual environmental report"

Jens Malmodin, Ericsson

Figure 2

•During 1996-1998, two large system LCA studies where carried out together with (actually requested by) two large operators/customers: Telia in Sweden and AT&T in US.

• Although the focus was on the wireless systems, fixed infrastructure and peripherals where included. The fixed system where not covered in as much detail as the wireless system and the Internet where not covered at all.

• One goal was to use regional specific environmental indicators in addition to traditional LCIA and one-value based evaluation systems.

Figure 3

•The total results in absolute values for the Stockholm system compared relative to the Sacramento system.

• The only indicator that is larger for the Stockholm system is radioactive waste, which is of scale (>200%). All other indicators are lower and the one and nearly only reason for that is the difference between the Swedish electricity grid (hydro/nuclear) and the grid in California (large % fossil)
- Energy is very important.

• The handling of the toxicological aspects of waste and emissions are as poor in this study (no critics to anyone but the author) as most LCA practitioners will agree all LCA studies are... Nevertheless, the consultants came to the conclusion that all such indicators where below threshold in the models that we had created. But... The models builds in most cases on LCI data from very good suppliers (of course they like to give data away...) and other sources alike.

• If you are forced to say what percentage the telecom system make up of the total energy consumption or even environmental impact of a region/country (I guess you could say), the answer is about **0,5%**. Depending on where you put the line for what's telecom or not. How much of a fax is telecom? Of a part of an office that has internet servers and work associated with them?
Peripherals and Internet can play a large roll.

• The phone books in the fixed system stood for the largest use of land measured as surface area. Second came base stations for the wireless system.

Figure 4

•We focused on the wireless system at Ericsson in the work together with Telia and AT&T

• The use phase was the largest source of impact and the radio base stations consumed the largest amounts of energy in the use phase.

• We where able to show that a new base station where better then the old model in US. The new base station consumed about 40% less energy and the weight of the actual base station was reduced by about 60%.

• AT&T on the other hand showed that by changing electricity supplier to an all hydro based supplier would lower their total load with more then 80% in nearly all the environmental categories. The increase in land area use for hydro where far less then expected. The base stations still use far more land area.

Figure 5

•The importance of fossil fuels is well documented in nearly all LCAs done. But we must not forget it’s a well known fact

• Amounts of fossil fuels or CO_2 is perhaps the best individual physical measurement you could present that is widely understood.

• The other area of great concern is waste and emissions and the following potential to have an impact on air and water. This is delt with in later parts of this presentation.

• Forrestry and agriculture and the following depletion of land areas and eco- systems are of course very important but are less of a problem in the telecom business.

Figure 6

•Since mobile phones, radio base stations, switching equipment and cables where part of the studies with Telia and AT&T, the step towards an LCA of Ericsson is not that hard.

• Instead of using the equipment count list of a telecom system, we would use the annual production count list of Ericsson.

• The overall estimations we make is that the LCAs and material declarations of large volume products can be used as an approximation to the total production within each product family. And then for the total production of Ericsson.

• We had already included so called office activities in our LCAs and did so also for the operators administration part in the system LCAs.

• The goal is to be able to keep a measuring system based on the LCA methodology for the environmental report and the EMS.

Figure 7

•Together with the Ericsson site reporting that has been ongoing and improved for nearly 10 years, we would add product LCAs.

Figure 8

•The key to all LCA studies is LCI data.

• We use an internal view on all sites - the “Site principle”.

• Total annual data is the first step. Offices should be included or the site may be made entirely of an office. And then the data is divided with the production (functional unit). An allocation between different products may be needed.

• The site principle is used in most supplier requests for LCI data.

• No sub-processes within the sites are studied. The nature of electronic manufacturing is that thousands of different products are manufactured within the same site making specific studies very hard or impossible.

Figure 9

•All sites at Ericsson should collect and report data.

• Nearly all factories do collect and report data but not all offices. The answering ratio is acceptable though.

• In order to get to a value for the whole Ericsson we assume that the average data for office employees per employee can be used to get to the Ericsson total figure. We also have to do like that for factories although a factory can be much more individual. All important factories do report.

Figure 10

•Building operation (electricity, other fuels), air travel (aircraft kerosene), car ravel (gasoline, diesel) and transports (aircraft kerosene, diesel) are the main energy consumers at *Ericsson sites* or *activities directly connected* to them. Leading to most of the CO_2 that can be directly connected to Ericsson.

• Workplace, travel and commuting are very much related to the individual employee and can be expressed as kg CO_2/employee.

• Transports to but especially from Ericsson, make up the largest individual part of this energy consumption / CO_2.

• This year's car travel figure is an average of about 17 000 employees answers in a environmental e-learning program at Ericsson. Compared to the years before we have to admit that we didn't estimate they would travel so much and so far by car to get to work.

Figure 11

•In order to find the production of the different product families all factories and supply organizations have been requested to provide information.

• The weight is presented here.

• The overall estimations we make is that the LCAs and material declarations of large volume products can be used as an approximation to the total production within each product family. And then for the total production of Ericsson.

Figure 12

•The total LCA CO_2 for Ericsson follows the wireless system LCAs to a large degree since they make up of 2/3 of the sales or even more.

• Energy consumption in the use phase has been decided to be one of the top priorities in the EMS and DfE.

• The supply chain is of greater importance then the Ericsson direct activities.

• Once again: This is just CO_2, but it's a good indicator towards fossil fuels, NO_x, SO_x and others. The same kind of diagram can be presented for many different resource, waste and emission categories, or any LCI data.

Figure 13

•The total life cycle data can be divided between different products and different phases/parts for each product.

• There can be big differences between different products.

• The mobile phone has it's largest values connected to the manufacturing phase. The use phase grows big when the chargers consumption plugged in, but not in use, is taken in account. About half of all Ericsson chargers are "smart" as they shuts down when not in use. The scenario used here is half of all chargers plugged in half of the time for three years.

Figure 14

•LCA results are no good unless they can be refered to an understandable functional unit - One year wireless subscription in this case [/subyear].

• The AT&T US system where more close to a world average system then the Telia system in Stockholm. The AT&T system therefore serves as the base for the average world wide Ericsson wireless system.

• The smaller circles and dotted lines in the left diagram intends to show that the results is uncertain in time and as absolute values. Due to a lot of different aspects where subscriber density, climate(!), mix of equipment and energy system are the most imortant ones.

• The right diagram shows the different system parts (mobile phones, base stations and switching) and the relation between them in the manufacturing and the use phase. In order of importance: Radio base station operation, operator activities, mobile phone manufacturing.

• The Telia system in Stockholm consumed energy equal to or below 10 litres gasoline per subscriber and year. The largest individual source of gasoline/CO_2 for Telia where the mobile phone manufacturing and not the radio base station operation.

Figure 15

•Energy is of course not everything. We also have waste and emissions. The waste and emissions from Ericsson sites do we have under control.

• Most emissions from manufacturing sites have been reduced drastically in the last 10 years. The waste and how that is treated is still of concern. A complete study of a hazardous waste treatment facility in Sweden (SAKAB) have been carried out.

