

Supporting Information

Comparing embodied greenhouse gas emissions of modern computing and electronics products

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This document contains 95 pages, one figure, and 42 tables.

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S1. Summary data tables

This section contains data tables summarizing all results for each graph in the text.

		Desktop (ei)	Desktop - tower	Desktop - small	Thin client	LCD monitor, 17" (ei)	LCD monitor, 21.5"	Laptop, with dock, 12" (ei)	Laptop, 16"	Netbook, 10"	iPad	iPod touch	Kindle	Rack server	Switch
Power supply	Mass (g)	1463	1461	476	182	114	173	537	433	297	89	89	89	2911	193
Casing	Mass (g)	6207	6171	1258	860	862	2157	1413	904	265	151	49	59	8767	1404
Circuit boards (excl. IC's)	Mass (g)	1558	1028	407	227	94	38	345	281	127	30	6	33	2199	460
IC's (packages)	Mass (g)	119	40	35	8	19	2	86	21	17	2	1	2	88	47
IC's (die)	Area (mm ²)	2195	500	218	126	355	22	1577	483	463	170	52	66	1683	366
IC's (die)	Mass (mg)	3970	905	394	228	642	39	2851	873	837	307	94	120	3043	663
Battery	Mass (g)	0	0	0	0	0	0	273	244	178	129	16	51	0	0
Display	Mass (g)	0	0	0	0	4006	2350	328	553	204	342	35	34	0	0
Other	Mass (g)	1796	1959	796	0	0	350	367	334	250	34	3	45	1506	16
Total	Mass(g)	11144	10660	2972	1277	5096	5070	3349	2770	1337	777	198	312	15471	2119

Table S1-I: Summary data table, product composition by mass

	Desktop (ei)	Desktop - tower	Desktop - small	Thin client	LCD monitor, 17" (ei)	LCD monitor, 21.5"	Laptop, with dock, 12" (ei)	Laptop, 16"	Netbook, 10"	iPad	iPod touch	Kindle	Rack server	Switch
Power supply	38.2	40.5	17.2	5.1	10.9	10.1	2.9	9.0	7.8	2.3	2.3	2.3	89.3	10.8
Casing	13.1	15.3	2.9	3.7	6.8	10.2	64.4	6.8	2.0	1.3	0.4	0.5	18.5	3.8
Circuit boards (excl. IC's)	76.9	38.6	23.7	12.6	9.6	2.2	32.0	16.2	8.6	1.7	0.4	2.4	128.8	25.3
IC's (packages)	80.4	15.0	11.2	5.6	14.2	1.2	58.9	15.5	12.1	1.3	0.6	1.2	50.8	34.3
IC's (die)	79.0	21.5	9.4	5.4	17.0	1.0	67.8	20.8	19.9	7.3	2.2	3.6	72.4	15.8
Battery	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.3	0.9	0.7	0.1	0.3	0.0	0.0
Display	0.0	0.0	0.0	0.0	236.3	138.6	19.3	31.9	6.7	9.9	0.8	2.0	0.0	0.0
Other	29.9	28.9	7.2	0.0	0.0	1.9	7.4	4.9	2.9	0.1	0.0	0.3	18.2	0.2
Transport	2.8	2.7	0.8	0.3	1.3	1.3	0.8	0.7	0.3	0.2	0.0	0.1	3.9	0.5
Assembly	1.2	1.2	1.2	0.9	1.2	1.2	1.2	0.9	0.9	0.6	0.6	0.6	1.2	1.2
Total	321.6	163.7	73.5	33.6	297.3	167.8	256.2	107.8	62.2	25.5	7.5	13.3	383.1	91.8

Table S1-II: Summary data table, embodied GHG emissions, in kg CO₂-eq

	Desktop (ei)	Desktop - tower	Desktop - small	Thin client	LCD monitor, 17" (ei)	LCD monitor, 21.5"	Laptop, with dock, 12" (ei)	Laptop, 16"	Netbook, 10"	iPad	iPod touch	Kindle	Rack server	Switch
Power supply	722.9	753.7	314.1	96.4	200.5	189.9	53.5	172.9	151.3	42.2	42.2	42.2	1653.4	202.7
Casing	214.7	272.9	48.5	70.1	120.8	203.2	330.2	134.2	39.1	21.8	7.2	7.9	302.4	57.6
Circuit boards (excl. IC's)	1620.9	757.0	439.0	233.1	180.4	41.0	605.6	322.7	160.9	32.0	7.0	44.8	2407.3	479.9
IC's (packages)	1778.1	301.1	229.0	126.0	268.5	23.7	1259.0	306.2	245.4	25.1	11.1	22.3	1008.2	650.1
IC's (die)	1222.8	318.3	138.4	80.3	255.5	15.7	1002.8	307.2	294.2	108.1	33.0	53.0	961.0	233.1
Battery	0.0	0.0	0.0	0.0	0.0	0.0	27.5	24.6	17.9	13.0	1.6	5.1	0.0	0.0
Display	0.0	0.0	0.0	0.0	3518.1	2063.8	288.0	475.4	100.7	148.4	11.4	29.8	0.0	0.0
Other	536.0	516.0	131.9	0.0	0.0	41.3	133.0	87.8	53.8	3.3	0.3	6.0	341.9	3.6
Transport	44.5	42.5	12.1	5.1	20.3	20.2	13.4	11.1	5.3	3.1	0.8	1.2	61.7	8.5
Assembly	25.3	25.3	25.3	19.0	25.3	25.3	25.3	19.0	19.0	12.7	12.7	12.7	25.3	25.3
Total	6165.2	2986.8	1338.3	630.1	4589.5	2624.1	3738.2	1861.1	1087.8	409.6	127.1	225.1	6761.1	1660.8

Table S1-III: Summary data table, product cumulative energy demand, in MJ

Product (this study)	Mass (g)	GHG (kg CO ₂ -eq)	MJ primary energy
Desktop (ei)	11144	321.6	6165.2
Desktop - tower	10660	163.7	2986.8
Desktop - small	2972	73.5	1338.3
Thin client	1277	33.6	630.1
LCD monitor, 17" (ei)	5096	297.3	4589.5
LCD monitor, 21.5"	5070	167.8	2624.1
Laptop, with dock, 12" (ei)	3350	256.2	3738.2
Laptop, 16"	2770	107.8	1861.1
Netbook, 10"	1337	62.2	1087.8
iPad	777	25.5	409.6
iPod touch	198	7.5	127.1
Kindle	312	13.3	225.1
Rack server	15471	383.1	6761.1
Switch	2119	91.8	1660.8

Table S1-IV: Summary data table, mass and embodied impacts, this study

Apple Product	Mass (g)	GHG (kg CO ₂ -eq)
27-inch LED Cinema Display	10900	516.6
Thunderbolt Display	10922	301.6
Apple TV	270	25.2
21.5-inch iMac	9304	349.2
27-inch iMac	13800	455.7
iPad 2	590	63
iPhone 3GS	135	24.75
iPhone 4	135	25.65
iPod classic	139	11.5
iPod nano	21.1	7.02
iPod shuffle	12.5	2.88
iPod touch	101	15.37
11-inch MacBook Air	1080	162
13-inch MacBook Air	1350	198.4
MacBook	2132	142.6
13-inch MacBook Pro	2041	203
15-inch MacBook Pro	2539	289.8
17-inch MacBook Pro	2994	334.8
Mac mini with Lion Server	1400	146.9
Mac mini	1300	153.9
Mac pro	18100	789.6
Xserve	13540	416

Table S1-V: Summary data table, mass and embodied impacts, Apple dataset (1)

Product	Mean (kg CO ₂ -eq)	Standard deviation (kg CO ₂ -eq)	Standard deviation (% of mean)
Rack server	378.6	40.9	0.11
Desktop (ei)	307.9	31.6	0.10
LCD monitor, 17" (ei)	295.0	45.4	0.15
Laptop, with dock, 12" (ei)	249.3	44.8	0.18
LCD monitor, 21.5"	167.4	31.8	0.19
Desktop – tower	158.0	15.2	0.10
Laptop, 16"	107.2	10.6	0.10
Switch	91.4	8.8	0.10
Desktop – small	72.7	7.6	0.10
Netbook, 10"	60.6	7.0	0.12
Thin client	34.9	3.4	0.10
iPad	25.7	3.9	0.15
Kindle	13.2	1.7	0.13
iPod touch	7.5	0.9	0.12

