TRANSLATING PRODUCT SPECIFICATIONS INTO ENVIRONMENTAL EVIDENCE – CARBON FOOTPRINT MODELS EXPLAINED ON THE EXAMPLE OF A NETBOOK, A CONSUMER LAPTOP AND AN ULTRABOOK

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Abstract: In a complex industry such as the electronics sector Life Cycle Assessments are still challenging. This holds true in particular for small and medium-sized enterprises with rarely any knowledge in LCA and limited resources to undertake comprehensive LCA studies. This paper describes the approach of the FP7 funded project LCA to go, which developed simplified online tools for SMEs to assess products from a selection of sectors on their own. The webtools build on embedded LCA data models and a translation of environmental impacts (Key Environmental Performance Indicators) into the technical terms found typically in the specification of computer products. As this spec has to be defined by a computer assembler anyway, he is aware of almost all the required entry data. This approach is demonstrated by establishing 3 benchmark laptop products, which can be used by SMEs to compare own designs with conventional laptops. Chosen benchmarks are a netbook, a consumer laptop 15,6" and a business ultrabook 14". The paper outlines the methodology and shows quantified results for these 3 benchmark products. Some remaining challenges will be discussed, such as product lifetime and modelling end-of-life. This approach is not intended to replace a detailed LCA or carbon footprint study compliant with ISO 14040 or 14067, but has to be understood as an entry-level for SMEs to Life Cycle Assessments.

1. INTRODUCTION

Life Cycle Assessment (LCA) is considered as the most advanced tool for improving the environmental performance of products. The flip side of the coin is, that LCA is also a very complex approach, typically too complex, time consuming and costly for a small and medium-sized enterprise (SME). The project "LCA to go - Boosting Life Cycle Assessment Use in European Small and Medium-sized Enterprises: Serving Needs of Innovative Key Sectors with Smart Methods and Tools" was kicked off in January 2011 with the vision to develop a methodology embedded in a free webtool, which lowers the entry barrier to life cycle thinking significantly (see [1]). The main approach to do that, was a translation of LCA terms and environmental terms into technical terms led by the insight, that "reference flow", "elementary flow", "system boundaries", or "eutrophication" are no terms with which SMEs are familiar at all. A computer assembler however is familiar with terms such as HDD capacity, memory, CPU performance and screen sizes. For this reason the LCA to go project embedded in its webtool (http://tool.lca2go.eu) parameterized carbon footprint models, which translate these technical parameters into carbon footprint values and cut-off all minor parts, which do not significantly contribute to the overall impacts of computers. This approach however means, that the tools are customized for very specific applications and cannot be used as universal tools.

The identification of the most important parts, components and sub-assemblies of computer products was done on the example of a full assessment of MicroPro's iameco v2 prototype. The analysis unveiled, that among the approx. 137 sub-assemblies and already aggregated component families only 10-12 entries contribute with a share of well beyond 80% of the total production related carbon footprint (see Figure 1).

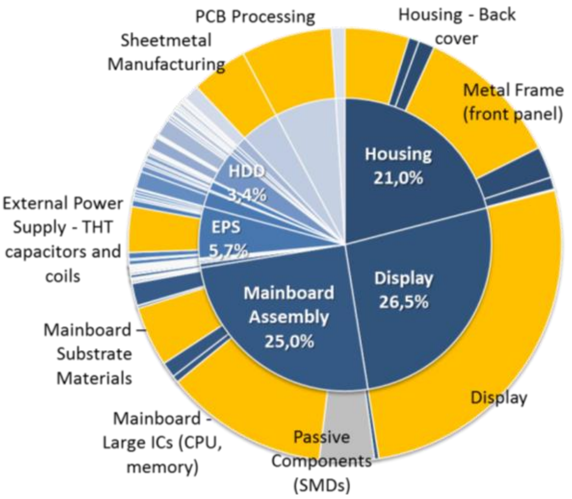

Figure 1: Carbon Footprint of computer production – share of main assemblies and components

The usability of the LCA to go tool for an SME is comprehensively documented by Ospina et al. [2].