• The information about waste (and how it is treated) and emissions in the supply chain is very limited.

Figure 16

•The material content of our products is an issue that has become more and more important. Various stakeholders ask for the material content of our products where the customers of course comes first.

• Ericsson has established a database with requested material contents of supplied products.

• Several material content requests to suppliers for specific products as well as material analyses of specific product parts (mostly PBAs) has been carried out.

• We may not have access to information on materials and chemicals used in the various manufacturing processes, but we have to know the chemical content of what we include in our products. Of course, the product content knowledge is a good guide to the use of materials and chemicals in the manufacturing processes.

• The material content of products is important for the EoL treatment.

Figure 17

•The total material flow in our products life can only be recognized by LCA studies.

• The presented material & energy flow represents the 1999 Ericsson production used in a world average scenario for 10 years (3 years for terminals).

• The LCA data may be limited in detail but quite good data exists for the materials consumed in large amounts: Steel, aluminium, copper, plastics, and all fossil fuels of course.

• Amounts of handled materials and waste are largest in the supply chain.

• Amounts of fuels incinerated are largest in the use phase.

• A lot of the materials and chemicals used in the life cycle comes from recycling and will be recycled when used.

Figure 18

•The LCI inventory of sites may be the key to a lot of the environmental work going on within companies and other organizations. LCA work, EMS work and other.

• The site LCI data have to be related to the production (functional unit) to be of good use.

• More and more companies ought to do LCIs and report results in annual reports. About what they do at their own sites.

• To do LCAs and larger scale analyses of the whole society in the end will be much more easier when more LCI data are made available this way.

• If everyone did...

Figure 19

•Companies and organizations could put their existance in a life cycle perspective, at least their products, if LCI data where more available.

• The step towards an understanding of the impact on the whole ... World could also actually be done. Or???

Figure 20

•An example of a try towards better understanding of the whole impact on society. Without any real proof or figures. Just a mind model. I can't explain it in text...

Fig.2)

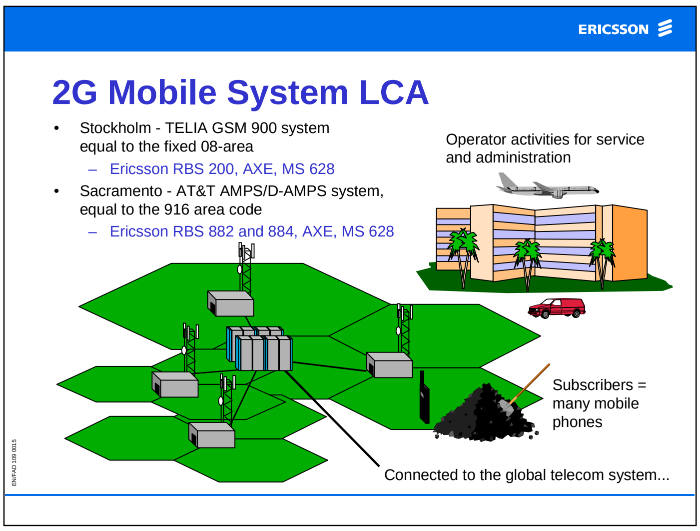


Fig.3)

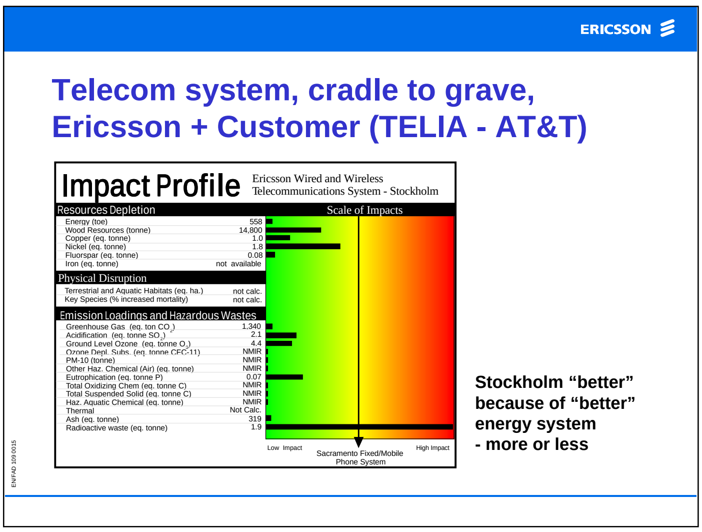


Fig.4)

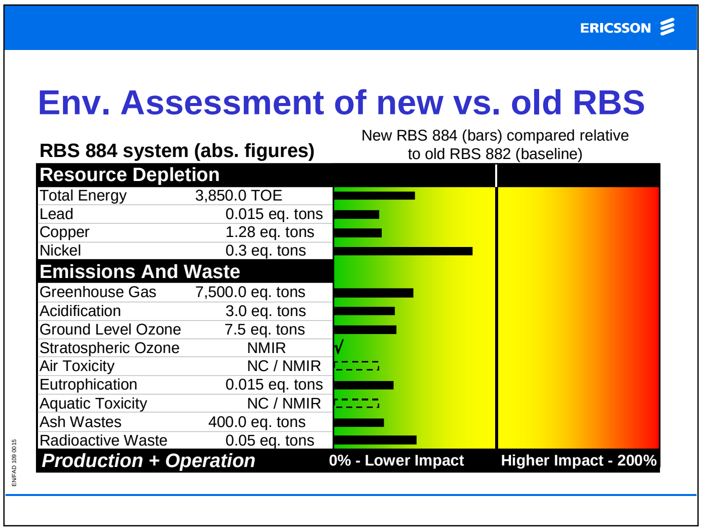


Fig.7)

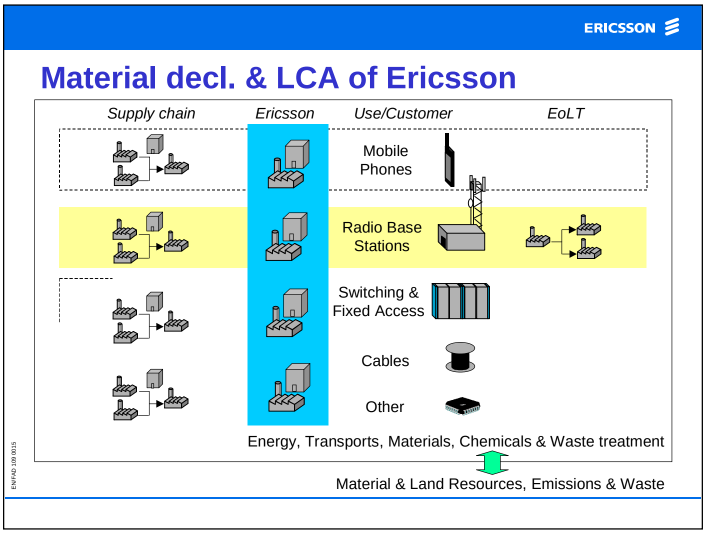


Fig.5)

