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ELECTRONIC PRODUCTS

Life cycle assessments of consumer electronics — are they consistent?

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Abstract
Background, aim, and scope During the last decades, the electronics industry has undergone tremendous changes due to intense research leading to advanced technology development. Multiple life cycle assessment (LCA) studies have been performed on the environmental implications of consumer electronics. The aim of this review is to assess the consistency between different LCA studies for desktop computers, laptop computers, mobile phones and televisions (TVs).
Materials and methods A literature study was conducted covering some key LCA contributions to the consumer electronics field. The focus is primarily on global warming potential during 100 years (GWP100) efficiency in different life cycle phases and secondarily on primary energy usage/electricity usages which are normalised per year to find inconsistencies.
Results The life cycle impact assessment GWP100 results for consumer electronics over the years suggest that most studies are of comparable quality; however, some studies are neither coherent nor transparent. Published LCAs for mobile phone and TV sets are consistent, whereas for laptop and desktop computers, the studies occasionally give conflicting messages.
Discussion The inconsistencies appear to be rooted in subjective choices and different system boundaries and lifetime, rather than lack of standardisation. If included, the amounts of emissions of sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) are crucial to the GWP100 in the various life cycle phases for a desktop using liquid crystal display (LCD) screen. Another important observation is that the MEEuP methodology report/tool underestimates the GWP100 of electronic component manufacturing processes.
Conclusions Between 1997 and 2010, the ISO 14040/44 standards have ensured a rather consistent set of GWP100 results for the studied products. However, the lack of transparency for consumer electronics LCAs sometimes makes benchmarking difficult. It is nevertheless possible to compare new LCA calculations to existing studies. It is also possible to reveal which product studies are consistent with studies of submaterials and subcomponents. In most cases, the GWP100 results for consumer electronics are consistent. Based on the survey of published work, recycling and other end-of-life processes have a tiny share of the total GWP100 score for consumer electronics.
Recommendations and perspectives LCA researchers should as a rule, if possible, make a historical survey of their technical system to establish trends, proportions and relations. Policy makers ought to ask for these surveys when using LCAs for decision support. This charter is necessary as to understand the reasonableness of the results. Additions to the ISO14040/44 LCA standardisation for mass–volume products would be worthwhile as a means of increasing the consistency.

Keywords Consistency · Consumer electronics · GWP100 results · Life cycle assessment · Life cycle inventory

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1 Background, aim, and scope

It is well known that research on environmental problems preferably should be carried out using a multidisciplinary approach, using appropriate tools. As such, life cycle assessment (LCA) has the potential to point out the important issues from an environmental point of view. LCA is, e.g., useful for rather small and distinct product systems or technologies. Recently, this has been shown as different systems such as polyols (Helling and Russell 2009), toys (Muñoz et al. 2009) and mountain huts (Goymann et al. 2008). During the last few decades, the electronics industry has undergone tremendous changes from intense research leading to advanced technology development. LCA requires large amounts of data when applied to complex electronic products involving many technologies. Even so, LCA has been used successfully to develop ecodesign strategies in the electronics industry (Alonso et al. 2003; Gurauskiene and Varzinskas 2006; Yung et al. 2009). Many studies have been conducted on the environmental implications of different consumer electronic technologies with the same function, but no comparison of the consistency of different studies has been carried out. This article presents such an overview of LCA results of some common consumer electronics. The focus is mainly on the results for CO_2 equivalents (CO_2e), expressed as the global warming potential during 100 years (GWP100). This is an indicator that is easy to communicate, whereas other indicators, such as primary energy usage (PEU), are not covered in detail. CO_2 emissions are, moreover, very important as they are one of the factors enhancing the acidification of the oceans (Rockström et al. 2009). The problems of LCA, in general, pointed, e.g., by Reap et al. (2008), will be discussed in light of LCA results for consumer electronics.

2 Materials and methods

2.1 Literature review

This section is an overview of LCA results from studies of certain electronic products produced in high volumes. In order to facilitate a comparison, the global warming potential expressed as CO_2e is used.

2.1.1 LCA studies of laptop PCs

Tekawa et al. (1997) presented LCA results, mixing personal usage and office usage, for a notebook (laptop) computer indicating that the emissions of greenhouse gases in production and use phases were similar. The GWP100 for the production of the main circuit board was approximately 85 kg CO_2e in the lifecycle of a notebook computer. No information was given about weight of product or product parts. The NIRE–LCA software program ver. 2.1 was used for the modelling and the GWP100 for the 1996 Japanese average electricity mix. The GWP100 index of sulphur hexafluoride (SF_6) was not included.