Table S1-VI: Monte Carlo analysis results

	Mass(g)	GHG (kg CO ₂ -eq)	Model estimates (kg CO ₂ -eq)		
			pcb+disp+batt	Mass only	All internal
Desktop (ei)	11144	321.6	285.4	302.5	310.3
Desktop - tower	10660	163.7	188.3	289.3	181.0
Desktop - small	2972	73.5	74.5	80.7	64.9
Thin client	1277	33.6	41.5	34.7	50.3
LCD monitor 17-inch (ei)	5095	297.3	296.2	138.3	294.7
LCD monitor 21.5-inch	5070	167.8	160.5	137.6	162.9
Laptop with dock 12-inch (ei)	3349	256.2	167.6	90.9	171.4
Laptop 16-inch	2770	107.8	161.8	75.2	162.2
Netbook 10-inch	1337	62.2	90.7	36.3	83.9
iPad	777	25.5	67.1	21.1	69.3
iPod touch	198	7.5	8.2	5.4	2.8
Kindle	312	13.3	23.8	8.5	21.5
Rack server	15471	383.1	402.7	419.9	383.5
Switch	2119	91.8	84.2	57.5	111.7

Table S1-VII: Linear regression model outputs, this study's dataset

	Mass(g)	GHG (kg CO ₂ -eq)	Model estimates (kg CO ₂ -eq)		
			pcb+disp+batt	Mass only	All internal
27-inch LED Cinema Display	10900	517	351.3	430.4	375.9
Thunderbolt Display	10922	302	359.4	431.2	386.5
Apple TV	270	25	16.2	10.7	0.3
21.5-inch iMac	9304	349	363.7	367.4	317.0
27-inch iMac	13800	456	551.8	544.9	525.8
iPad 2	590	63	74.2	23.3	68.9
iPhone 3GS	135	25	18.1	5.3	17.2
iPhone 4	135	26	17.2	5.3	16.8
iPod classic	139	12	8.1	5.5	8.7
iPod nano	21	7	1.9	0.8	1.1
iPod shuffle	13	3	0.9	0.5	0.0
iPod touch	101	15	10.6	4.0	7.1
11-inch MacBook Air	1080	162	128.3	42.6	112.0
13-inch MacBook Air	1350	198	163.8	53.3	140.6
MacBook	2132	143	204.8	84.2	193.7
13-inch MacBook Pro	2041	203	222.1	80.6	237.6
15-inch MacBook Pro	2539	290	264.3	100.2	272.1
17-inch MacBook Pro	2994	335	334.0	118.2	344.7
Mac mini with Lion Server	1400	147	132.5	55.3	112.1
Mac mini	1300	154	132.5	51.3	102.0
Mac pro	18100	790	588.7	714.7	782.5
Xserve	13540	416	588.7	534.6	428.1

Table S1-VIII: Linear regression model outputs, Apple dataset

S2. Adjustments and comparison to ecoinvent

This study used the data and assumptions from the ecoinvent database, with a few adjustments and modifications. Three products from the ecoinvent database (2), a desktop ('desktop computer, without screen, at plant'), laptop ('laptop computer, at plant'), and LCD monitor ('LCD flat screen, 17 inches, at plant'), were re-implemented in our modeling framework. Our results can be compared against the original results from the ecoinvent database both to illustrate the impact of the adjustments we have made, and to confirm that our framework reproduces the ecoinvent modeling assumptions. A summary of the original results and our adjusted results is in Table S2-I below, followed by a summary of the major adjustments we have made.

Parts were categorized as follows: *circuit boards* includes mainboards, RAM, video cards, and any other circuit boards, as well as all integrated circuits, connectors, capacitors, processor heat sinks, and other board-mounted components; *casing* includes all metal and plastic frames and screws from the device exterior; *display* is the screen unit only; *power supply* includes power cables as well as internal power supplies and smaller external supplies including chargers; *battery* includes only large cells, such as lithium-ion laptop batteries; and *other* includes any remaining components such as interior power cables, internal frames, disk and optical drives, case fans, and any remaining parts.

	Desktop	Adjusted	Laptop	Adjusted	LCD monitor	Adjusted
Assembly	1.4	1.2	0.9	1.2	52.7	1.2
Battery			1.6	1.4		
Casing	15.6	13.1	61.0	64.4	6.9	6.8
Circuit boards	180.1	236.4	104.0	158.7	34.3	40.8
Display			19.3	19.3	236.3	236.3
EOL	5.5		3.9			
Other	32.7	29.9	9.1	7.4		
Packaging	2.8		2.9		3.1	
Power supply	28.4	38.2	3.8	2.9		10.9
Transport	2.7	2.8	0.8	0.7		1.3
Total	269.3	321.6	207.4	256.0	333.3	297.3

Table S2-I: Global warming potential results for original ecoinvent study and our adjustments, in kg CO₂-eq

A. System boundary

Our study excludes the use and end-of-life phases, because we are focusing on impacts during device production. We exclude device packaging because we did not have any information about packaging for some of the products in our study; ideally we would include packaging for all products, but the magnitude of impacts due to packaging are typically small, so its exclusion will not significantly affect the results. Final assembly and transport are included using the standard ecoinvent assumptions. Note that

the LCD screen in ecoinvent did not include transport, and included an extra assembly step which we believe is spurious (see discussion below); we have adjusted this study so it is consistent with the others.

B. Silicon die and integrated circuits

We calculate the silicon die content using an empirically derived relationship, discussed in Section S4. The silicon die content per packaged chip is estimated to be about 18mm^2 die per gram of packaged chip, which is significantly larger than the ecoinvent processes, which estimates 5.5mm^2 per gram for logic chips (integrated circuit, IC, logic type, at plant) and 10.1mm^2 die per gram for memory chips (integrated circuit, IC, memory type, at plant). The lower estimates in ecoinvent are due to apparently erroneous assumptions in the ecoinvent database, discussed in previous work (3, 4) and in Section S4. We have adjusted the desktop, laptop, and LCD monitor processes to use our estimates, which has significantly increased the impacts due to integrated circuits. In addition, we have applied updated life cycle assessment results for silicon die (5), though this has a relatively small influence on the results.

C. LCD assembly

The ecoinvent process ‘LCD flat screen, 17 inches, at plant’ includes an assembly process called ‘assembly, LCD screen’ which includes significant chemical usage. However, the top-level process for the LCD monitor also includes an LCD module (‘LCD module, at plant’) which itself contains a very similar assembly process (‘assembly, LCD module’). The two processes, ‘assembly, LCD screen’ and ‘assembly, LCD module’, are in fact nearly identical in their contents, except the inventory contents in the latter are 3.91 times larger in all cases, and there are a small number of items present in the latter process but not in the former. The ecoinvent documentation is not fully clear on the purpose and function of the ‘assembly, LCD screen’ process.

There is no reason to suppose that additional chemical-intensive processes are required in order to assemble the completed components of an LCD monitor (casing, LCD module, cables, etc.); the finished product can be disassembled into such components using a hand screwdriver. Therefore, either the chemical-intensive ‘assembly, LCD screen’ process is spurious, or the ‘LCD module, at plant’ process is intended to represent only part of the central display apparatus. We believe the former is more likely, for two reasons. First, this would be more consistent with the conventions of ecoinvent in which top-level processes include finished components; notably, the laptop computer process includes this LCD module, but not the ‘assembly, LCD screen’ process. Second, the study upon which this data was originally drawn defines an ‘LCD module’ as including “the LCD panel (i.e., front and back glass panels, liquid crystals and polarizers, column and row drivers), the backlight unit, and the main LCD controller PWB” (6). This represents all of the major components in an LCD monitor (6) which implies that the LCD module is indeed the entire central display apparatus.

In order to maintain a consistent approach we have assumed that the ‘LCD module, at plant’ process represents a finished display component, and that products which include this component do not require an additional chemical-intensive assembly step. Therefore, we have adjusted the ‘LCD flat screen, 17 inches, at plant’ process to remove the ‘assembly, LCD screen’ component. This process accounted for 53.0 kg CO₂-eq of the LCD flat screen’s global warming potential.

D. LCD power supply

There is no power supply modeled in the ecoinvent LCD monitor process. However, the main circuit board process is defined as a mixture of a surface-mount populated printed wiring board and a through-hole populated printed wiring board. The surface-mount board modeled in ecoinvent contains components which suggest it is used for logic applications, while the through-hole board contains power electronics which suggest it is used in power supplies. In order to maintain consistency with other products, we have split these two components in our adjusted study and assumed that the through-hole circuit board models the monitor's power supply.

E. Other variation

The above adjustments account for nearly all of the differences between our results and the original ecoinvent studies. The remainder is caused by our modeling framework which has condensed the ecoinvent database into a subset of about 100 important processes. In some cases there is a reduction of detail in which we have chosen to use proxy materials; for example, we model only one type of radial cylindrical inductor, whereas ecoinvent has separate processes for small and large inductors. The reduction of detail simplifies our project with minimal loss of accuracy.

S3. Uncertainty factors

The ecoinvent database uses a semi-quantitative scale based on pedigree matrices to assign uncertainty distributions (7). In general, if a product includes n kg of a substance, then n is assumed to be the mean of a random variable N with standard deviation s , where s depends on the quality of data which produced the estimate of n kg, and the value of s is a function of expert judgments and is determined using a pedigree matrix. Because impact models are linear, the calculated impacts due to this substance will have a relative standard deviation (i.e. standard deviation divided by mean) equivalent to the amount of the substance present.