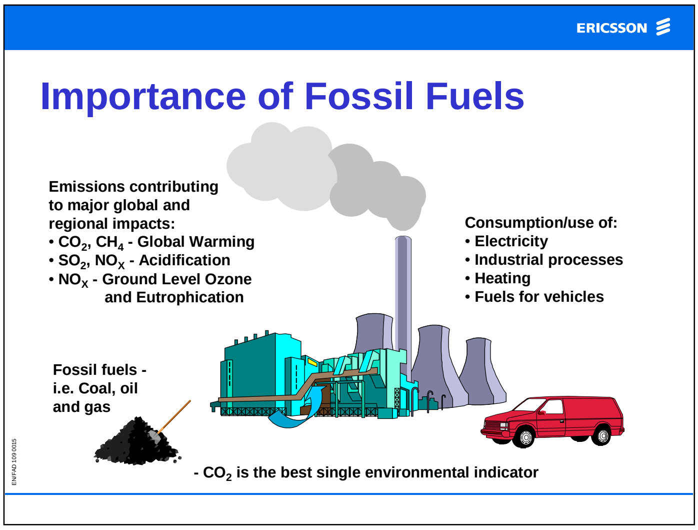


Fig.8)

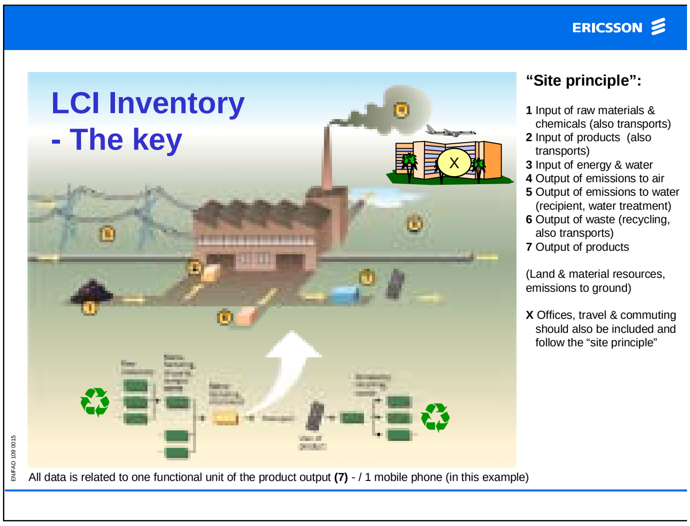


Fig.6)

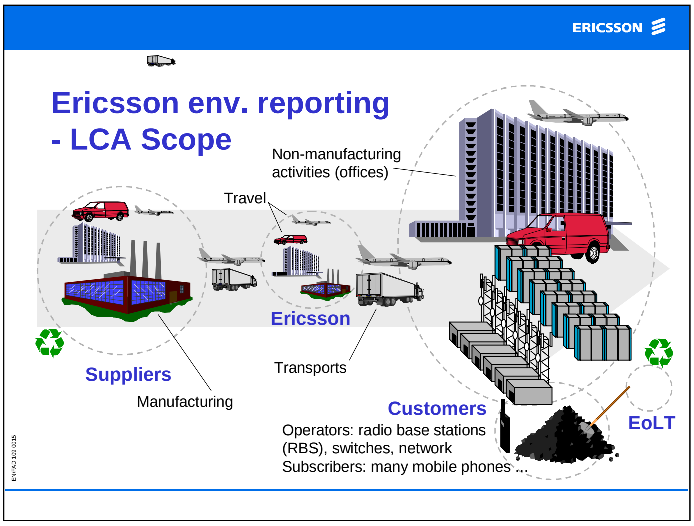


Fig.9)

ERICSSON

Ericsson total site figures

	Answer covers	Total no employees	Answer ratio
Offices	57 400	83 000	69%
Factories	19 200	21 200	91%
Ericsson total	76 600	105 000	73%

Four types of averages :
Sweden / World - Offices / Factories

Total figure for each type =
(Reported figure / employees covered) * total employees

Fig.10)

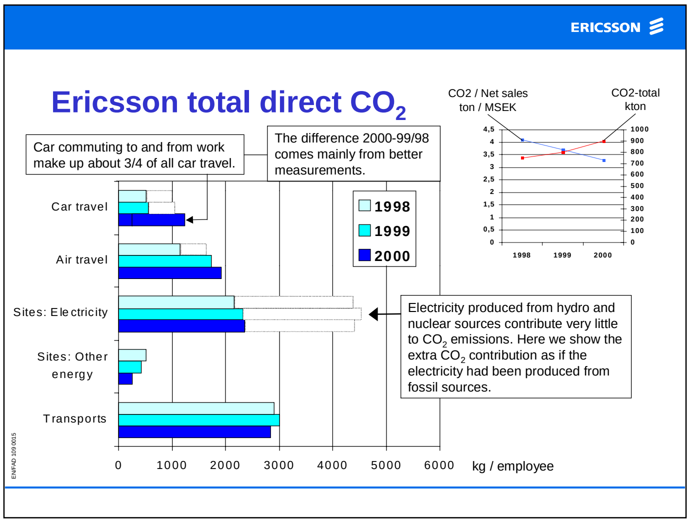


Fig.13)

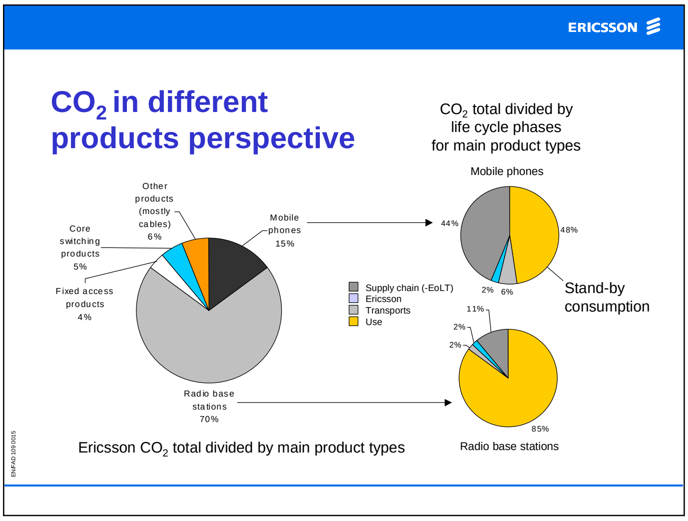


Fig.11)