Lu et al. (2006) explored the economic and environmental implications of notebook computer recycling in China (Taiwan). They estimated that during its life cycle, a typical laptop computer emits 51 kg CO_2, 120 g methane and 240 mg N_2O, i.e., 54 kg CO_2e. The weight of the laptop was 2.3 kg, of which 10 wt.% were integrated circuits (ICs) and 15 wt.% was printed wiring board (PWB). Spontaneously, 54 kg for GWP100/p seems rather small, and it is not possible to derive the distribution between life cycle phases. SimaPro ver. 5.0 was used for the modelling which is not transparent.

The ecoinvent database (Ecoinvent database 2008a, b, c) contains life cycle inventory (LCI) data modules for manufacturing, usage and end-of-life of a typical laptop of 3.2 kg. These modules can be combined for a life cycle in, e.g., SimaPro ver. 7.1, as in this paper. Then the use phase contribution to total GWP100, 660 kg, is only around 7% due to LCD manufacturing loadings and particularly nitrogen trifluoride (NF_3) emissions from assembly of the LCD module. The use phase was 4 years and used 190 kW h (Table 1) The main circuit board production emits around 55 kg CO_2e per notebook computer. Over the years, for GWP100, the Intergovernmental Panel on Climate Change (IPCC) has increased the number of gases included. Bearing in mind that NF_3 lacked a GWP100 value in IPCC ver. 2001, the calculation was redone with NF_3 set to zero. Even so, the use phase contribution only increases to 15%, as explained by SF_6 emissions from LCD module assembly and magnesium production.

Swedish Institute of Production Engineering Research (IVF) presented a comprehensive report for the European Commission (IVF 2007a). Several useful facts were reported about laptop computers such as bill of materials (BOM), electricity usages and LCA results. The EuP EcoReport tool was used for the calculations (European Commission 2005).

PE International (2008) showed, upon mixing office and personal usages, that a small laptop of 1.5 kg emits around 410 kg CO_2e for 4 years. The contribution to total GWP100 from the use phase is around two thirds, and the main circuit board emits around 70 kg CO_2e per lifecycle of a notebook computer. Even though the literature reference is a presentation with little transparency, it is reasonable to assume that GaBi LCA software and GaBi databases corresponding to 2008 were used.

From the above, there are not only some possible inconsistencies between the results but also consistencies. Table 1 shows facts which can be used to explain differences between published laptop LCAs.

The consistency will be discussed in Section 4 by performing a normalisation of electricity usage per year.

Table 1 Summary of benchmarking data for laptops

Device and technology, nation, reference, system boundary	Lifetime (years)	Electricity usage in use stage, office (kW h)	PEU in use stage, office (kW h)	Electricity usage in manufacturing (kW h)	PEU in manufacturing (kW h)
Laptop, Europe, IVF (2007a), cradle-to-grave	5	580	1,600	66	350
Laptop PC, Switzerland, Ecoinvent database (2008a, b, c), cradle-to-grave	4	190	610	170	840

2.1.2 LCA studies of desktop computers and peripherals

Several LCA studies of desktop computers have been conducted. One of the earliest was a Japanese study by Tekawa et al. (1997). No "key" product data were presented such as power usage, weight or BOM.

Shortly after this, Atlantic Consulting presented much cited and transparent results for a desktop PC system consisting of monitor, control unit and keyboard (Atlantic Consulting and IPU 1998). One PC system used 1,000 kW h PEU for manufacturing and 880 kW h electricity during its 3-year lifetime, i.e., a considerate dominance of the use phase.

Kim et al. (2001) conducted an LCA for a colour computer monitor. They produced useful figures on material contents. Unfortunately, the absolute figures were omitted, but they reported that for 6 years, the "use stage-operating mode" was 63%, the "use stage-passive mode" 10%, the "cathode ray tube (CRT) assembly" 10%, the "PCB assembly" 7% and "others" 10% of the global warming potential.

Contrary to earlier desktop LCAs, Williams (2004) estimated that for a computer (weight 24 kg), the total energy use of the production is more important (81%) than the usage (19%). A so-called separate hybrid analysis in a global approach was used for modelling. He calculated that a desktop computer with a 17-inch CRT monitor, during 3 years of usage at home, used 1,500 MJ (420 kW h) of electricity. The production has a usage of electricity and direct fossil energy of 1,500 MJ (430 kW h) and 3,300 MJ, respectively. Energy extraction from direct fossil (3,300 MJ) corresponds to approximately 1,200 MJ global average electricity. For the life cycle, using 0.18 kg CO_2e/MJ electricity suggests that the CO_2e emissions are around 760 kg/computer and 32 kg CO_2e/kg computer. It also suggests that the actual distribution for Williams study should be corrected to 65% production and 35% use.