The following examples show, how computer products can be modelled in the LCA to go tool by the user, solely based on available information. They are not examples from SMEs, but SMEs can do it similarly for their own products or brandname products refurbished by them.

2. BENCHMARK PRODUCT: NETBOOK

The archetype for a typical netbook is the Acer C270-2848 Chromebook from the Amazon Bestseller list as of February 2014 (retail price 199 USD). The following assessments are not meant to exactly assess this specific model, but the assessment follows its specification where possible as something as an "average netbook specification" hardly can be defined. Therefore the "bestseller approach" has been chosen to identify a typical representative of netbooks.

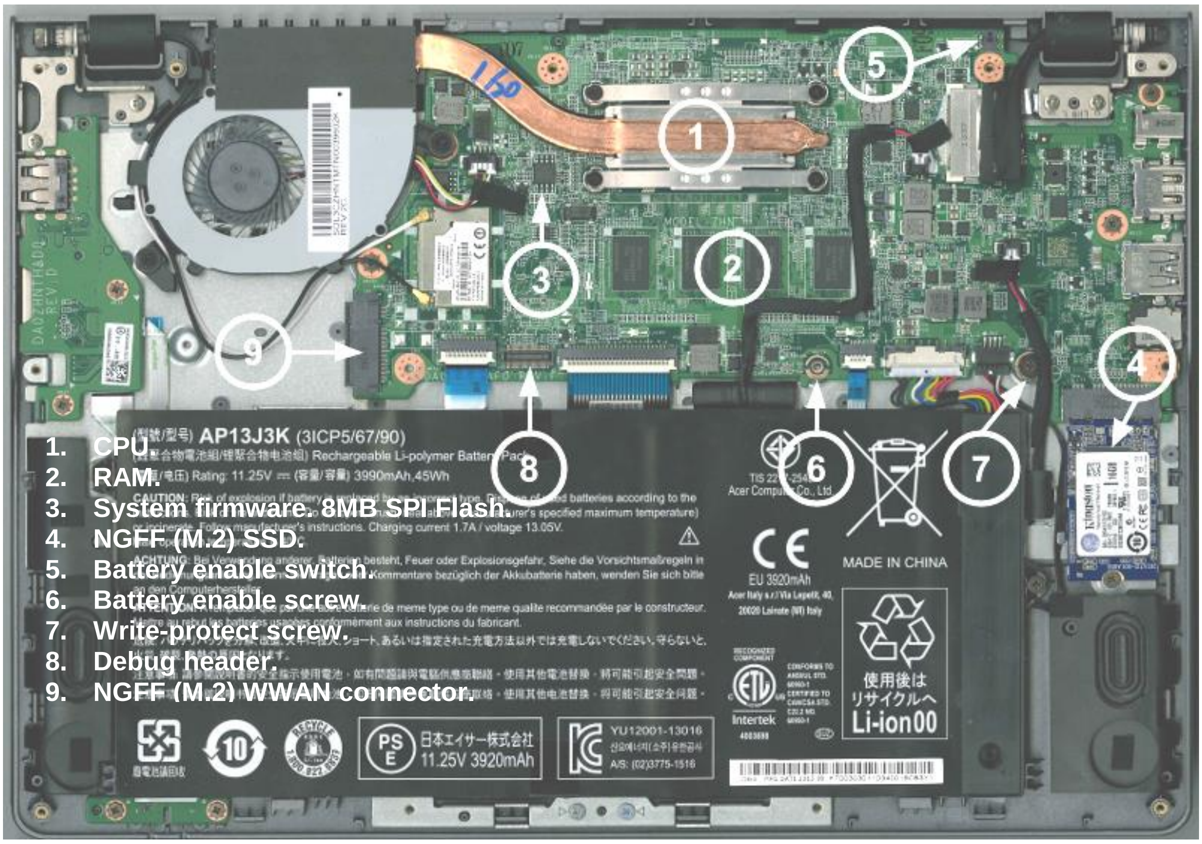

Figure 2: Acer C720 Chromebook inner parts [3]