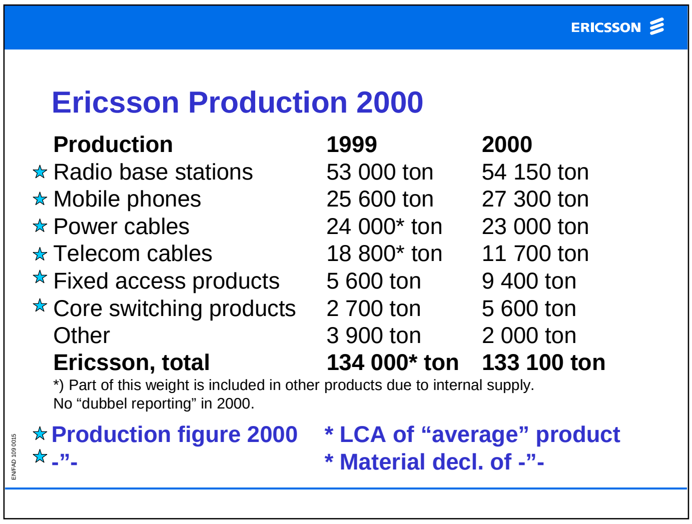


Fig.14)

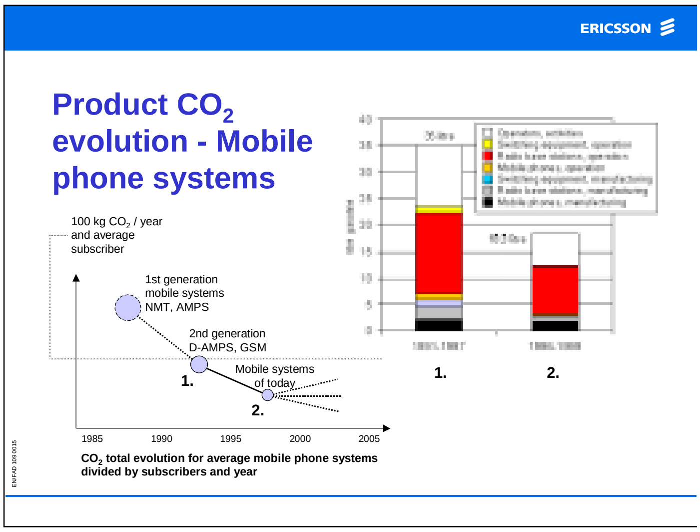


Fig.12)

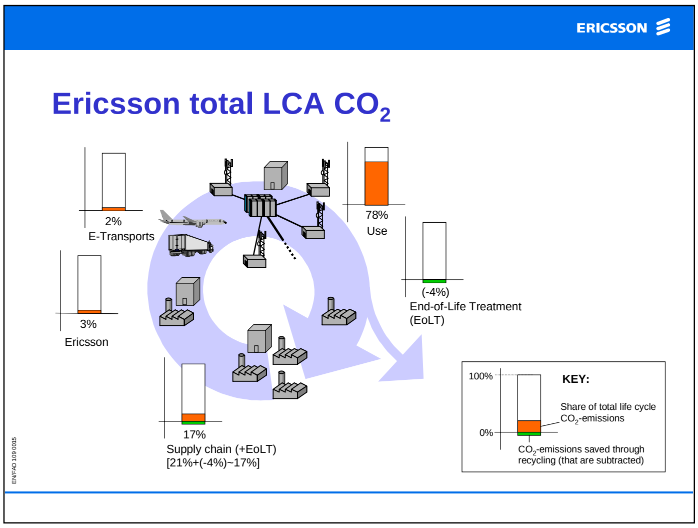


Fig.15)

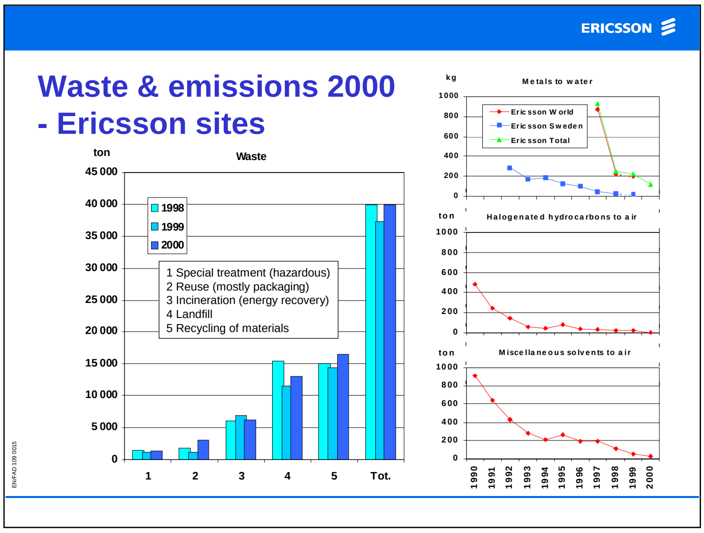
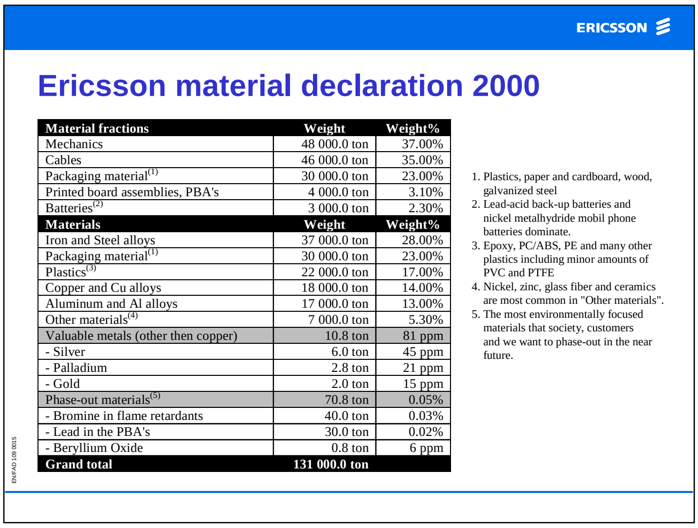


Fig.16)



Material fractions	Weight	Weight%
Mechanics	48 000.0 ton	37.00%
Cables	46 000.0 ton	35.00%
Packaging material(1)	30 000.0 ton	23.00%
Printed board assemblies, PBA's	4 000.0 ton	3.10%
Batteries(2)	3 000.0 ton	2.30%
Materials	**Weight**	**Weight%**
Iron and Steel alloys	37 000.0 ton	28.00%
Packaging material(1)	30 000.0 ton	23.00%
Plastics(3)	22 000.0 ton	17.00%
Copper and Cu alloys	18 000.0 ton	14.00%
Aluminum and Al alloys	17 000.0 ton	13.00%
Other materials(4)	7 000.0 ton	5.30%
Valuable metals (other then copper)	10.8 ton	81 ppm
- Silver	6.0 ton	45 ppm
- Palladium	2.8 ton	21 ppm
- Gold	2.0 ton	15 ppm
Phase-out materials(5)	70.8 ton	0.05%
- Bromine in flame retardants	40.0 ton	0.03%
- Lead in the PBA's	30.0 ton	0.02%
- Beryllium Oxide	0.8 ton	6 ppm
Grand total	**131 000.0 ton**	

1. Plastics, paper and cardboard, wood, galvanized steel
2. Lead-acid back-up batteries and nickel metalhydride mobil phone batteries dominate.
3. Epoxy, PC/ABS, PE and many other plastics including minor amounts of PVC and PTFE
4. Nickel, zinc, glass fiber and ceramics are most common in "Other materials".
5. The most environmentally focused materials that society, customers and we want to phase-out in the near future.