A South Korean study by Choi et al. (2006) in SimaPro ver. 4.0 argued that the component manufacturing was of more importance than use for a Pentium IV PC. However, their study did not present absolute numbers, which limits the value of their estimations. For example, the main board impact per piece or mass is difficult to estimate. The functional unit was 4 years of usage in South Korea and manufacturing and scrapping in the same nation. Electricity usages for homes and offices were 197 and 305 kW h, respectively. The monitor (display) was excluded so eventual SF_6 and NF_3 emissions from the LCD module, in the case of current technology, were also excluded.

The results presented by Williams and Choi et al., blaming mostly manufacturing for the CO_2e emissions, are remarkable considering the "general idea" of CRT desktops.

Zhou and Schoenung (2007) analysed a comparative and transparent LCA of display technologies originally performed by Socolof et al. (2005). "PWB and electronic components" were 4.0 wt.% of a 17-inch CRT monitor (weight 21 kg) and 6.5 wt.% for a 15-inch LCD monitor (weight 5.7 kg). The collected primary and secondary data were imported to the LCA software program "Life-Cycle Design Software Tool". An effective life of 13,547 h (1.5 years) was estimated for both monitors.

The BOM for this study enables a benchmarking with LCI data for PWBs, ICs and other components. The LCD module manufacturing emits SF_6, which partly explains the GWP100 difference between CRT and LCD manufacturing. As noted earlier, the ecoinvent database has also included NF_3 emissions in their LCD assembly LCI model, giving similar effect as SF_6.

IVF (2007b, c) presented a comprehensive report for the European Commission. Several useful facts were reported about personal computers (PCs) such as BOM, electricity usages and LCA results. MEEuP methodology report/tool was used for the modelling (European Commission 2005).

The ecoinvent database (Ecoinvent database 2008d, e, f, g, h, i, j, k, l, m, n) contains LCI data modules for manufacturing, usage and end-of-life of desktops. Assuming 4 years of office use, it is possible to make LCA calculations of desktops using either a 17-inch CRT screen (weight 20 kg) or a 17-inch LCD screen (weight 5.1 kg). The GWP100 for desktops using LCD screens becomes 140% higher than for CRT desktops. The reason is LCD manufacturing loadings and particularly NF_3 emissions from assembly of the LCD module, LCI data used by both LCD flat screens and laptops.

It could be problematic for policy makers that Williams (2004) and Choi et al. (2006), on one hand, and Tekawa et al. (1997), Atlantic Consulting and IPU (1998), IVF (2007b) and the ecoinvent database (Ecoinvent database 2008d, e, f, g, h, i, j, k, l), on the other hand, obtained such different conclusions for life cycle modelling of similar types of desktop computers with CRT screens.

Duan et al. (2009) published the first Chinese LCA study on desktop PCs. The assumption is 50% CRT screens and 50% LCD screens used for 6 years globally but mostly in China. The paper unfortunately avoided to publish any inventory results; it only aggregated Eco-Indicator ’99 scores, which limits the transparency. The CO_2e distribution of manufacturing, use and end-of-life is approximately 40%, 65% and -5%, respectively. This is similar to ecoinvent data for a desktop using 100% CRT screen.

Apple (2009) provided an environmental report for iMac. The report contains some useful data (Table 5), but the transparency for the estimated life-cycle greenhouse emissions is low.

Table 2 shows facts which can be used to explain differences between desktop LCAs.

The consistency of desktop PCs will be discussed in Section 4 by performing a normalisation of electricity usage per year.

2.1.3 LCA studies of mobile phones

Nokia (2005) performed an LCA of a 3G mobile phone using GaBi software. The raw material acquisition and processing together with all the production steps for the populated PWB (including IC production) were around 60% of the total life cycle PEU, which was around 78 kW h (Transport 8 kW h), and the GWP100 was around 14 kg/phone. The electronic components were 48% of the GWP100 value and the “unpopulated” PWBs using AuNi surface treatment were 40% alone. The ICs were only 2.9% of the life cycle GWP100 score for the mobile phone. The PEU trends were very similar to the ones for GWP100.

In a South Korean study, Park et al. (2006) claim that the manufacturing of the raw materials were 59% of a weighted score, the assembly of components and phone 2%, the use stage 38% and the end-of-life 1%.

Frey et al. (2006) presented an ecological footprint analysis of a typical mobile phone weighing 90 grams. The study mentions a PEU distribution very similar to the Nokia (2005) study, but elsewhere, it is too abstract to be useful in the present context of benchmarking.