2.1. Specification

To establish the manufacturing phase entries the following list of parameters are fully sufficient, all of them can be taken from publicly available information about the aforementioned archetype from Acer or estimated based on a non-destructive optical inspection of the product (see figure 1 as an illustration, which optical impression is sufficient). Some data entries, such as mainboard size is usually

not given in a specification but can easily be measured. Inner count of mainboard layers is more difficult to obtain and therefore is already embedded in the printed circuit board model of LCA to go. Data consequently can be compiled within few minutes.
The first two entries are the default entries of the LCA to go tool, a typical use lifetime of computer products of 4 years and a reasonable Annual Device Failure Rate of 10% per year (technical failures and accidental damages terminating the product life).

Table 1: Netbook specification

Lifetime	4 years
Annual Device Failure Rate	10%
Display	LCD
Display Size	11.6 Inches
Display Ratio	16:9
Processor	1.4 GHz Intel Celeron
Processor Count	Dual-core
Memory	2 GB DDR3L SDRAM
Flash Memory Size	16 GB
Hard Drive	16 GB SSD
Graphics Coprocessor	Intel HD Graphics
Wireless Type	802.11 abg
No. of USB 2.0 Ports	1
No. of USB 3.0 Ports	1
HDMI port	1
Audio-out Ports	1
Battery	Li-ion
Battery Capacity	45 Wh
Housing Plastics PC/ABS	Estimated 400 g PC/ABS
Estimated Mainboard dimensions	19cm x 8cm
External power supply	Maximum output rating 65 W
Tantalum capacitors	2 units (3.5x2.8mm)

This specification has to be entered in the LCA to go tool as seen in Figure 3. The smartness of the approach is, that the complexity of a laptop product, which easily consists of 1,000 individual components is shrunk down to 14 most important data entries, which are modelled through technical parameters.

Part	Material/Component	Quantity	Unit
Housing & internal structural elements	PC/ABS	400.00	g
Display	LCD, edge lit, 250 cd/m^2	370.95	cm^2
Printed Circuit Board Assemblies	Laptop mainboard (270 cm^2)	0.56	units
Tantalum capacitors	SMD, case size B, 3.5x2.8mm	2.00	units
Memory	DRAM, DDR3, 30 nm, 2Gb/chip	2.00	GB
Processor	2 cores, application: mobile	1.00	units
Storage	NAND Flash, 20nm, 32Gb/chip and above	16.00	GB
Connectivity	WLAN	1.00	units
Connectivity	USB	2.00	units
Connectivity	HDMI	1.00	units
Power supply	Power Supply	65.00	VA output rating
Cables	cable	60.00	g
Battery	battery (Li-ion)	45.00	Wh Capacity
Memory	NAND Flash, 20nm, 32Gb/chip and above	16.00	GB

Figure 3: Data entries for the manufacturing phase of a netbook

2.2. Distribution

The distribution scenario reflects transport by plane from East Asia to Europe. Transport by plane is a worst case scenario. Transport by container ship would yield a significantly lower impact at longer transport times, which is critical for new product models.
Weight of the packaged product is approximately 3 kg.

Table 2: Netbook distribution scenario

Shipping distance	9200 Km
Packaging estimated	700 g Corrugated board box

2.3. Power consumption

For generic use phase entries of laptop products power consumption averages for the appropriate class of laptops can be taken from EU EnergyStar databases [4] under the assumption, that Energy Star covers a significant market share and that the average of the registered products might come close to a realistic market average, although there is the risk of underestimating power consumption with this approach.
The time-per-mode model is readily implemented in the LCA to go tool. As the Energy Star database does not yet cover short idle values, these are approximated with 1.5times power consumption in long idle, according to supplementary information published in the course of revising Energy Star criteria.
For the exemplary assessment in this paper however real declared data for an Acer Chromebook is taken, approximating short-idle with 1.5 times long idle power consumption.