Fig.19)

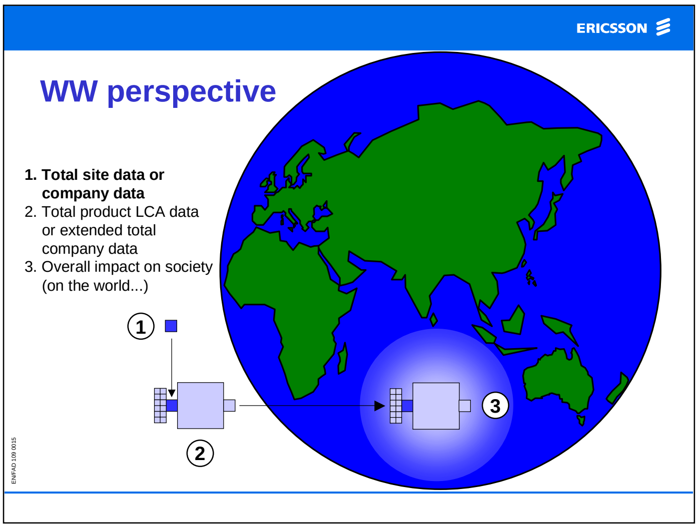


Fig.17)

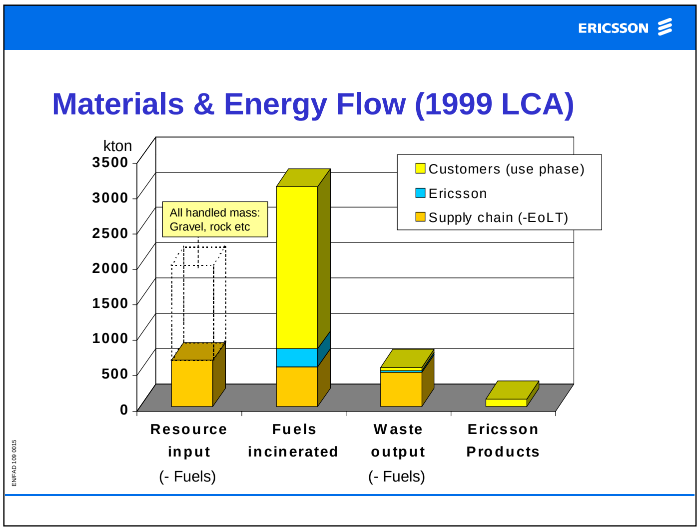


Fig. 20)

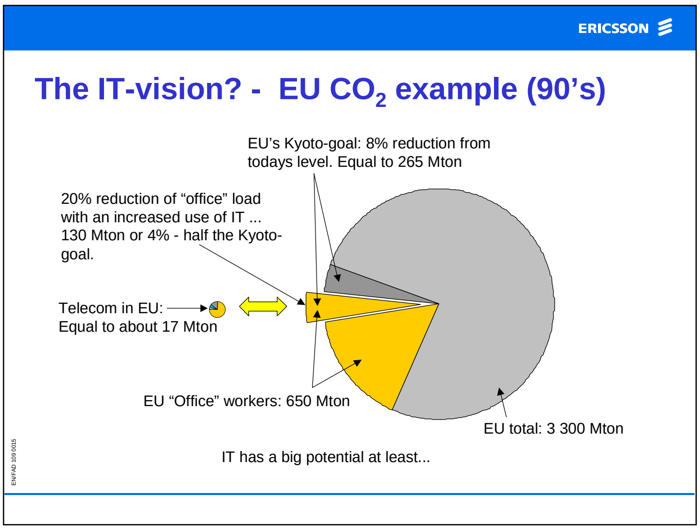
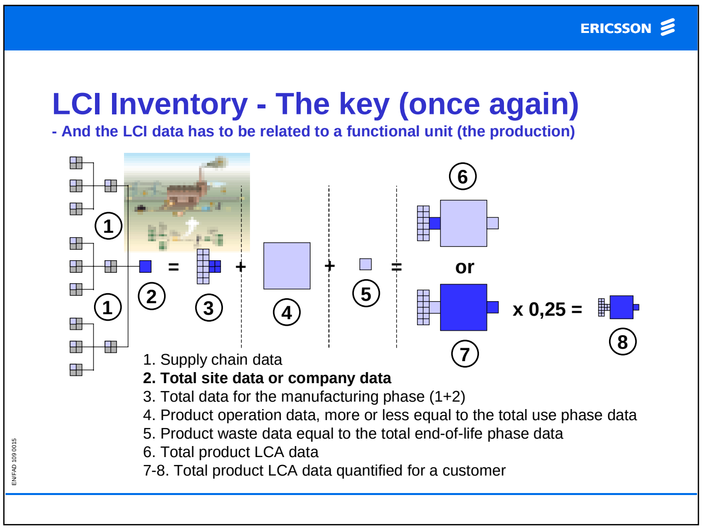


Fig.18)



"Comparison of Process LCA and Input/Output Analysis: Case studies on Internet and the Role of Retail and Wholesale Trade in the Life Cycle"

Filippo Della Croce, EPFL–LC Group and Prof. Greg Norris, Harvard University

Comparison of Process and Input Output LCA based on the Primary Embodied Energy of a Control Unit

The goal of this study was to compare two Life Cycle Assessment Methods, the Process Life Cycle Assessment (Process LCA) and the Input Output Life Cycle Assessment (IO-LCA). The comparison has been made based on the primary embodied energy of the control unit of a personal computer.

The primary embodied energy of a control unit from Process LCA has been taken from Atlantic Consulting, 1998 and the software LCNetbase has been used to calculate the primary embodied energy of a control unit with IO-LCA.

We found that the result from the IO-LCA was a factor of 4.5 greater than the result of the Process LCA. The reasons of this difference have been discussed and quantified.

We found that the main source of difference is the larger number of inputs considered by the IO-LCA. The differences regarding the geographical and temporal sources of the data used in the two methods have also been discussed and quantified.

A comprehensive list of possible sources of difference between process LCA and IO-LCA results can be found in the literature. Only the following ones are relevant for the purpose of this study:

1) differences in the energy efficiency of Europe and the US

There are significant differences between the energy efficiency of Europe and the US and it is widely known that the US are less energy efficient than Europe. This can explain part of the difference between the two results.

We implied the Primary Embodied Energy of a control unit from European IO-LCA data for the product group " Type writers, counting machines and calculators" (Kees Vringer and Kornelis Blok, 1995) and we compared it with the corresponding value found with US IO-LCA data. This gave us an estimation of how the difference in the energy efficiency of the two countries can affect the IO-LCA results for the Primary Embodied Energy of a Control Unit.

2) Different levels of comprehensiveness of the two methods

In a conventional process LCA, as the one considered in this study, inputs to the system such as Legal Services, Hotel and Lodging Places, Wholesale Trade, Banking and so forth are not considered, whereas IO-LCA allows to consider them. We estimated the total contribution of such inputs to the Primary Embodied Energy of a Control Unit using IO-LCA and making the assumption that the remaining ones need a same proportion of those mentioned inputs.