PE International (2008) showed overview results for a 250 g handheld mobile phone in 2008. The system boundaries were global, e.g., component manufacturing in Asia and transports to the US and Europe. Manufacturing was responsible for 80% of the GWP100 score obtained from the GaBi software.

Bergelin (2008) demonstrated a comprehensive LCA in GaBi software for Sony Ericsson W890 which is a 3G mobile phone.

Table 5 includes a CO_2e result summary for mobile phones. Table 3 presents facts which can be used to explain differences between mobile phone LCAs.

Table 3 shows that the 3G mobile phone LCAs are consistent. The published LCA GWP100 results of mobile phones are thus more consistent than those of desktop and laptop computers.

Table 2 Summary of benchmarking data for desktops

Device and technology, nation, reference, system boundary	Lifetime (years)	Electricity usage in use stage, office (kW h)	PEU in use stage, office (kW h)	Electricity usage in manufacturing (kW h)	PEU in manufacturing (kW h)
CRT display unit for desktop, US, Socolof et al. (2005), cradle-to-grave	1.5	630	2,300	n.a.	5,200
LCD display unit for desktop, Japan/US, Socolof et al. (2005), cradle-to-grave	1.5	240	850	n.a.	580
Desktop PC, CRT screen, Europe, Atlantic Consulting and IPU (1998), cradle-to-grave	3	880	2,800	n.a.	1,000
Desktop PC, CRT screen, USA, Williams (2004), cradle-to-gate	3	420	1,100	430	2,100
Desktop PC, CRT screen, South Korea, Choi et al. (2006), cradle-to-grave	4	305	n.a.	n.a.	n.a.
Desktop PC, CRT screen, Europe, IVF (2007b), cradle-to-grave	6	1,300	3,600	44	270
Desktop PC, LCD screen, Europe, IVF (2007c), cradle-to-grave	6	600	1,700	44	270
Desktop PC, LCD screen Switzerland, Ecoinvent database (2008d, f, g, h, i, j, k, m, n), cradle-to-grave	4	860	2,500	340	2,200
Desktop PC, CRT screen Switzerland, Ecoinvent database (2008d, e, f, g, h, i, j, k, l), cradle-to-grave	4	1,460	5,200	410	2,400

n.a. = not available

Table 3 Summary of benchmarking data for mobile phones

Device and technology, nation, reference, system boundary	Lifetime (years)	Electricity usage in use stage (kW h)	PEU in use stage (kW h)	Electricity usage in manufacturing (kW h)	PEU in manufacturing (kW h)
3G mobile phone, Finland, Nokia (2005), cradle-to-grave	2.5	7.1–9.3	28		42
3G mobile phone, Sweden/China, Bergelin (2008), cradle-to-grave	3.5	6.2	23	12	64

2.1.4 LCA studies of TVs

Aoe (2003) presented life cycle greenhouse gas emissions comparing three types of 32-inch television (TV) technologies: CRT, LCD and plasma display panel (PDP). The JEMAI–LCA LCA software program was used by equipped with original LCI data from Matsushita Product Assessment Support System.

Dodbiba et al. (2008) used LCA to indicate whether the plastic part of a TV should be mechanically recycled or incinerated. They provided a material content declaration for a TV of unknown type in which the share of the "circuit board" was 3.0 wt.%.

The most recent LCA study of TVs was done ambitiously in China (Feng and Ma 2009). Their functional unit was 10,000 units of colour TVs used in China 8 h /day for 300 days/year in 10 years. Although a relatively detailed and transparent LCA, it is not clear how the electronic components were modelled. The authors used Dodbiba et al. (2008) to estimate the material shares, e.g., electronics 3.0 wt.%. The study contains many recent Chinese LCI data for electricity, steel, copper, aluminium and glass production.

Barba-Gutierrez et al. (2008) used LCA methodology to study the implications of e-waste transport as a consequence of the waste treatment directive WEEE. Their research explored whether recycling and long transports would be the preferred option compared to landfill. PCs and TV sets were part of the scope. The research is of limited value for the purpose of this article. The paper includes rough material compositions of a TV set and a computer weighing 15 and 23 kg, respectively.

Barba-Gutierrez et al. (2009) presented Eco-Indicator'99 scores for TV sets, cell phones and computers based on their material content.

Table 4 presents facts which can be used to explain differences between TV LCAs.

A summary of the results from the studies covered in this review is given in Table 5.

3 Results

Table 5 gives a summary of the studies covered in this literature review, which by no means claims to be exhaustive. The carbon intensity and the distribution between life cycle phases have been used as indicators of consistency.