This approach neglects the fact, that in on-mode power consumption is significantly higher but as there is no standard to measure on-mode power consumption the TEC (Total Energy Consumption) approach of the Energy Star specification is considered the best possible approach.
Carbon Footprint of power consumption is modelled with the EU power grid mix.

Table 3: Power consumption Acer Chromebook according to EU Energy Star database

Mode	Avrg. power consumption	Time in this mode
Power off	0.2 W	25%
Power sleep	0.4 W	35%
Power long idle	5.0 W	10%
Power short idle	(7.5 W)	30%

Table 4: Netbook Carbon Footprint and selected material consumption results

	CF	Cu	Au	Ta
	kg CO_2-eq	g	g	g
TOTAL per product lifecycle	119.44	61.93	0.02	0.03
MANUFACTURING	54.74	71.14	0.03	0.03
Housing & internal structural elements	1.74	-	-	-
Display	6.49	-	-	-
Printed Circuit Board Assemblies	5.02	15.18	0.01	-
Tantalum capacitors	-	-	-	0.03
Memory	5.25	-	0.01	-
Processor	8.00	-	-	-
Storage	2.07	-	0.00	-
Optical Disc Drive	-	-	-	-
Connectivity	0.67	-	0.00	-
Power supply	4.52	19.50	-	-
Cables	0.25	30.00	-	-
Battery	15.75	-	-	-
Overhead miscellaneous parts	4.98	6.47	0.00	0.00
DISTRIBUTION	30.47	-	-	-
Packaging	1.06	-	-	-
Transport	29.41	-	-	-
USE	35.33	-	-	-
Power consumption	35.33	-	-	-
Replacement	-	-	-	-
END-OF-LIFE	-1.10	-9.22	0.00	-
Reuse	-	-	-	-
Recycling	-1.10	-9.22	0.00	-

2.4 End of life

The LCA to go tool provides a default end-of-life, i.e. recycling scenario, which considers a 50% collection rate and credits the share of typically recycled metals. For the benchmark product this scenario remains unchanged. Reuse is not considered.

2.5 Results of the assessment

The results of the assessment for a netbook with the configuration of an Acer C270-2848 Chromebook show that the total life cycle carbon footprint of the Acer Chromebook is 119 kg CO2-eq. (Table 4)..
The results comprise the Carbon Footprint over the whole modelled life cycle and resource consumption values for selected metals, but the latter only for selected highly relevant components, not as a 100% declaration. The purpose of these partial material declaration values is a comparison of different product and lifetime concepts, which will result in a "minimum material saving" for the stated metals.
The result table also shows, that the entry of tantalum capacitors only counts towards the tantalum consumption, not towards the carbon footprint: Tantalum capacitors just as other passive components are not assessed individually, but covered with a 10% overhead on all production entries ("overhead miscellaneous parts").

3. BENCHMARK PRODUCT: CONSUMER LAPTOP 15,6"

3.1 Specifications

Specifications follow the Toshiba Satellite C55-A5245 from the Amazon Bestseller list as of February 2014 (retail price 449 USD).
In this case it has to be taken into account, that the mainboard is not rectangular, and will not provide optimal coverage on the substrate panel. Cut-off losses are considered substantial. Even worse, for the Life Cycle Assessment, what is cut off goes through the complete PCB process before, so has to be considered. Only calculating with the final PCB area neglects these cut-offs.