We have assigned standard deviations to all line items in our bills of materials according to our judgments of how well the ecoinvent processes, especially those modeling electronics components, map to the components in the products we have analyzed. In the interests of simplicity we have assigned a general data quality score to the entire ecoinvent dataset and applied this score to all items, with the exception of silicon die and LCD screens. The scoring according to the pedigree matrix format in the ecoinvent database is shown below in Table S3-I.

Category	Score	Uncertainty factors U_i
Reliability	3: Non-verified data partly based on qualified estimates	1.10
Completeness	4: Representative data from only one site relevant for the market considered OR some sites but from shorter periods	1.10
Temporal correlation	3: Less than 10 years of difference to our reference year (2000)	1.10
Geographical correlation	2: Average data from larger area in which the area under study is included	1.01
Further technological correlation	3: Data on related processes or materials but same technology, OR Data from processes and materials under study but from different technology	1.20
Sample size	5: unknown	1.20

Table S3-I: Pedigree matrix scoring for uncertainty characterization

Using the formulas supplied in the ecoinvent documentation $\sigma_g^2 = \exp(U)$ where $U = \sqrt{\sum_i (\ln^2 U_i)}$ with the above uncertainty factors yields a geometric standard deviation $\sigma_g^2 = 1.36$. This factor is applied as the default for all inventory items in our study.

For silicon die and LCD screens which have additional uncertainty, we downgrade the reliability and technological correlation scores from 3 to 4, which changes the uncertainty factors from 1.10 and 1.20 to 1.20 and 1.50, respectively, and results in a new geometric standard deviation $\sigma_g^2 = 1.65$.

Transport processes are assigned a score of $\sigma_g^2 = 2.1$ in order to maintain consistency with other electronics processes in ecoinvent.

S4. Silicon die content in integrated circuits

Figure S4-1 below shows the results of X-ray measurements of packaged IC's which were used to derive conversion ratios for estimating silicon die content. Twenty-two IC's were successfully X-rayed and their silicon die area measured. The dataset is split to illustrate that most surface-mount IC's are very small and show high diversity in package types; the linear trend is mostly driven by large ball-grid array IC's with large die. Errors are thus likely when estimating die content of small IC's, but the absolute magnitude of these errors will also be small in proportion to the size of these IC's. Diversity in packaging technique leads to non-linear variation which is more pronounced in measurements of mass; it is thus preferable to use the top-down area of the package to estimate die content.

These results were used to create ratios that allow estimation of silicon die by packaged IC area and by IC mass. The mass of a die was calculated using the volume density of silicon, 2.33g per cm^3 , and the standard thickness of a 300mm wafer, 775 μm (8). Using a simple linear fit, we derived a best-fit mass ratio of about 18 mm^2 of silicon die per gram of packaged chip ($R^2=0.58$), and a best-fit area ratio of about 0.078 mm^2 of silicon die per mm^2 of package area ($R^2=0.70$). By comparison, the ecoinvent database assumes 5.5 mm^2 silicon die per gram for logic chips and 10.1 mm^2 silicon die per gram for memory chip.

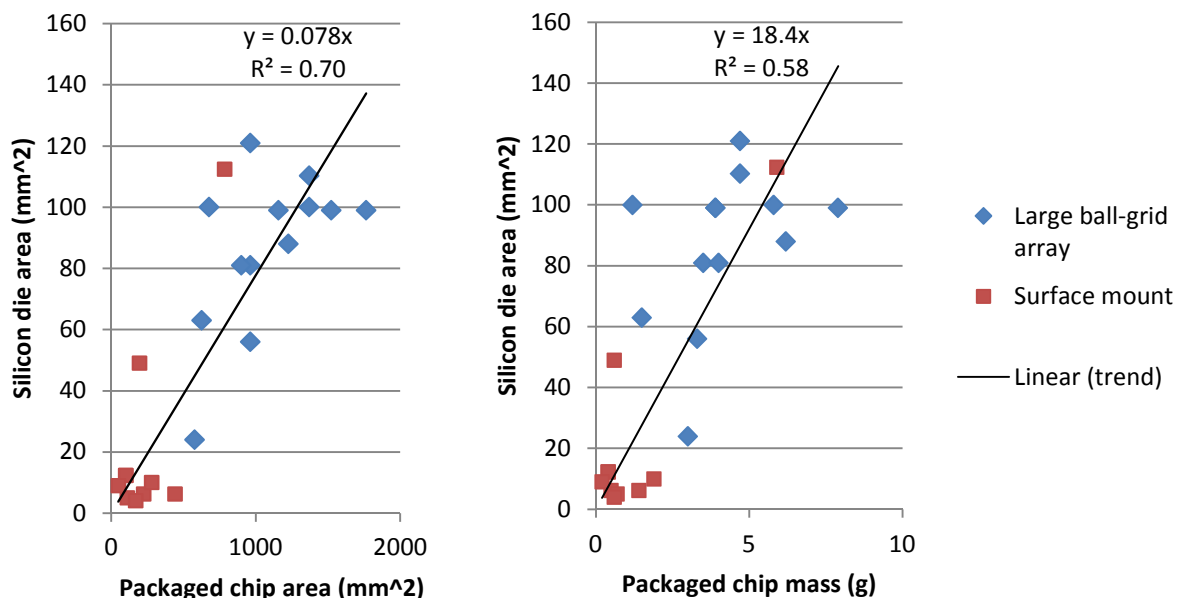


Figure S4-1: Silicon die area measurements via X-ray

A. Discrepancy in ecoinvent models

The ecoinvent calculation uses a mass ratio to determine die size. Given an example packaged chip with dimensions of 27mm*27mm*2.36mm, a mass of 2.6g, and an assumption that the silicon die is 2% of the packaged chip mass, the ecoinvent calculation of silicon die area per kilogram of packaged chip is as follows, from (1):

$$\text{Die area per kg packaged chip} = (0.027 \times 0.027) \times 0.02 / 0.00262 = 0.0056 \text{ m}^2 \text{ per kg}$$

The equation has the following factors:

Left side of equation: Die area / packaged chip mass

Right side of equation: Packaged chip area * (die mass / packaged chip mass) / (packaged chip mass)

The units of each factor are as follows:

Left side of equation: m² die/ kg chip

Right side of equation: (kg die/kg chip) / kg chip

Unfortunately, the units on the right side of the equation do not resolve to those on the left side; this is the source of the discrepancy. The difficulty could be resolved by replacing the mass ratio with a ratio expressing die area divided by packaged chip area:

Left side of equation: m² die / kg chip

Right side of equation: m² chip * (m² die/m² chip) / kg chip

We measured an area ratio of 0.078 mm² die per mm² chip. Using the example chip with area 27 mm * 27 mm and mass of 2.6 g would imply a die area of $(0.027 \times 0.027) \times 0.078 / 0.00262 = 0.021 \text{ m}^2 \text{ per kg}$, which is a factor of 3.9 higher than the ecoinvent calculated result of 0.0056 m² per kg.

Alternatively, the intended result, m² die / kg chip, can be determined empirically as we have done by examining the die area and chip masses of several packaged chips. The area ratio we measured, 18mm² per gram of packaged chip, or 0.018 m² per kg, is a factor of 3.2 higher than ecoinvent's assumption of 0.0056 m² per kg. These results indicate that the ecoinvent dataset significantly underestimates the silicon die content of packaged IC's.

B. Stacked IC's

Some IC packages contain multiple die in order to save space and improve connectivity between modules. The practice is especially common in mobile devices which require high performance but are heavily space-constrained; a common use is to combine multiple memory die, alone or with a processor, either by stacking silicon die directly on top of one another within one package, a technique known as "stacked die", or by stacking packaged chips, a technique known as "package-on-package" (9). Our assessment technique of x-raying packages was not able to clearly detect stacked die or package-on-package configurations, so we referred to industrial literature to identify these chips and make appropriate corrections to our bills-of-materials.

Third party analysis of the iPad showed that its A4 processor contains one CPU die and two memory die (10). Cross-sectional photographs from that analysis show that the RAM dies are 85% of the size of the processor die in one dimension. Assuming the same is true in the other dimension, the RAM die area is 72% of the processor die, which means that the approximately 50mm² CPU die is accompanied by two RAM die with area about 36mm² each. The NAND solid-state storage chip did not include stacked die in the iPad model we analyzed, though higher-capacity iPad models would have (11). The 4th generation iPod touch uses the same A4 processor with memory die as the iPad (12). The 3rd generation model we analyzed has a Samsung ARM processor with the same amount of RAM (13) and thus also likely uses a stacked configuration; the package is smaller, but we assume the same ratio of stacked memory die to processor die as in the iPad. The 3rd generation Kindle uses a low-cost ARM processor which does not appear to include stacked die or chips (14). The use of stacked packaging technologies is unlikely in this product due to its low cost and lower performance requirements.