4 Discussion

The consumer electronics product groups in the present paper have different functions and cannot strictly be directly compared. They are, moreover, produced and used in different geographical locations and are thus not equal. The use phase can occasionally be benchmarked by using a common electricity mix, and the manufacturing phase can be normalised per year if the lifetime assumption is known. However, few studies allow such benchmarking. It is therefore difficult to judge whether the life cycle emissions of CO_2e per product or per mass are reasonable. Moreover, it is important to understand if the published LCI/life cycle impact assessment (LCIA) results of electronic components are reasonable in comparison to the electronic product LCI/LCIA results and vice versa.

The CO_2e emissions per mass of microchip is dominantly decided by the area (area mass) of the die, m_{die}, inside the chip. The following algorithm, developed by Huawei Technologies, expresses the (global average) carbon footprint for any IC: m_{die} (mg) × 0.0308 (kg CO_2e/mg) + m_{die} (mg) × 0.0066 (kW h/mg) × 0.6 (kg CO_2e/kW h). The first factor is based on Boyd et al. (2009).

However, most of the papers studied here contain very little information about functional die areas or die masses which prevent a deeper benchmark analysis.

Table 4 Summary of benchmarking data for TVs

Device and technology, nation, reference, system boundary	Lifetime (years)	Electricity usage in use stage (kW h)
TV, CRT, Japan, Aoe (2003), cradle-to-grave	8	1,800
TV, PDP, Japan, Aoe (2003), cradle-to-grave	8	2,600
TV, LCD, Japan, Aoe (2003), cradle-to-grave	8	1,700
TV, CRT, China, Feng and Ma (2009), cradle-to-grave	10	2,900

Table 5 Summary of life cycle CO_2e emissions of desktops, laptops, mobile phones and TVs

Device and technology, nation, reference, system boundary	Weight (kg)/piece	Kg CO_2e/piece	kg CO_2e /kg	% Production and transports	% Use	% End-of-life
CRT display unit (Colour computer monitor), South Korea, Kim et al. (2001), cradle-to-grave	23	n.a.	n.a.	25	75	0
CRT display unit for desktop, US, Socolof et al. (2005), cradle-to-grave	21	690	33	34	66	0.2
LCD display unit for desktop, Japan, Socolof et al. (2005), cradle-to-grave	5.7	590	100	71	29	0.1
Laptop PC, Japan, Tekawa et al. (1997), cradle-to-grave	n.a.	260		44	53	3
Laptop PC, China, Lu et al. (2006), cradle-to-grave	2.3	54	23	n.a.	n.a.	n.a.
Laptop, Europe, IVF (2007a), cradle-to-grave	2.5	360	140	26	74	-0.3
Laptop PC, Switzerland, Ecoinvent database (2008a, b, c), cradle-to-grave	3.2	660	210	93	6.6	0.1
Laptop, global, PE International (2008), cradle-to-grave	1.5	410	270	41	63	-5
Desktop PC, CRT screen, Japan, Tekawa et al.(1997), cradle-to-grave	n.a.	750	n.a.	18	89	0.2
Desktop PC, CRT screen, Europe, Atlantic Consulting and IPU (1998), cradle-to-grave	22	650	30	29	68	3
Desktop PC, CRT screen, USA, Williams (2004), cradle-to-gate	24	870	36	71	29	Not included
Desktop PC, CRT screen, South Korea, Choi et al. (2006), cradle-to-grave	n.a.	n.a.	n.a.	91	8	1
Desktop PC, CRT screen, Europe, IVF (2007b), cradle-to-grave	27	660	24	12	87	1
Desktop PC, LCD screen, Europe, IVF (2007c), cradle-to-grave	17	340	20	22	78	0.3
Desktop PC, LCD screen Switzerland, Ecoinvent database (2008d, f, g, h, i, j, k, m, n), cradle-to-grave	18	3,300	180	97	3	0.1
Desktop PC, CRT screen Switzerland, Ecoinvent database (Ecoinvent database, 2008d, e, f, g, h, i, j, k, l), cradle-to-grave	33	1,300	41	36	64	0.2
Desktop PC, China, Duan et al. (2009), cradle-to-grave	n.a.	n.a.	n.a.	40	65	-5
Desktop, US, Apple (2009), cradle-to-grave	8.3	870	105	49	50	1
3G mobile phone, Finland, Nokia (2005), cradle-to-grave	0.08	14	180	71	29	~0
Handheld mobile phone, global, PE International (2008), cradle-to-grave	0.25	30	120	93	13	-7
3G mobile phone, Sweden/China, Bergelin (2008), cradle-to-grave	0.08	20	250	80	20	~0
HSDPA phone, Confidential (2009), cradle-to-grave	0.11	22	200	89	11	~0
TV, CRT, Japan, Aoe (2003), cradle-to-grave	59	1,000	17	20	80	~0
TV, PDP, Japan, Aoe (2003), cradle-to-grave	28	1,600	57	29	71	~0
TV, LCD, Japan, Aoe (2003), cradle-to-grave	21	1,100	52	28	72	~0
TV, CRT, China, Feng and Ma (2009), cradle-to-grave	30	1,100	36	32	68	0.5