Figure 4: Toshiba C55s motherboard shape

Table 5: Consumer Laptop specification

Lifetime	4 years

Annual Device Failure Rate	10%
Display Material	LCD
Display Size	15.6 Inches
Display Ratio	16:9
Processor	Intel Celeron Processor 1037U
Processor Count	Dual-core
Memory	4 GB DDR3 SDRAM
Flash Memory Size	16 GB
Hard Drive	500 GB HDD
Graphics Coprocessor	Intel HD Graphics
Wireless Type	802.11 b/g/n
Number of USB 2.0 Ports	3
HDMI port	1
VGA	1
Audio-out Ports	1
Battery	Li-ion
Battery Capacity	48 Wh
Housing Plastics PC/ABS	Estimated 500 g
Estimated Mainboard dimensions	17,6cmx24,7cm (23%cut-offs)
External power supply	Maximum output rating 45 W
Tantalum capacitors	1 unit (7.3x4.3mm)

3.2 Distribution

The distribution scenario reflects transport by plane from East Asia to Europe. Weight of the packaged product is approximately 3 kg.

Table 6: Consumer Laptop distribution scenario

Shipping distance	9200 Km
Packaging estimated	700 g Corrugated board box

3.3 Power consumption

Power consumption values used for the exemplary calculation are those stated in the EU EnergyStar database for Toshiba Satellite C55 products.

Table 7: Power consumption Toshiba Satellite C55 according to EU Energy Star database

Mode	Avrg. power consumption	Time in this mode
Power off	0.5 W	25%
Power sleep	0.8 W	35%
Power long idle	7.3 W	10%
Power short idle	(11.0 W)	30%

3.4 End of life

Default entries for recycling. No reuse / repair considered.

3.5 Results of the assessment

The results of the assessment for a consumer laptop with the configuration of a Toshiba Satellite C55 show that the total life cycle carbon footprint is 155 kg CO2-eq..

Table 8: Consumer Laptop Carbon Footprint (aggregated results)

	CF
	kg CO_2-eq
TOTAL per product lifecycle	154.91
MANUFACTURING	72.76
DISTRIBUTION	30.47
USE	53.29
END-OF-LIFE	-1.61

4. BENCHMARK PRODUCT: BUSINESS LAPTOP 14”, ULTRABOOK

4.1 Specifications

The specifications follow the Lenovo ThinkPad T440 20B6005EUS from the Amazon Bestseller list as of February 2014 (retail price 1.283 USD). According to a study by IDC average lifetime of business laptops is 29 months [5]. To account for the usually higher reliability of business products, the default Annual Failure Rate of 10% is reduced to 7,5%, which is significantly less than the failure rates stated in the IDC paper. However, for the simplified LCA it is important, which rate of failures terminates the product life. Those failures, which are fixed usually should be reflected in the repair scenario embedded in the LCA to go tool. For the sake of simplicity, no such repair is modelled here and cut-off.

Table 9: Business Laptop specification

Lifetime	2.42 years
Annual Device Failure Rate	7.5%
Display Material	Active Matrix TFT Colour LCD
Display Size	14 Inches
Display Ratio	16:9
Processor	Intel core i5-4300U Processor
Processor Count	Dual-core
Memory	4 GB DDR3L SDRAM
Flash Memory Size	64 GB-129 GB
Hard Drive	500 GB HDD / 16 GB SSD
Graphics Coprocessor	Intel HD Graphics
Wireless Type	802.11a/b/g/n/ac
Number of USB 2.0 Ports	2
Number of USB 3.0 Ports	2
VGA	1
Audio-out Ports	1
Battery	Li-ion
Battery Capacity	46.40 Wh
Housing Plastics PC/ABS	300 g
Housing Magnesium	300 g (73 kg CO2-eq/kg)
Estimated Mainboard dimensions	19.7cmx33.5cm (45%cut-offs)
External power supply	Maximum output rating 45 W

Figure 5: Lenovo ThinkPad T440 motherboard shape

4.2 Distribution

The distribution scenario reflects transport by plane from East Asia to Europe. Although a packaged ThinkPad actually weighs less than the other two benchmark products, for a coherent assessment of generic benchmarks a similar weight of the packaged product is assumed to be 3 kg.

Table 10: Business Laptop distribution scenario

Shipping distance	9200 Km
Packaging estimated	700 g Corrugated board box

4.3 Power consumption

Power consumption values used for the exemplary calculation are those stated in the EU EnergyStar database for Lenovo ThinkPad T440 products.