Stacked-die packages are common in flash memory used in memory cards and in cell-phone processors (9). Because of the added cost and complexity of using stacked die packaging, they are most likely to appear in small devices which are heavily area-constrained, and unlikely to appear in laptop and desktop computers and other larger equipment. We found no third-party teardowns of the other products in our study to compare against, but did search for information on each major IC (CPU and RAM) and found no evidence to suggest that any stacked-die or package-on-package technologies were in use. As such, we made no further adjustments to account for stacking technologies.

Technical and economic constraints point to future widespread usage of many types of stacking technologies, especially in mobile devices (9). These trends will make identifying the die area used in a product considerably more difficult. Mass of packaged chips would no longer be viable as a functional unit; life cycle assessments must accurately account for die area. X-raying would no longer be a viable technique for tabulating this area, unless very high-resolution cross-sectional x-rays were available; grinding packages away to reveal the die inside will probably be the only reliable technique for accurately measuring silicon die content of an integrated circuit. Ideally, manufacturer specifications could be made available and incorporated into life cycle assessments in order to make such painstaking measurements unnecessary.

S5. Linear regression model selection

Three linear models are discussed in the text. Below are the fit results for the best fifteen models which were attempted during the model selection process. The cross-validated sum of squares (cvss) and raw and adjusted R^2 are shown for each of two datasets; dataset one represents our study, and dataset two is Apple's dataset. The cvss scores are normalized to the mass-only model. The combined score is equal to the sum of the squares of the two cvss scores. Shaded rows represent the three models which are presented in the text.

Model predictors	cvss ₁	cvss ₂	score	R^2_1	R^2_1 -adj	R^2_2	R^2_2 -adj
Ma, int=0	1.00	1.00	2.00	0.85	0.84	0.89	0.88
Bo, Ps, Di, Ba, int=0	0.38	1.39	2.09	0.97	0.96	0.96	0.96
Bo, Di, Ba, int=0	0.42	1.40	2.12	0.97	0.96	0.94	0.93
Bo, Di, Ba	0.45	1.40	2.17	0.92	0.90	0.87	0.84
Ca	1.32	1.25	3.30	0.55	0.51	0.75	0.74
Bo, Ps, Di, Ba, Ca, Ot	0.62	1.81	3.66	0.94	0.88	0.95	0.93
Bo, Ps	1.36	1.91	5.50	0.55	0.47	0.68	0.64
Ca, int=0	1.63	1.94	6.42	0.73	0.71	0.80	0.79
Bo	1.24	2.36	7.11	0.55	0.51	0.59	0.57
Bo, Vo	1.98	1.91	7.56	0.57	0.50	0.70	0.67
Bo, Ps, Di, Ba, Ca, Ot, int=0	0.45	2.77	7.85	0.97	0.95	0.97	0.96
Bo, Ps, Di	0.51	2.76	7.88	0.86	0.82	0.82	0.78
Ca, Vo, int=0	2.30	1.94	9.04	0.74	0.69	0.82	0.80
Bo, Ps, Di, Ba, Vo, int=0	0.56	3.01	9.37	0.97	0.95	0.96	0.95
Bo, Ps, Di, Ba, Vo	1.69	2.77	10.49	0.93	0.89	0.93	0.91

Ma: product mass; Bo: circuit board mass; Ps: power supply mass; Di: display mass; Ba: battery mass; Ca: casing mass; Ot: other mass; Vo: product volume; int: y-intercept term

Table S5-I: Model selection results for the top fifteen models.

The circuit board + display + battery model, which had the third-best score, was selected because its score is very close to that of the model with the second-best score, and it requires one fewer predictor. The circuit board + power supply + display + battery + casing + other model was selected as an illustrative case because it had very low residual error (visible through its high R^2) but performed poorly when cross-validated on Apple's dataset. This suggests that the apparent additional precision supplied by adding more terms to that model is due to over fitting.

S6. Bills of materials for products analyzed

This section contains full bills-of-materials (BOM) for each of the 11 products under study and the 3 ecoinvent products compared against. Measurements are the result of primary disassembly and weighing. All parts are identified with a physical description, and mapped to the best-fitting process from a custom-developed listing of appropriate processes. The processes are in turn mapped to ecoinvent processes according to the mapping provided in the final section of this document.

A summary table is provided before each full bill of materials. Parts are categorized as either power supply, casing, circuit boards (excluding IC's), IC's (packages), IC's (die), battery, display, and 'other'; the only non-material impacts considered are transport and assembly. Packaging, exterior parts such as manuals and CDs, production facilities, R&D, and logistics aside from assembly and final ship are all excluded due to non-uniform or missing data. Activities related to use-phase and end-of-life are excluded as out of scope.

Impact assessment results are provided in aggregate by subsystem. The impact values of each line item are not provided in order to protect the copyright of the underlying data source.

A. Full-size desktop

The product is a Dell Optiplex 780 Minitower desktop, circa 2010 manufacture, with dimensions 41cm x 43cm x 19cm, and total mass 10.7kg, excluding external packaging.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply (excl. IC's)	Mass (g)	1461	40	749
Casing	Mass (g)	6171	14	255
Circuit boards (excl. IC's)	Mass (g)	1028	38	744
IC's (packages)	Mass (g)	40	15	301
IC's (die)	Area (mm ²)	500	22	318
Battery	Mass (g)	0	0	0
Display	Mass (g)	0	0	0
Other	Mass (g)	1959	28	502
Transport	Mass (g)	10660	3	43
Assembly	Products	1	1	25
Total	Mass(g)	10660	161	2937

Table S6-I: Summary of bill of materials, large desktop

Subsystem	Description	Process (best fit)	Unit	Measurement
Assembly	Assembly	099-Assembly - large product	Products	1
Transport	Transport to regional assembly	087-Transport - SE Asia to regional assembly (per g)	Mass (g)	10659.7
Power supply	240W power supply - PCB	019-Electronics - PCB (2 layer, bare)	Mass (g)	60
Power supply	Internal power cables	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	158
Power supply	24-pin connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	12
Power supply	Casing, magnetic metal	001-Metal - steel (sheet)	Mass (g)	560
Power supply	Medium case fan 8x8cm 12V 2.6W	067-Electronics - components - medium case fan	Mass (g)	91.4
Power supply	Large cylindrical coil 35x23x42mm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	84

Subsystem	Description	Process (best fit)	Unit	Measurement
Power supply	Large cylindrical coil 25x15x20mm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	13.3
Power supply	Large cylindrical coil 10x10x11	049-Electronics - Inductor, large cylindrical wound	Mass (g)	2.6
Power supply	Toroidal coil 3cm diameter	047-Electronics - Inductor, toroidal	Mass (g)	55
Power supply	Toroidal coil 3cm diameter	047-Electronics - Inductor, toroidal	Mass (g)	62
Power supply	Thick wire cylindrical coil 1x2.5cm (diameter x height)	049-Electronics - Inductor, large cylindrical wound	Mass (g)	6.4
Power supply	Thick wire cylindrical coil 1x2.5cm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	6.4
Power supply	Thick wire cylindrical coil 7x11mm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	3.1
Power supply	Thick wire cylindrical coil 6x8mm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	1
Power supply	Secondary board 10x5cm 2-layer	019-Electronics - PCB (2 layer, bare)	Mass (g)	18.3
Power supply	Toroidal coil 2cm diameter	047-Electronics - Inductor, toroidal	Mass (g)	16.4
Power supply	Toroidal coil 2cm diameter	047-Electronics - Inductor, toroidal	Mass (g)	16.4
Power supply	Boxed coil 2x2x1cm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	6.8
Power supply	Boxed coil 8x18x15mm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	2.8
Power supply	Boxed coil 16x11x16mm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	3.5
Power supply	Boxed coil 18x4x11mm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	6.3
Power supply	Cap, large ceramic 15x6x15mm	045-Electronics - Capacitor, ceramic (button)	Mass (g)	2.5
Power supply	Cap, ceramic 15mm diameter	045-Electronics - Capacitor, ceramic (button)	Mass (g)	1.6
Power supply	Cap, ceramic 8mm diameter	045-Electronics - Capacitor, ceramic (button)	Mass (g)	0.5
Power supply	Cap, ceramic 8mm diameter	045-Electronics - Capacitor, ceramic (button)	Mass (g)	0.5
Power supply	Power transistor 20x3x19mm	042-Electronics - Transistor, large/power	Mass (g)	3.6
Power supply	Cap, ceramic 15mm diameter	045-Electronics - Capacitor, ceramic (button)	Mass (g)	2.3
Power supply	Cap, ceramic 9mm diameter	045-Electronics - Capacitor, ceramic (button)	Mass (g)	0.7
Power supply	Cap, ceramic 9mm diameter	045-Electronics - Capacitor, ceramic (button)	Mass (g)	0.7
Power supply	Cap, electrolytic, 2cm diameter x 4.5cm height	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	29.1
Power supply	Cap, electrolytic, 13mmx25mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	4.6