n.a. = not available

4.1 Inconsistencies

In this paper, several major inconsistencies were found, and some can partly be analysed by normalising electricity/energy usages and by checking CO_2e flows.

First, the laptop PC from China (Taiwan) seems suspiciously low in CO_2e, 54 kg/piece. ICs were 10 wt.% alone, and they typically have CO_2e intensities of at least 1,000 kg CO_2e/kg. The Japanese notebook (Tekawa et al. 1997), on the other hand, has a reasonable CO_2e score per piece, 260 kg/p. This assumes similar weight and share of PWBs and ICs as for the Taiwanese laptop.

Second, the ecoinvent laptop (Ecoinvent database 2008a, b, c) is inconsistent with IVF laptop (IVF 2007a) regarding life cycle phases as shown by Fig. 1. This is clarified by normalising the electricity or PEU in Table 1. The PEUs are pointing in different directions for the manufacturing and use phases.

Third, for CRT desktops, Choi et al. (2006) claim that the "pre-manufacturing" (monitor excluded) is by far the most important life cycle phase for a desktop in South Korea.

Forth, having a global perspective, Williams arrived at the same conclusion as Choi et al. (2006). These two differ from other CRT desktop case studies as shown in Fig. 2.

This is awkward as it could give the impression that LCA cannot be used to support ecodesign. But, on the other hand, the improved understanding of the magnitude of manufacturing impacts, together with generally decreased power usages, could have changed the importance of the life cycle phases. Nevertheless, two later analyses (IVF 2007b and Ecoinvent database 2008d, e, f, g, h, i, j, k, l) contradict that trend as they clearly point out the use phase for CRT desktops. This is also evident from normalisation per year for PEU/electricity in Table 2.

The fifth is the ecoinvent desktop using LCD screen (Ecoinvent database 2008d, f, g, h, i, j, k, m, n), which has a much higher share of manufacturing GWP100 than Duan et al. (2009), even though the latter used 50% LCD screens and 50% CRT screens. For the ecoinvent LCI data set

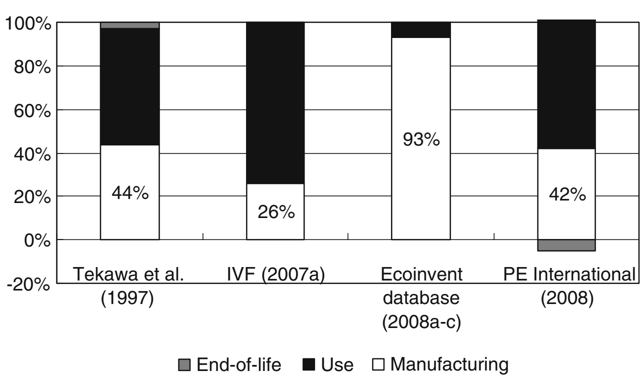

Fig. 1 CO_2e shares of life cycle phases for laptop computers

"assembly, LCD module/GLO U", the amounts of emissions of SF_6 and especially NF_3 are crucial to the overall GWP100 result and the distribution between life cycle phases for a desktop using LCD screen. As a result, for computer subparts, the ecoinvent LCD screen manufacturing (4,400 kg CO_2e/p) is inconsistent with the LCD screen manufacturing results by Socolof et al. (2005), 420 kg CO_2/p. The main reason is the NF_3 emissions from LCD assembly. Figure 3 shows the inconsistency of desktop computers using LCD screens.

Sixth, Table 2 shows for desktop PC with LCD monitors that IVF (2007c) and Ecoinvent database (2008d, f, g, h, i, j, k, m, n) have dramatically different PEUs for the manufacturing stage, underlining that the MEEuP methodology report/tool (European Commission 2005) underestimates electronic component manufacturing processes. This is evident from the comparison between IVFs and ecoinvent LCAs of CRT and LCD desktops.

Seventh, Table 2 also demonstrates that the CRT LCA by Socolof et al. (2005) is not consistent with LCAs for desktop CRT systems which include CRT units.