Table 11: Power consumption Lenovo ThinkPad T440 according to EU Energy Star database

Mode	Avrg. power consumption	Time in this mode
Power off	0.4 W	25%
Power sleep	0.6 W	35%
Power long idle	3.8 W	10%
Power short idle	(5.7 W)	30%

4.4 End of life

Business products typically are more often channelled to appropriate recycling than consumer products. Therefore the collection rate for the business laptop is adjusted from the default value of 50% collection to 80% collection.
No reuse or repair is considered.

Table 12: Business Laptop Carbon Footprint (aggregated results)

	CF
	kg CO_2-eq
TOTAL per product lifecycle	144.28
MANUFACTURING	98.08
DISTRIBUTION	30.47
USE	18.43
END-OF-LIFE	-2.70

4.5 Results of the assessment

The results of the assessment for the Lenovo ThinkPad T440 as a bestseller example for business laptops show a total Carbon Footprint of 144 kg CO2-eq..

5. PRODUCT COMPARISONS

The main purpose of modelling a benchmark product actually is to compare own product designs or business models targeting e.g. at repair, refurbishment and reuse with these benchmarks.

5.1 Results

To illustrate a comparison with the LCA to go tool Figure 6 and 7 depict the Carbon Footprint of all three benchmark products for the full life cycle and per year of use. This comparison neglects the fact, that the functionality of the three products is different, so actual comparability is limited. According to this exemplary calculation the total carbon footprint of a typical netbook is 119 kg CO2-eq, of a typical consumer laptop 155 kg CO2-eq. and of a business laptop is 144 kg CO2-eq.,.