Subsystem	Description	Process (best fit)	Unit	Measurement
Power supply	Cap, electrolytic, 9x30mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	3.3
Power supply	Cap, electrolytic, 10x25mm, 2X@2.8g each	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	5.6
Power supply	Cap, electrolytic, 10x21mm, 3X@1.7g each	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	5.1
Power supply	Cap, electrolytic, 9x16mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	1.6
Power supply	Cap, electrolytic, 8x14mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	0.9
Power supply	Cap, electrolytic, 7x13mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	0.7
Power supply	Cap, electrolytic, 6x11mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	0.6
Power supply	Cap, electrolytic, 5x11mm, 7X@0.4g each	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	2.8
Power supply	Power transistor 9x4x9mm, 13X @ 2.0g each	042-Electronics - Transistor, large/power	Mass (g)	26
Power supply	Heat spreaders - gray non-magnetic metal	006-Metal - aluminum heatsink	Mass (g)	108.9
Power supply	Small SMT IC's, 2X 16-pin @ 1.1g each	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	2.2
Power supply	Silicon die, by mass ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	40.48
Power supply	Tiny SMT IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	1.4
Power supply	Power resistors 2X @ 3.8g each, 7mm diameter x 24mm length	051-Electronics - Resistor, large (power)	Mass (g)	7.6
Power supply	Power resistors 3X @0.6g each 11mm length	051-Electronics - Resistor, large (power)	Mass (g)	1.8
Power supply	Power resistors 3X @0.25g each 8mm length	051-Electronics - Resistor, large (power)	Mass (g)	0.75
Power supply	Power resistors 4X @0.1g each 7mm length	051-Electronics - Resistor, large (power)	Mass (g)	0.4

Subsystem	Description	Process (best fit)	Unit	Measurement
Power supply	Power diode 3X @ 0.7g each 8mm length	050-Electronics - Diode, large (power)	Mass (g)	2.1
Power supply	Power diode 5X @ 0.2g each 4 to 6mm length	050-Electronics - Diode, large (power)	Mass (g)	1
Power supply	Toroidal coil (small)	047-Electronics - Inductor, toroidal	Mass (g)	2.3
Power supply	Small cables/wires	084-Electronics - cables - small cables and wires	Mass (g)	11
Power supply	AC power plug	075-Electronics - ports - AC power plug	Mass (g)	13.6
Power supply	White epoxy blobs	016-Plastic - epoxy	Mass (g)	3.4
Power supply	Rubber/plastic wrapping	012-Plastic - silicone rubber	Mass (g)	1.6
Power supply	Small plastic connector/plug	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	1.5
Power supply	Metal screws	002-Metal - steel (screws)	Mass (g)	9
Power supply	Foam padding	015-Plastic - polyurethane foam (packaging)	Mass (g)	1
Power supply	Clear stiff plastic piece	008-Plastic - ABS	Mass (g)	2
Power supply	Hard plastic piece	008-Plastic - ABS	Mass (g)	3.2
Power supply	Remaining bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	8
Power supply	Subtotal: Power supply (excl IC's)		Mass (g)	1461.15
Graphics card	ATI Radeon. Bare PCB 12 layer 17x6cm	024-Electronics - PCB (12 layer, bare)	Mass (g)	43.9
Graphics card	ATI GPU. Mounted bare die 644-pin, 25x25mm PCB, 7x9mm die.	033-Electronics - IC, large BGA (mounted bare die, 672 pin)	Mass (g)	1.5
Graphics card	Silicon die, exposed	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	63
Graphics card	Video RAM, 82-pin, 8x14mm, 4@0.2g each	037-Electronics - IC, packaged RAM chip	Mass (g)	0.8
Graphics card	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	34.944
Graphics card	Small SMT IC's 8 to 16 pin, 13X, 0.8g total	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0.8
Graphics card	Silicon die, by mass ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	14.72
Graphics card	Cap, electrolytic, 8mm dia x 14mm height	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	1.5

Subsystem	Description	Process (best fit)	Unit	Measurement
Graphics card	Cap, electrolytic, 6x8	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	0.5
Graphics card	Cap, electrolytic, 6x8	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	0.4
Graphics card	Small wound coils, thick wire: 8x10mm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	2.4
Graphics card	Small wound coils, thick wire: 8x5mm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	1.2
Graphics card	Small wound coils, thick wire: 4x4mm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	0.4
Graphics card	S-video port	072-Electronics - ports - video multi-pin	Mass (g)	4.1
Graphics card	DVI port	072-Electronics - ports - video multi-pin	Mass (g)	10.3
Graphics card	Small connector	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	0.1
Graphics card	Tiny IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	1
Graphics card	Front plate - magnetic metal	001-Metal - steel (sheet)	Mass (g)	15.1
Graphics card	Back brace for man connector - magnetic metal	001-Metal - steel (sheet)	Mass (g)	3.6
Graphics card	Metal screws	002-Metal - steel (screws)	Mass (g)	3
Graphics card	Heat sink - black coated metal non-magnetic	006-Metal - aluminum heat sink	Mass (g)	29.5
Graphics card	Clear plastic cover - polycarbonate ("PC" label)	010-Plastic - PC	Mass (g)	9.7
Graphics card	CPU fan - 12V DV 2.3W - 4.5cm diameter	065-Electronics - components - small CPU fan	Mass (g)	11.2
Mainboard	Main logic board - 10 layer - 26.5x26.5cm	024-Electronics - PCB (12 layer, bare)	Mass (g)	247
RAM	RAM IC's - 8X @ 0.15g each, 78-pin 8x11mm	037-Electronics - IC, packaged RAM chip	Mass (g)	1.2
RAM	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	54.912
RAM	RAM: PCB - 13.3x3cm, 4 Layer	020-Electronics - PCB (4 layer, bare)	Mass (g)	13.2
Mainboard	2xUSB + Ethernet port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	15

Subsystem	Description	Process (best fit)	Unit	Measurement
Mainboard	VGA+serial port	072-Electronics - ports - video multi-pin	Mass (g)	26.1
Mainboard	2x audio port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	9.6
Mainboard	4x USB port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	16.9
Mainboard	Parallel port	072-Electronics - ports - video multi-pin	Mass (g)	24
Mainboard	Firewire port, 2X @ 2.2g each	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	4.4
Mainboard	Firewire port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	1
Mainboard	RAM slots 14cm, 2X @ 19g each	076-Electronics - connectors - full-size RAM slot	Mass (g)	38
Mainboard	PCI-type slots - 2X @ 12.2g each	079-Electronics - connectors - PCI-type slot	Mass (g)	24.4
Mainboard	Video (AGP) slot	078-Electronics - connectors - video card slot	Mass (g)	7.1
Mainboard	On-board connectors and plug	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	20.2
Mainboard	Cap, electrolytic, 7x20mm: 4X @ 1.6g each	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	6.4
Mainboard	Cap, electrolytic, 9x12mm: 2X @ 1.2g each	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	2.4
Mainboard	Cap, electrolytic, 7x9mm: 7x @ 0.5 each	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	3.5
Mainboard	Cap, electrolytic, 7x12mm: 8x @ 1.0 each	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	8
Mainboard	Cap, electrolytic, 6x12mm: 24x @ 0.5 each	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	12
Mainboard	Cap, electrolytic, 5x11mm: 2x @ 0.4 each	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	0.8
Mainboard	Coil, toroidal: 13mm diameter, 2X @ 5.8g each	047-Electronics - Inductor, toroidal	Mass (g)	11.6
Mainboard	Coil, toroidal: 11mm diameter, 3X @ 3.2g each	047-Electronics - Inductor, toroidal	Mass (g)	9.6