3) Different levels of aggregation of the two methods

Process LCA can be considered as a more precise method, within its boundaries, than IO-LCA. In fact IO-LCA uses mean values of energy consumption per dollar of output for the entire

Electronic Computer Sector. This sector may produce commodities that require different amounts of Primary Energy per dollar of output.

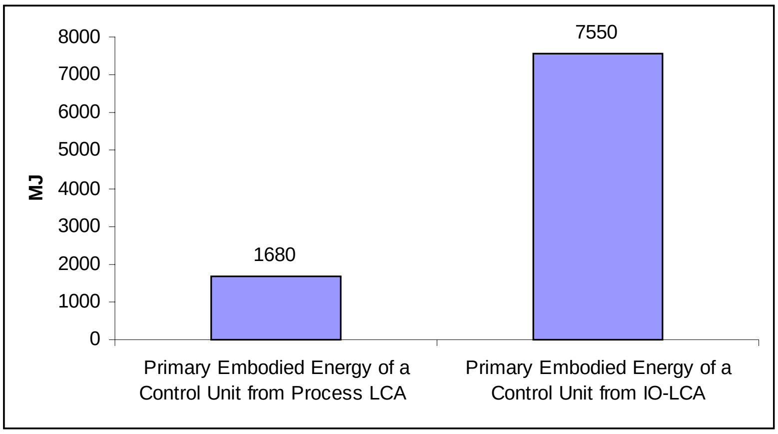
4) Temporal difference between process LCA and IO-LCA data and energy efficiency improvements

The IO-LCA data are relatively old (1992) and from 1992 and 1987 (year in which the process LCA of Atlantic Consulting has been made) the energy efficiency of processes and transportation in the US has increased.

In the period between 1992 and 1997 the energy intensity of the US, in other words the amount of energy needed to support the nation's economy, declined by an average rate of 1.3 % per year. (John A. Laitner, 2000)

The Primary Embodied Energy from the two methods

Here below we show the values of primary embodied energy from process LCA and from the IO-LCA.



The Primary Embodied Energy of the Control Unit from IO-LCA is greater than the Primary Embodied Energy found with the process LCA. There is a factor of 4.5 between the two results.

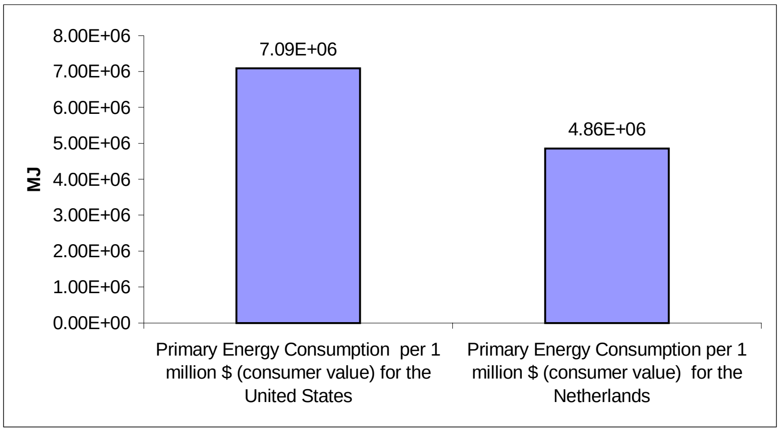
Reasons of the difference and their quantification

Here we show the results of the quantification of the four reasons that can explain the difference between process LCA and IO-LCA results and that have been already mentioned in Methods.

1) Differences in the energy efficiency of Europe and the US

Here below we show a comparison between our IO-LCA results based on US data and the corresponding result using European data (Kees Vringer and Kornelis Blok, 1995) for 1 million $ of output from the Electronic computer sector.

The IO-LCA value of Primary Embodied Energy from European data is approximately 30% lower than the corresponding value from US data.



2) Different levels of comprehensiveness of the two methods

Here below we show a list of the inputs required by the Electronic Computers Sector to produce a Control Unit. This list has been created using IO-LCA software LCNetbase (because of the luck of space, we do not show here the complete list, but the inputs in the list contribute to 93% of the total Primary Embodied Energy).

The highlighted inputs are those inputs that have not been considered by the process LCA and they contribute to 30% of the total Primary Embodied Energy from IO-LCA. We assumed that the remaining inputs need as well inputs like those that have been highlighted and in the same proportion. Therefore, we obtain that 50% of the Primary Embodied Energy calculated with IO-LCA (corrected for Europe) is due to inputs that are only considered by IO-LCA and not by the process LCA.

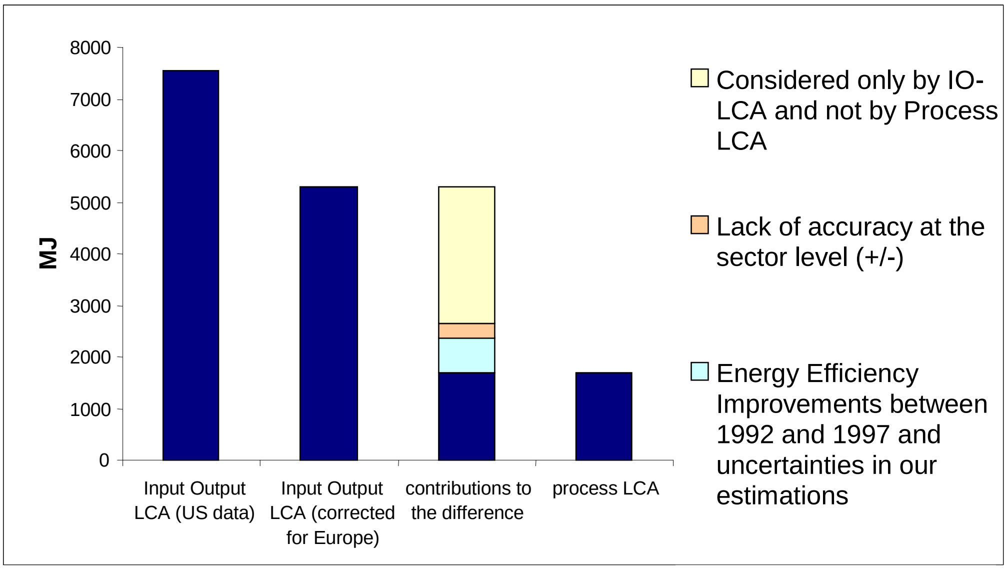
	% of total primary embodied energy	cumulative %
Air transportation	11.9%	12%
Electric services (utilities)	11.9%	24%
Computer peripheral equipment	9.9%	34%
Wholesale trade	9.7%	43%
Semiconductors and related devices	9.3%	53%
Petroleum refining	6.3%	59%
Other electronic components	5.4%	64%
Miscellaneous plastics products, n.e.c.	4.0%	68%
Relays and industrial controls	2.8%	71%
Gas production and distribution (utilities)	2.5%	74%
Automotive rental and leasing, without drivers	2.4%	76%
Hotels and lodging places	1.9%	78%
Telephone and telegraph apparatus	1.8%	80%
Aluminum rolling and drawing	1.7%	81%
Motors and generators	1.2%	83%
Blast furnaces and steel mills	1.2%	84%
Sheet metal work	0.9%	85%
Electron tubes	0.8%	85%
Nonferrous wiredrawing and insulating	0.7%	86%
Fabricated metal products, n.e.c.	0.7%	87%
Legal services	0.7%	87%
Paperboard containers and boxes	0.7%	88%
Motor freight transportation and warehousing	0.6%	89%
Power, distribution, and specialty transformers	0.6%	89%
Gaskets, packing, and sealing devices	0.6%	90%
Metal stampings, n.e.c.	0.6%	91%
Real estate agents, managers, operators, and lessors	0.6%	91%
Banking	0.6%	92%
Eating and drinking places	0.5%	92%
Management and consulting services, testing and research labs	0.5%	**93%**