4.2 Consistencies

The CRT screen manufacturing show resemblance, 230 kg CO_2e/p for Socolof et al. (2005) and 270 kg CO_2e/p from ecoinvent (Ecoinvent database 2008e).

For CRT PCs, as shown in Table 2, Williams (2004) and Ecoinvent database (2008d, e, f, g, h, i, j, k, l) have similar PEU per year for the manufacturing stage.

For LCD PCs, as shown in Table 2, Socolof et al. (2005) for LCD unit is consistent with Ecoinvent database (2008d, f, g, h, i, j, k, m, n) for a whole PC system including LCD unit.

4.3 Electronic component checks

Moreover, when Dodbiba's material content information (Dodbiba et al. 2008) was added into the LCA software SimaPro7 and assuming 8 years of usage (Aoe 2003) and weight 59 kg/CRT TV, then the result became 880 kg CO_2e. This can be compared to Aoe's 1,000 kg CO_2e.

Although not many data were found, it is likely that the CO_2e share values, e.g., around 11% for Chinese TV by Feng and Ma (2009) for "PWB and electric components" for all products in the present investigation, will be higher than their weight share, e.g., 3 wt.%, Feng and Ma (2009). Providing a kind of validation, electronics, in form of the average of 34 advanced populated PWBs for telecom products, could have a CO_2e load of around 140 kg/kg (coefficient of variance 48%) and a cumulative energy demand of 2,500 MJ/kg. This was calculated in SimaPro7 LCA software at the authors company (Huawei Technologies

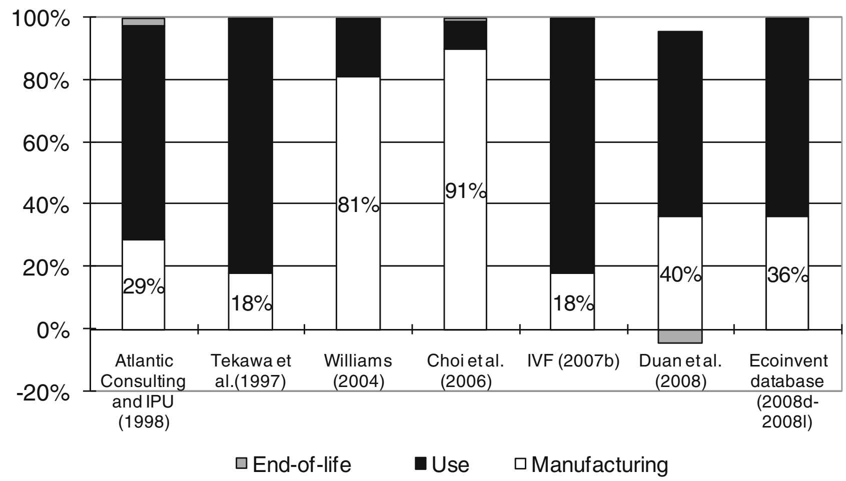

Fig. 2 CO_2e shares of life cycle phases for desktop computers using CRT screen

2009). That is, 0.9 kg "PWB and electric components" would emit around 130 kg CO_2e.

IVF (2007b) mentioned that their office desktop PC (excluding display) contains around 1.4 kg electronics emitting 96 kg CO_2e, i.e., 69 kg/kg. Microchips emitted at the most 420 kg/kg and, using the previously mentioned algorithm, 1,700 kg/kg IC. This indicates again that MEEuP methodology report/tool underestimates component manufacturing. Moreover, IVF's 17-inch LCD display manufacturing seems underestimated with 7.5 kg/kg compared to 71 kg/kg (Socolof et al. 2005). Also CRT display manufacturing by IVF is noticeably lower than ecoinvent and Socolof et al. (2005).

For mobile phones and TVs, the LCAs seem to be more consistent than PCs. However, the ecoinvent database ver. 2.1 lack unit processes, enabling mobile phone and TV LCAs to be conducted in the same way as for desktops and laptops. It is an open question whether LCAs of mobile phones and TVs, carried out in the MEEuP methodology report/tool (European Commission 2005) or in the ecoinvent database, would maintain the apparent consistency.