Subsystem	Description	Process (best fit)	Unit	Measurement
Mainboard	Coil, toroidal: 8mm diameter, 2X @ 1.2g each	047-Electronics - Inductor, toroidal	Mass (g)	2.4
Mainboard	Intel Pentium E5800 3.2 Ghz; Mounted with heat spreader, 777-pin, 37x37mm PCB, 35x35mm spreader	030-Electronics - IC, large BGA (with heat spreader, 672 pin)	Mass (g)	23.6
Mainboard	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	106.782
Mainboard	1225-pin mounted bare die, 39x39mm PCB, 11x9mm die	033-Electronics - IC, large BGA (mounted bare die, 672 pin)	Mass (g)	3.9
Mainboard	Silicon die, exposed	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	99
Mainboard	652-pin mounted package; 31x31mm PCB, 26x26mm package	027-Electronics - IC, large BGA (mounted, plastic package, 672 pin)	Mass (g)	3.8
Mainboard	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	52.728
Mainboard	CPU socket - magnetic metal	001-Metal - steel (sheet)	Mass (g)	25.6
Mainboard	CPU socket - plastic seat	008-Plastic - ABS	Mass (g)	6.9
Mainboard	CPU heatsink - white non-mag metal	006-Metal - aluminum heatsink	Mass (g)	256.3
Mainboard	Secondary chip heatsink - white non-mag metal	006-Metal - aluminum heatsink	Mass (g)	34.3
Mainboard	128-pin SMT, 14x20mm	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	1.7
Mainboard	56-pin SMT, 14x6mm	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0.3
Mainboard	16-pn SMT, 7x10mm	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0.4
Mainboard	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	33.852
Mainboard	Transistors 6x6mm, 21X @ 0.33g each	041-Electronics - Transistor, small	Mass (g)	6.93
Mainboard	Crystal oscillator	085-Electronics - crystal oscillator	Mass (g)	0.4
Mainboard	CR2032 3V Li battery	056-Battery - CR2032 3V Li-Ion (CMOS)	Mass (g)	2.7
Mainboard	Buzzer - KPM1205A	071-Electronics - components - speaker	Mass (g)	1.3
Mainboard	Small IC's and little bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	8.2
Daughtercards	Small PCB: 4x12.5cm, 2 layer	019-Electronics - PCB (2 layer, bare)	Mass (g)	21.1
Daughtercards	USB port: 2X @ 3g each	073-Electronics - ports - small metal (USB, firewire,	Mass (g)	6

Subsystem	Description	Process (best fit)	Unit	Measurement
		ethernet)		
Daughtercards	Audio port: 2X @ 2.4g each	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	4.8
Daughtercards	Cap, electrolytic, 6x12mm: 3X @ 0.6g each	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	1.8
Daughtercards	Misc. connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	3.9
Daughtercards	Ribbon cable 40 cm	083-Electronics - cables - large ribbon cables	Mass (g)	49
	Subtotal: Circuit boards (total)		Mass (g)	1068.25
	Subtotal: Circuit boards (excluding IC's)		Mass (g)	1028.05
Interior parts	Plastic heatsink airflow ducting "PC + 20% GF"	010-Plastic - PC	Mass (g)	145
Interior parts	Front-plating: ABS plastic	008-Plastic - ABS	Mass (g)	86
Interior parts	Fan housing: "PC + 20% GF"	010-Plastic - PC	Mass (g)	171
Interior parts	Large case fan: 12x12cm, 12V 0.9A (10.8W)	068-Electronics - components - large case fan	Mass (g)	215
Interior parts	Blue plastic piece "PC + ABS - FR(40)"	009-Plastic - ABS + PC blend	Mass (g)	18
Interior parts	Plastic piece ABS	008-Plastic - ABS	Mass (g)	11
Interior parts	Metal piece magnetic	001-Metal - steel (sheet)	Mass (g)	11
Interior parts	Plastic piece PC+20%GF	010-Plastic - PC	Mass (g)	14
Interior parts	Plastic piece PC+ABS-FR40K	009-Plastic - ABS + PC blend	Mass (g)	40
Interior parts	Plastic piece PC+ABS-FR40K	009-Plastic - ABS + PC blend	Mass (g)	3.5
Interior parts	Plastic piece - clear plastic	015-Plastic - polyurethane foam (packaging)	Mass (g)	4.8
Interior parts	Hard drive: 4", 10x15x2.5 cm	062-Electronics - components - full-size hard disk	Mass (g)	447
Interior parts	DVD+RW drive, 14.5x17x4cm	061-Electronics - components - DVD drive	Mass (g)	690
Interior parts	Small metal bits - magnetic	001-Metal - steel (sheet)	Mass (g)	61
Interior parts	Power cables - 130cm	084-Electronics - cables - small cables and wires	Mass (g)	42
Interior parts	Subtotal: Other		Mass (g)	1959.3

Subsystem	Description	Process (best fit)	Unit	Measurement
Casing	Interior frame, magnetic metal	001-Metal - steel (sheet)	Mass (g)	4260
Casing	Side panel, magnetic metal	001-Metal - steel (sheet)	Mass (g)	1250
Casing	Plastic panels "ABS"	008-Plastic - ABS	Mass (g)	640
Casing	Metal screws	002-Metal - steel (screws)	Mass (g)	21
Casing	Subtotal: Casing		Mass (g)	6171
	Subtotal: IC's (packaged)		Mass (g)	40.2
	Subtotal: IC's (die)		Area (mm^2)	500.418
				0
	Total		Mass(g)	10659.7

Table S6-II: Full bill of materials, large desktop

B. Small desktop

The product is a Dell Optiplex 780 Ultra-Small Form Factor (USFF) desktop, circa 2010 manufacture, with dimensions 24x23.5x6.5cm, and total mass 2.97kg, excluding external packaging.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply (excl. IC's)	Mass (g)	476	17.2	314.1
Casing	Mass (g)	1258	2.9	48.5
Circuit boards (excl. IC's)	Mass (g)	407	23.7	439.0
IC's (packages)	Mass (g)	35	11.2	229.0
IC's (die)	Area (mm ²)	218	9.4	138.4
Battery	Mass (g)	0	0	0
Display	Mass (g)	0	0	0
Other	Mass (g)	796	7.2	131.9
Transport	Mass (g)	2972	0.8	12.1
Assembly	Products	1	1.2	25.3
Total	Mass(g)	2972	73.5	1338.3

Table S6-III: Summary of bill of materials, small desktop

Subsystem	Description	Process (best fit)	Unit	Measurement
Assembly	Assembly	099-Assembly - large component	Product	1
Transport	Transport to regional assembly	087-Transport - SE Asia to regional assembly (per g)	Mass (g)	3020
Mainboard	Mainboard: 3V CR2032 Li battery	056-Battery - CR2032 3V Li-Ion (CMOS)	Mass (g)	3
Mainboard	Mainboard: Main logic board - 20.5x22cm - 15cm ² - 8 layer	022-Electronics - PCB (8 layer, bare)	Mass (g)	180
RAM	RAM: PCB - 13.3x3cm, 4 Layer	020-Electronics - PCB (4 layer, bare)	Mass (g)	13
RAM	RAM: IC's, 8x, 1.4g total	037-Electronics - IC, packaged RAM chip	Mass (g)	1
RAM	Silicon die, by mass ratio	095-Silicon die - 2007 process (65 nm)	Area (mm ²)	26

Subsystem	Description	Process (best fit)	Unit	Measurement
Mainboard	Plastic CR-2032 battery housing	009-Plastic - ABS + PC blend	Mass (g)	2
Mainboard	Serial port	072-Electronics - ports - video multi-pin	Mass (g)	6
Mainboard	VGA port	072-Electronics - ports - video multi-pin	Mass (g)	7
Mainboard	Double-USB port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	5
Mainboard	Double-USB+ethernet port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	15
Mainboard	Audio port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	2
Mainboard	Audio port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	2
Mainboard	RAM slot (13cm)	076-Electronics - connectors - full-size RAM slot	Mass (g)	10
Mainboard	RAM slot (13cm)	076-Electronics - connectors - full-size RAM slot	Mass (g)	10
Mainboard	Power plug, on-board 8-pin	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	2
Mainboard	Power plug, on-board 4-pin	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	1
Mainboard	Firewire port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	2
Mainboard	Firewire port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	2
Mainboard	USB port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	2
Mainboard	Jumpers	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	5
Mainboard	Ribbon plug	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	1
Mainboard	Small other connector bits from mainboard	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	0
Mainboard	Caps - electrolytic - 9mm diameter 11mm height - 4X	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	5

Subsystem	Description	Process (best fit)	Unit	Measurement
Mainboard	Caps - electrolytic - 6mm diameter 8mm height - 13X	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	6
Mainboard	Coils - large cylindrical - 11x11x8mm, 4X	049-Electronics - Inductor, large cylindrical wound	Mass (g)	21
Mainboard	Coils - large cylindrical - 10x7x9mm, 3X	049-Electronics - Inductor, large cylindrical wound	Mass (g)	8
Mainboard	Coils - toroidal	047-Electronics - Inductor, toroidal	Mass (g)	1
Mainboard	Small heatsink - grey metal non-magnetic	006-Metal - aluminum heatsink	Mass (g)	37
Mainboard	CPU socket - magnetic metal	001-Metal - steel (sheet)	Mass (g)	33
Mainboard	CPU - Intel Celeron 2.2Ghz/512/800/86; 985-pin mounted with heat spreader; 38x38mm, 34x34mm heat spreader	030-Electronics - IC, large BGA (with heat spreader, 672 pin)	Mass (g)	24
Mainboard	Large IC mounted die 1181-pin, 34x34mm PCB, 9x11mm die	033-Electronics - IC, large BGA (mounted bare die, 672 pin)	Mass (g)	4
Mainboard	Silicon die, exposed	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	99
Mainboard	Intel AF82801JD0 mounted package 160-pin 31x31mm PCB 25x25mm package	025-Electronics - IC, large BGA (mounted, plastic package, 144 pin)	Mass (g)	4
Mainboard	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	49
Mainboard	138-pin SMT 20x14mm	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	2
Mainboard	16-pin SMT	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0
Mainboard	56-pin SMT	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0
Mainboard	28-pin SMT	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0
Mainboard	Silicon die, by mass ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	44
Mainboard	Tiny bits and IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	10
Daughterboards	Small PCB 10x2cm 2-layer	019-Electronics - PCB (2 layer, bare)	Mass (g)	8
Daughterboards	USB port, 2x 2.1g each	073-Electronics - ports - small metal (USB, firewire,	Mass (g)	4