3) Different levels of aggregation of the two methods

The luck of accuracy at the sector level in IO-LCA do not contribute to a big part of the difference found in the results from IO and Process LCA. Based on our observation of the energy consumption per dollar of output for several commodities and based on the proportions between shares of commodities produced by several sectors, we estimated that this can contribut to 5-10 % of the difference found.

Summary of the results

Here below we show in the graphic a summary of the results found to explain the difference between our IO-LCA and the Process LCA results.



From a methodological standpoint only the second and third reasons discussed here above are relevant (respectively the different levels of aggregation of the two methods).

If we discard the temporal and geographical differences regarding the data sources, and according to our findings, we can say that for the Primary Embodied Energy of a Control Unit, the IO-LCA result is more than 2.5 times greater than the corresponding result from Process LCA. The difference between the two values is mainly due to the wider range of inputs considered by the IO-LCA compared to those considered by the Process LCA.

The Energy role of retail and wholesale trade in the LC

The objective of this research was to assess the energy role of retail trade and wholesale trade in the life cycle of products using Input-Output LCA (IO-LCA) mainly focusing on the Electronic Computers Sector.

We used economic data for retail and wholesale trade margins of the US Bureau of Economic Analysis (NIPA data) and the IO-LCA software LCNetbase, developed by Gregory Norris of Sylvatica Consultants.

The Distribution phase of a life cycle, which corresponds to all the activities carried out to facilitate the transfer of manufactured products from their final manufacturer to their ultimate end user, including warehousing and retailing and their supporting functions (SETAC, 1990), is significantly important from an energy standpoint.

For the electronic computer sector it represents 47% of the energy consumption in the Total Pre-consumer phase, which is the sum of production and distribution.

According to our results, the physical transfers of products within the Distribution phase play a minor role in terms of energy consumption compared with wholesaling and retailing. For the Electronic Computers Sector, for example, the transfers in the Distribution phase are responsible for only 8% of the total distribution energy consumption. As a mean value for 658 commodities studied in this research, transfers account for 14.7 % of the energy consumption in the distribution phase.

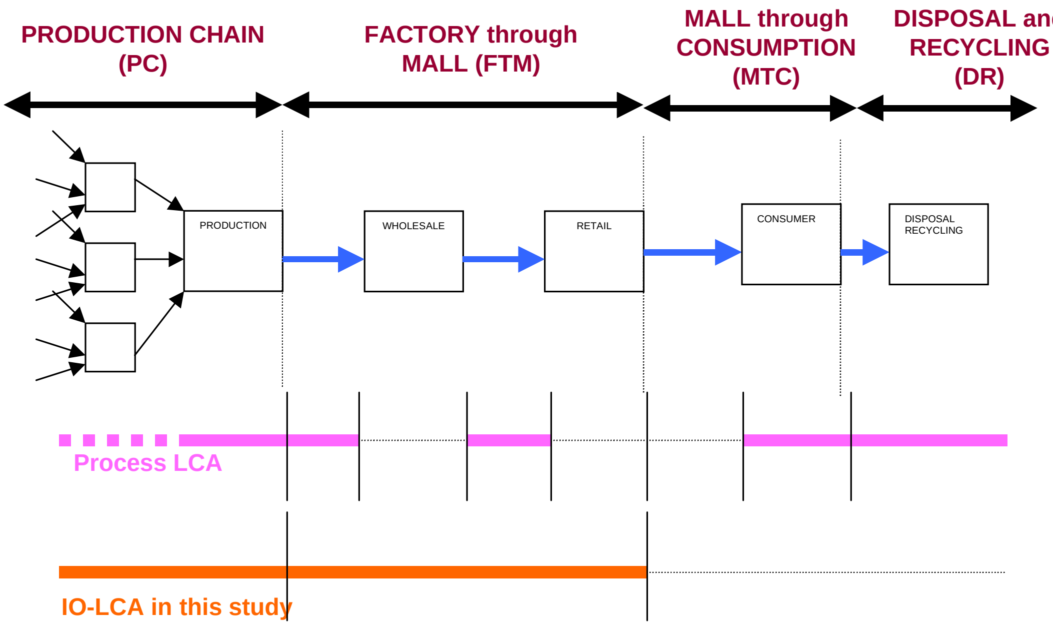
Distribution and transportation are important steps in the life cycle of a product.

Transportation includes all the movements of materials or energy between operations at different locations while distribution includes all non-transportation activities carried out to facilitate the transfer of manufactured products from their final manufacturer to their ultimate end-user (SETAC, 1990).

Distribution includes warehousing, wholesaling, retailing and support activities carried out at these locations, such as internal movements of goods, inventory control or repackaging. It does not include the production or manufacture of a product at a retail or wholesale facility, such as in-store bakery operation (SETAC, 1990).

For the purpose of this study, we decided to call the Distribution phase *Factory Through Mall* phase (**FTM**). We use here **PC** to indicate the Production phase.

In this study we focused on the FTM phase and we used IO-LCA to assess the importance of retailing and wholesaling within this phase from an energy standpoint. In fact, although retailing and wholesaling should be considered in a conventional process LCA, their are commonly not included in the system.



To be able to use IO-LCA, we used economic margins for retail, wholesale and transportation (in the sense of internal movements within the FTM phase) of the US Bureau of Economic Analysis, BEA (NIPA data). From the NIPA data it was possible to know for more than 650 commodities, their total producer value, the purchase value and in-between margins to transportation (rail, truck, water and air), wholesaling and retailing for the US.

Here below we show these data for some commodities as an example.