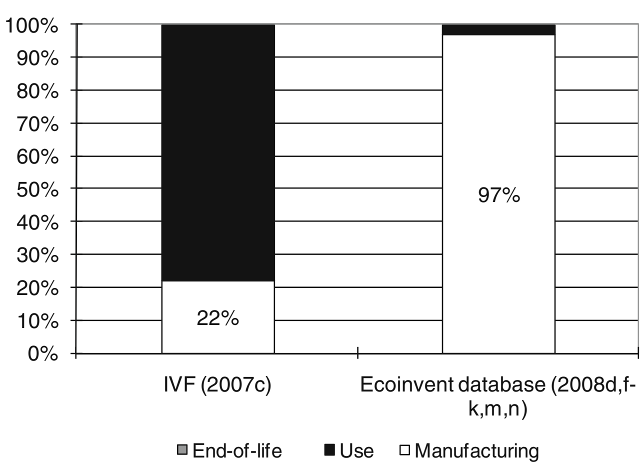

Fig. 3 CO_2e shares of life cycle phases for desktop computers using LCD screen

4.4 Harmonisation

This paper echoes Reap et al. (2008) which continued the discussion about selection of functional unit and unit process boundary in goal&scope. For LCI, the major controversial issues are to which degree allocation, cutoff and local technical uniqueness affect the precision. We have commented on the unit process boundary and the local technical uniqueness by mentioning how the ecoinvent database and MEEuP methodology report/tool (European Commission 2005) play a role in arriving at the results for several products. Anyway, a proper LCA should identify similar hotspots for similar technologies (e.g., laptops) if the functional unit is the same.

The LCA method cannot be criticised for the inconsistencies, as partly the explanation lies in which subjective choices the LCA practitioner is forced to make. For example, the choice of effective life, manufactured life and operating pattern for computers can greatly affect the relative importance of the use phase. The choice of LCI database has definitely affected the degree of consistency too.

Also Scharnhorst (2008) identified the issue of having a well-balanced LCI for electronics products. Product category rules are one means to this end. Choi et al. (2006) is an example of a non-balanced LCI of a desktop PC excluding the (CRT/LCD) monitor which earlier LCAs (Socolof et al. 2005) had shown to be important. It is necessary but not sufficient to have transparent and unit process-based LCI data sets.

Standardisation for product groups would not make LCA results from two different practitioners exactly comparable, but it would probably eliminate the risks of omitting important unit processes (Choi et al. 2006).

5 Conclusions

The lack of transparency of LCA studies of different consumer electronics makes benchmarking somewhat difficult. It will nevertheless be possible to relate new LCA calculations to some of the existing studies. When BOMs are available, it is also feasible to reveal which product studies are incoherent with other LCA studies of submaterials and subcomponents. All in all, published GWP100 results for TVs and mobile phones seem to be consistent to a larger degree than desktops and laptop computers. Based on the survey of published work, recycling and other end-of-life processes have a tiny share of the total GWP100 score for consumer electronics.

6 Recommendations and perspectives

Public LCAs of electronic products and others have been accused of being biased and inadequately transparent for successful communication. The major difficulty is getting a grip on the magnitude of the flows involved in the supply chain, and moreover, the maturity of existing data is perceived as very low. It is especially important to reach a wider consensus of (1) functional units, (2) allocation and (3) system boundary selection. As a rule, LCA researchers, if possible, should make a historical survey of their technical system to establish trends, proportions and relations. This survey is necessary as to understand the reasonableness of the result. Policy makers ought to ask for these surveys when using LCAs for decision support.

The International Electronic Manufacturing Initiative (iNEMI) in the US is developing a noncompetitive process to do consistent LCA, thus reducing the current redundant effort. The idea is that several companies agree on the ranges and algorithms, procedures for update and for carbon footprint for the most important LCI modules which make up the life cycle of ICT products.

Moreover, Huawei has recently taken some initiative in Europe (within European Telecommunications Standards Institute) along these lines by suggesting LCA standards for telecom equipment. These harmonisation efforts will likely improve the speed at which LCAs of complicated electronic products can be performed, as well as the credibility of LCAs. In the meantime, more LCA results, which are not presented in the present charter, should be added.

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Ecoinvent database (2008c) Name in db: disposal, laptop computer, to WEEE treatment/CH U

Ecoinvent database (2008d) Name in db: desktop computer, without screen, at plant/GLO U

Ecoinvent database (2008e) Name in db: CRT screen, 17 inches, at plant/GLO U

Ecoinvent database (2008f) Name in db: keyboard, standard version, at plant/GLO U

Ecoinvent database (2008g) Name in db: mouse device, optical, with cable, at plant/GLO U

Ecoinvent database (2008h) Name in db: use, computer, desktop, with CRT monitor, office use/RER U

Ecoinvent database (2008i) Name in db: disposal, mouse device, optical, with cable, to WEEE treatment/CH U

Ecoinvent database (2008j) Name in db: disposal, keyboard, standard version, to WEEE treatment/CH U

Ecoinvent database (2008k) Name in db: disposal, desktop computer, to WEEE treatment/CH U

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