Subsystem	Description	Process (best fit)	Unit	Measurement
		ethernet)		
Daughtercards	Audio port, 2x1.7g each	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	3
	Subtotal: Circuit boards (total)		Mass (g)	442
	Subtotal: Circuit boards (excluding IC's)		Mass (g)	407
Casing	Front plate ABS plastic	008-Plastic - ABS	Mass (g)	63
Casing	Main frame piece, magnetic metal	001-Metal - steel (sheet)	Mass (g)	840
Casing	Side piece, magnetic metal	001-Metal - steel (sheet)	Mass (g)	330
Casing	Screws	002-Metal - steel (screws)	Mass (g)	25
	Subtotal: Casing		Mass (g)	1258
Interior parts	Medium case fan - 6x6x2cm	067-Electronics - components - medium case fan	Mass (g)	62
Interior parts	Ribbon cables	083-Electronics - cables - large ribbon cables	Mass (g)	18
Interior parts	Metal plate - magnetic	001-Metal - steel (sheet)	Mass (g)	21
Interior parts	Hard drive 2.5" (laptop size) 250GB SATA 7200 RPM	063-Electronics - components - laptop-size hard disk	Mass (g)	106
Interior parts	HD carriage, magnetic metal	001-Metal - steel (sheet)	Mass (g)	267
Interior parts	Main heatsink - welded metal, approx. 20% copper	007-Metal - copper heatsink	Mass (g)	51
Interior parts	Main heatsink - welded metal, approx. 80% non-magnetic metal	006-Metal - aluminum heatsink	Mass (g)	205
Interior parts	Heatsink front plate - magnetic metal	001-Metal - steel (sheet)	Mass (g)	24
Interior parts	Medium case fan - 7cm diameter	067-Electronics - components - medium case fan	Mass (g)	42
	Subtotal: Other		Mass (g)	796
Power supply	180W internal power supply - PCB, 7x15cm 2 layer	019-Electronics - PCB (2 layer, bare)	Mass (g)	30
Power supply	Tiny IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	10
Power supply	Stiff clear plastic	015-Plastic - polyurethane foam (packaging)	Mass (g)	6

Subsystem	Description	Process (best fit)	Unit	Measurement
Power supply	Casing, magnetic metal	001-Metal - steel (sheet)	Mass (g)	216
Power supply	Coil, large cylindrical - 3x2.5x1.8cm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	42
Power supply	Coil, large cylindrical - 1.5x2.3x2.2	049-Electronics - Inductor, large cylindrical wound	Mass (g)	30
Power supply	Coil, large cylindrical - 1.1x1.7x2.1cm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	7
Power supply	Coil, large cylindrical - 2.5x1.6x1.7cm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	27
Power supply	Coil, large cylindrical - 1.8x1x1cm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	11
Power supply	Coil, large cylindrical - 6x21x15mm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	4
Power supply	Coil, large cylindrical - 7x27x20mm	049-Electronics - Inductor, large cylindrical wound	Mass (g)	4
Power supply	Caps, electrolytic - 30mm diameter x 20mm height	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	18
Power supply	Caps, electrolyte - 10x15mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	2
Power supply	Caps, electrolyte - 8x15mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	1
Power supply	Caps, electrolyte - 8x15mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	1
Power supply	Caps, electrolyte - 6x12mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	1
Power supply	Caps, electrolyte - 6x11mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	1
Power supply	Caps, electrolyte - 5x11mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	0
Power supply	Caps, electrolyte - 5x12mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	0
Power supply	Caps, electrolyte - 8x11mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	1

Subsystem	Description	Process (best fit)	Unit	Measurement
Power supply	Caps, ceramic - 13mm diameter	045-Electronics - Capacitor, ceramic (button)	Mass (g)	2
Power supply	Caps, ceramic - 13mm diameter	045-Electronics - Capacitor, ceramic (button)	Mass (g)	2
Power supply	Caps, ceramic - 7mm diameter	045-Electronics - Capacitor, ceramic (button)	Mass (g)	0
Power supply	Caps, ceramic - 9mm diameter	045-Electronics - Capacitor, ceramic (button)	Mass (g)	0
Power supply	Power transistor, 10mmx17mm, 6X, 11.5g total	042-Electronics - Transistor, large/power	Mass (g)	12
Power supply	Metal heat spreader - light non-magnetic	005-Metal - aluminum (solid)	Mass (g)	11
Power supply	AC power plug + small wires	075-Electronics - ports - AC power plug	Mass (g)	18
Power supply	Internal power plugs and small wires	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	14
Power supply	Screws	002-Metal - steel (screws)	Mass (g)	4
Power supply	Rubber bits	012-Plastic - silicone rubber	Mass (g)	0
Power supply	Small IC's and tiny bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	2
Subtotal: power supply			Mass (g)	476
				0
Subtotal: IC's (packaged)			Mass (g)	35
Subtotal: IC's (die)			Area (mm^2)	218
Total			Mass (g)	2972

Table S6-IV: Full bill of materials, small desktop

C. Thin client

This product is a Dell FX-100 thin client (or "zero client"), circa 2010 manufacture, with dimensions 13cm x 22cm x 5cm, and total mass 1.28kg, excluding external packaging, but including a 182g external power supply.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply (excl. IC's)	Mass (g)	182	5.1	96
Casing	Mass (g)	860	3.7	70
Circuit boards (excl. IC's)	Mass (g)	227	12.6	233
IC's (packages)	Mass (g)	8.4	5.6	126.0
IC's (die)	Area (mm ²)	126	5.4	80
Battery	Mass (g)			
Display	Mass (g)			
Other	Mass (g)			
Transport	Mass (g)	1277	0.3	5
Assembly	Products	1	0.9	19
Total	Mass(g)	1277	33.6	630

Table S6-V: Summary of bill of materials, thin client

Subsystem	Description	Process (best fit)	Unit	Measurement
Assembly	Assembly	098-Assembly - large component or medium product	Products	1
Transport	Transport to regional assembly	087-Transport - SE Asia to regional assembly (per g)	Mass (g)	1277
Casing	Backplate - magnetic metal	001-Metal - steel (sheet)	Mass (g)	157
Casing	Frame - magnetic metal	001-Metal - steel (sheet)	Mass (g)	200
Casing	Backplate - plastic PC+ABS (labeled)	009-Plastic - ABS + PC blend	Mass (g)	104
Casing	Metal screws, magnetic	002-Metal - steel (screws)	Mass (g)	10
Casing	Plastic plating - PC+ABS	009-Plastic - ABS + PC blend	Mass (g)	111

Subsystem	Description	Process (best fit)	Unit	Measurement
Casing	Plastic plating - PC+ABS	009-Plastic - ABS + PC blend	Mass (g)	37
Casing	Bottom stand - PC+ABS plastic	009-Plastic - ABS + PC blend	Mass (g)	69
Casing	Bottom stand - metal plate, magnetic	001-Metal - steel (sheet)	Mass (g)	172
Subtotal (casing)			Mass (g)	860
Power supply	36W power supply, external AC/DC converter - bare PCB 3x9cm 2 layer	019-Electronics - PCB (2 layer, bare)	Mass (g)	6.2
Power supply	Plastic casing PC+FR plastic	010-Plastic - PC	Mass (g)	27
Power supply	Plastic piece PC+FR plastic	010-Plastic - PC	Mass (g)	5.8
Power supply	Power cord	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	58
Power supply	Thin metal sheeting, non-magnetic	003-Metal - aluminum (sheet)	Mass (g)	7.7
Power supply	Power plug	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	7.7
Power supply	Power transistors - 2.2g, 1.9g, 1.9g	042-Electronics - Transistor, large/power	Mass (g)	6.0
Power supply	Copper sheeting (heat spreader)	004-Metal - copper (sheet)	Mass (g)	8.4
Power supply	Large coil 3cm diameter 15mm height	049-Electronics - Inductor, large cylindrical wound	Mass (g)	30
Power supply	Toroidal coil 16mm diameter	047-Electronics - Inductor, toroidal	Mass (g)	6.0
Power supply	Toroidal coil 11mm diameter	047-Electronics - Inductor, toroidal	Mass (g)	1.8
Power supply	Cap electrolytic 15 diameter 26mm height	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	8.7
Power supply	Cap electrolytic 7x16mm, 2X@1.2g each	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	2.4
Power supply	Cap electrolytic 5x12mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	0.3
Power supply	Cap box 18x7x14mm	046-Electronics - Capacitor, polyester film (box)	Mass (g)	2.5
Power supply	Cap box small	046-Electronics - Capacitor, polyester film (box)	Mass (g)	0.3