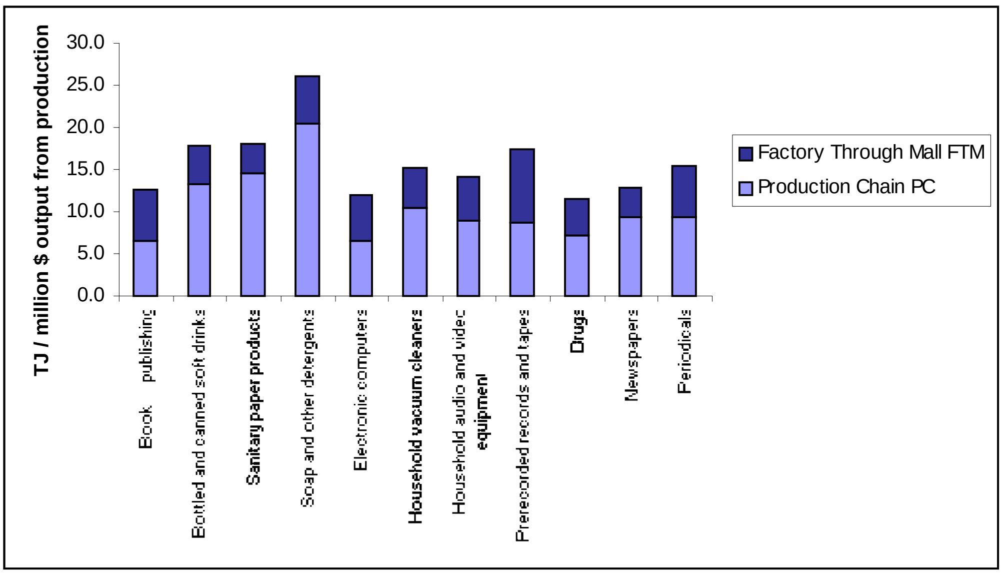
BEA code	Commodities	ProducerVal	Rail	Truck	Water	Air	WholesaleMargin	RetailMargin
260301	Book publishing	100.000%	0.000%	3.001%	0.000%	0.378%	18.606%	51.034%
142200	Bottled and canned soft drinks	100.000%	0.014%	0.483%	0.005%	0.000%	20.216%	38.713%
240500	Sanitary paper products	100.000%	0.000%	1.093%	0.000%	0.000%	9.280%	34.020%
290201	Soap and other detergents	100.000%	0.000%	4.199%	0.000%	0.080%	28.814%	33.141%
510103	Electronic computers	100.000%	0.000%	0.032%	0.000%	1.063%	16.269%	52.448%
540500	Household vacuum cleaners	100.000%	1.074%	3.624%	0.000%	0.000%	1.812%	46.913%
560100	Household audio and video equipment	100.000%	0.046%	0.937%	0.000%	0.121%	16.835%	48.362%
560200	Prerecorded records and tapes	100.000%	0.167%	3.913%	0.000%	2.914%	13.405%	74.938%
290100	Drugs	100.000%	0.014%	0.397%	0.005%	0.138%	15.915%	41.132%
260100	Newspapers	100.000%	0.000%	0.891%	0.000%	1.873%	5.127%	26.024%
260200	Periodicals	100.000%	0.045%	4.609%	0.000%	2.001%	15.494%	39.175%

In the tables below, we show the BEA sectors that we used in our IO-LCA to calculate the energy requirements in the FTM phase and the commodities that we selected as examples for our study.

Sector	**BEA** industry code
Rail transportation	65.0100
Truck transportation	65.0301
Water transportation	65.0400
Air transportation	65.0500
Wholesale trade	69.0100
Retail trade	69.0200

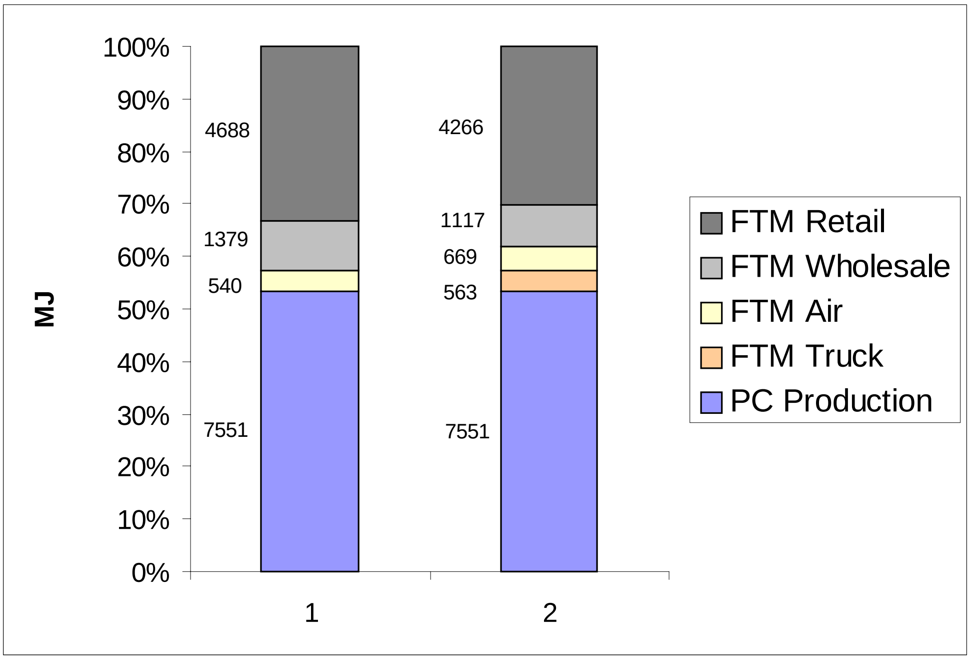
Commodities	**BEA** industry code of the main producer sector
Books	26.0301
Bottled and canned soft drinks	14.2200
Toilet paper	24.0500
Soap and other detergents	29.0201
Electronic Computers	51.0103
Household vacuum cleaners	54.0500
Household audio and video equipment	56.0100
Prerecorded records and tapes	56.0200
Drugs	29.0100
Newspapers	26.0100
Periodicals	26.0200

In the following table we show the primary energy consumption of the production of 1 million $ of each commodity and the corresponding primary energy consumption of the transportation, wholesale and retail sale of the same quantity of commodities in the FTM phase.



The energy consumption related to the transportation, the retail sale and the wholesale (FTM energy requirements) corresponds to a significant portion of the energy required in the total pre-consumer (TPC) phase (TPC = PC + FTM). The percentages shown in the last right column of the table above are also considerably variable, they are not constant fractions of the total pre-consumer phase. For the Electronic Computers Sector, the FTM and PC energy requirements are almost the same.

We then focused on the Electronic Computers Sector. Here below we show the energy consumption in the FTM phase for a control unit and the energy requirement for hits production. The first bar shows the IO results from the BEA (NIPA) data. But the retail and wholesale sector also include some transportation, particularly road (truck) transportation. We therefore subtracted the energy consumption due to this transportation respectively from the retail and wholesale total energy consumption and we added these energy to the external transportation that we previously found. (See second bar in the graphic.



The energy consumption due to transportation in the FTM phase corresponds to 20% of the total FTM energy consumption. The Wholesale and Retail trades are often neglected in LCA and this result shows that at list for energy consumption they play a significant role, even more important than transportation in the FTM phase. Similar results have been found for a large number of other commodities.