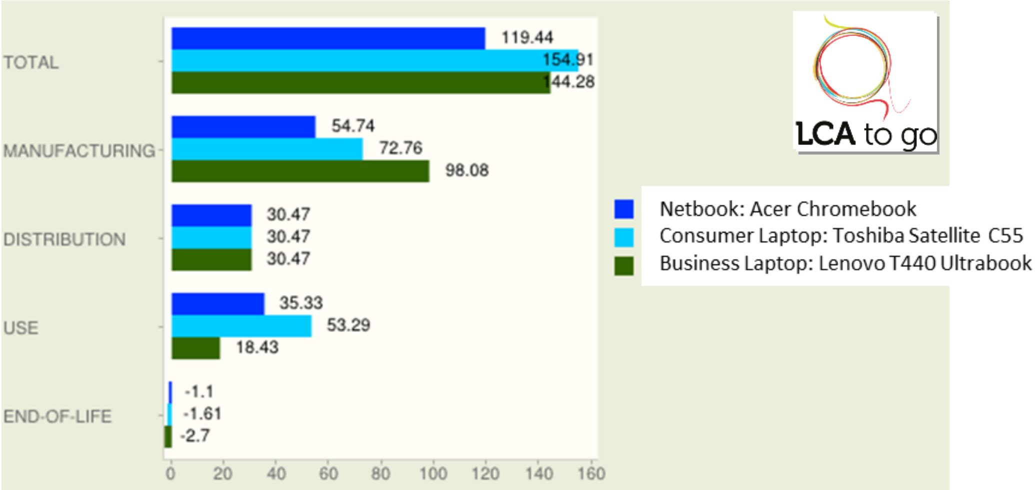

Figure 6: Carbon Footprint (in kg CO2-eq,) per life cycle

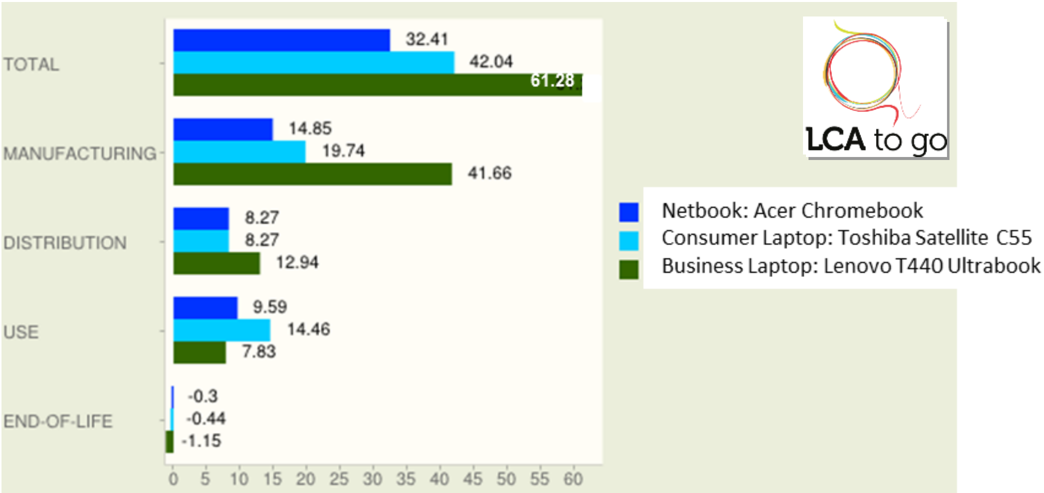

Figure 7: Carbon Footprint (in kg CO2-eq,) per year of use

5.2 Sensitivity Analysis

When interpreting the above results it should be kept in mind, that the distribution scenario follows a worst case whereas the power consumption of the chosen benchmark products unintentionally are all very low in comparison even to other products found in the EU EnergyStar databases in the corresponding product classes. By copying a product assessment in the tool, alternative scenarios for a sensitivity analysis can be calculated and compared with the defined benchmark.

5.3 Discussion

For a consumer such Carbon Footprint data might be relevant and appropriate, if he has to make the decision, whether he wants to purchase a standard consumer laptop or if for his purpose a netbook might suffice. With a netbook the carbon footprint can be reduced significantly due to the lower manufacturing impact and use phase energy consumption. Due to the shorter life time of business laptops, which are exchanged more frequently in most enterprises, the annual carbon footprint of laptop use is much higher in businesses than for consumer use – even as the same use profile is assumed. A second life for a business laptop could significantly lower the carbon intensity of using such a laptop.
The high contribution of the distribution (worst case: air cargo of the packaged product) can be a starting point to discuss improvement options:

- other means of transportation,
- longer lifetime to reduce number of shipped products,
- final assembly in Europe, possibly using reuse components sourced locally.

Another trend of laptop technology becomes evident: Due to the achievements in the field of energy efficiency in recent years, the use phase is less important than the manufacturing carbon footprint, and even through standard material recycling at end-of-life only a very limited carbon credit can be realized. All these facts give good reasons to extend now the lifetime of energy efficient laptop products, either has a whole through durability, repair and refurbishment, or through component reuse.

6. CONCLUSIONS

The presented approach allows SMEs to establish a sound screening LCA for computer products within maximum 1 hour, largely based on data, which is available in the product specification anyway and without the need to invest in costly software and consultancy. Although not a fully accurate LCA, the most important aspects throughout the product life cycle are properly covered. Deviating from the default settings for repair, reuse and recycling however might require a bit more work to get clear about realistic settings and assumptions.
One of the main advantages of the approach is also the possibility to model products of other manufacturers easily, which allows for fair comparisons as the modelling follows the same routine then for own products. Just comparing own LCA results with LCA results published by others still is not a scientifically valid approach, as variations in assumptions, scenarios, modelling approaches and background data along with a lack of transparency regarding these aspects hinders comparability. See the wide variation of LCA results for laptop products (manufacturing only) compiled by Liu et al. [6].
The LCA to go tool is suitable for SMEs, who want to quantify carbon savings benefits for external communication of D4R designs or refurbishment services, or for improving designs and business strategies internally (see [2]).
Those companies having made first experiences with LCA through this tool might excel further through the change-over to commercial LCA software tools, which allow a more detailed assessment and analysis of a product.

7. ACKNOWLEDGEMENTS

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