Subsystem	Description	Process (best fit)	Unit	Measurement
Power supply	Small ceramic caps, 2X @ 0.2g each	045-Electronics - Capacitor, ceramic (button)	Mass (g)	0.4
Power supply	Small diodes 3X @ 0.2g each	050-Electronics - Diode, large (power)	Mass (g)	0.6
Power supply	Small rubbery pieces	012-Plastic - silicone rubber	Mass (g)	0.4
Power supply	Small white epoxy blobs	016-Plastic - epoxy	Mass (g)	1.0
Subtotal (power supply)			Mass (g)	182
Mainboard	Main logic board: 8-layer, 19x12.5cm	022-Electronics - PCB (8 layer, bare)	Mass (g)	99
Mainboard	Toroidal coils, 5@ 2.4 g each average	047-Electronics - Inductor, toroidal	Mass (g)	12
Mainboard	Caps, electrolytic, 5@ 2.2g each average	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	11
Mainboard	LED's	052-Electronics - LED	Mass (g)	1.2
Mainboard	2x USB port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	5.2
Mainboard	2x USB port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	5.2
Mainboard	DVI video port	072-Electronics - ports - video multi-pin	Mass (g)	6.6
Mainboard	DVI video port	072-Electronics - ports - video multi-pin	Mass (g)	6.6
Mainboard	Ethernet port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	9.3
Mainboard	Other misc. connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	15
Mainboard		027-Electronics - IC, large BGA (mounted, plastic package, 672 pin)	Mass (g)	4.7
Mainboard	SMT flat package RAM-style 102-pin 15x15mm	037-Electronics - IC, packaged RAM chip	Mass (g)	0.4
Mainboard	SMT 126-pin 20x14mm	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	1.9
Mainboard	SMT 64-pin 10x10mm	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	0.4
Mainboard	SMT 64-pin 10x10mm	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	0.4

Subsystem	Description	Process (best fit)	Unit	Measurement
Mainboard	SMT 48-pin 7x7mm	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0.2
Mainboard	SMT 16-pin 10x8mm	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0.4
Mainboard	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	126
Mainboard	Tiny IC's and little bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	6.0
Mainboard	Metal heatsink - grey non-magnetic	006-Metal - aluminum heatsink	Mass (g)	50
Subtotal: Circuit boards (total)			Mass (g)	235
Subtotal: Circuit boards (excluding IC's)			Mass (g)	227
Subtotal: IC's (packaged)			Mass (g)	8.4
Subtotal: IC's (die)			Area (mm^2)	126
Total			Mass (g)	1277

Table S6-VI: Full bill of materials, thin client

D. LCD Monitor

This product is Samsung Syncmaster 2243 21.5" LCD monitor, circa 2009 manufacture, with dimensions 32cm x 51cm x 5cm (excluding stand), and total mass 5070, excluding external packaging, but including power and video cables.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply	Mass (g)	173	10.1	189.9
Casing	Mass (g)	2157	10.2	203.2
Circuit boards (excl. IC's)	Mass (g)	38	2.2	41.0
IC's (packages)	Mass (g)	2	1.2	23.7
IC's (die)	Area (mm ²)	22	1.0	15.7
Battery	Mass (g)	0	0.0	0.0
Display	Mass (g)	2350	138.6	2063.8
Other	Mass (g)	350	1.9	41.3
Transport	Mass (g)	5070	1.3	20.2
Assembly	Products	1	1.2	25.3
Total	Mass(g)	5070	167.8	2624.1

Table S6-VII: Summary of bill of materials, LCD monitor

Subsystem	Description	Process (best fit)	Unit	Measurement
Assembly	Assembly	099-Assembly - large component	Products	1
Transport	Transport to regional assembly	087-Transport - SE Asia to regional assembly (per g)	Mass (g)	5070
Display	LCD module 50x29cm (48x27cm viewable, 21.5" diagonal)	058-Display - LCD module	Mass (g)	2350
Casing	Stand: ABS plastic pieces	008-Plastic - ABS	Mass (g)	331
Casing	Stand: metal pieces (magnetic)	001-Metal - steel (sheet)	Mass (g)	332
Casing	Stand: metal screws	002-Metal - steel (screws)	Mass (g)	9
Casing	Plastic front frame: ABS + PMMA	008-Plastic - ABS	Mass (g)	130
Casing	Housing - ABS plastic	008-Plastic - ABS	Mass (g)	42

Subsystem	Description	Process (best fit)	Unit	Measurement
Casing	Backplate plastic high-impact polystyrene (HIPS)	009-Plastic - ABS + PC blend	Mass (g)	600
Casing	Metal frame (magnetic)	001-Metal - steel (sheet)	Mass (g)	650
Casing	HIPS plastic piece	009-Plastic - ABS + PC blend	Mass (g)	50
Casing	metal screws	002-Metal - steel (screws)	Mass (g)	7.0
Casing	small steel piece	001-Metal - steel (sheet)	Mass (g)	5.5
Subtotal: Casing			Mass (g)	2157
Mainboard	2-layer PCB, 6.5 x 8.5 cm	019-Electronics - PCB (2 layer, bare)	Mass (g)	18
Mainboard	VGA port	072-Electronics - ports - video multi-pin	Mass (g)	6.0
Mainboard	DVI port	072-Electronics - ports - video multi-pin	Mass (g)	5.5
Mainboard	misc. connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	2.2
Mainboard	20x14mm Samsung QFP chip 136-pin	034-Electronics - IC, large BGA SMT, no PCB (144 pin)	Mass (g)	1.7
Mainboard	Silicon die, by area ratio	092-Silicon die - 1999 process (180 nm)	Area (mm^2)	22
Mainboard	Small IC's and bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	2.0
Mainboard	ribbon cable	083-Electronics - cables - large ribbon cables	Mass (g)	4.7
Subtotal: Circuit boards (total)			Mass (g)	40
Subtotal: Circuit boards (excluding IC's)			Mass (g)	38
Power supply	2-layer PCB 16x13cm	019-Electronics - PCB (2 layer, bare)	Mass (g)	18
Power supply	caps large electrolytic	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	24
Power supply	coils large cylindrical wound	049-Electronics - Inductor, large cylindrical wound	Mass (g)	77
Power supply	caps ceramic	045-Electronics - Capacitor, ceramic (button)	Mass (g)	6.3
Power supply	caps polyester film	046-Electronics - Capacitor, polyester film (box)	Mass (g)	6.8
Power supply	diodes large	050-Electronics - Diode, large (power)	Mass (g)	5.1

Subsystem	Description	Process (best fit)	Unit	Measurement
Power supply	power MOSFETs	042-Electronics - Transistor, large/power	Mass (g)	4.3
Power supply	AC power plug	075-Electronics - ports - AC power plug	Mass (g)	8.3
Power supply	metal heatsink aluminum	006-Metal - aluminum heatsink	Mass (g)	18
Power supply	connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	5.6
Subtotal: Power supply			Mass (g)	173
Extra parts	Power cable	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	150
Extra parts	VGA cable	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	90
Extra parts	DVI cable	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	110
Subtotal: Other			Mass (g)	350
Subtotal: IC's (packages)			Mass (g)	1.7
Subtotal: IC's (die)			Area (mm^2)	22
Total				5070

Table S6-VIII: Full bill of materials, LCD monitor

E. Laptop

This product is an HP 530 laptop, circa 2009 manufacture, with dimensions 35cm x 25cm x 3cm, and total mass 2.77kg, excluding external packaging, but including a 433g external power supply.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply	Mass (g)	433	9.0	172.9
Casing	Mass (g)	904	6.8	134.2
Circuit boards (excl. IC's)	Mass (g)	281	16.2	322.7
IC's (packages)	Mass (g)	21	15.5	306.2
IC's (die)	Area (mm ²)	483	20.8	307.2
Battery	Mass (g)	244	1.3	24.6
Display	Mass (g)	553	31.9	475.4
Other	Mass (g)	334	4.9	87.8
Transport	Mass (g)	2770	0.7	11.1
Assembly	Products	1	0.9	19.0
Total	Mass(g)	2770	107.8	1861.1

Table S6-IX: Summary of bill of materials, laptop

Subsystem	Description	Process (best fit)	Unit	Measurement
Assembly	Assembly	098-Assembly - large component or medium product	Products	1
Transport	Transport to regional assembly	087-Transport - SE Asia to regional assembly (per g)	Mass (g)	2770
Battery	14.4V, 32WH Li-ion battery (encased in plastic)	054-Battery - Li-Ion 32 Whr (Laptop)	Mass (g)	244
Casing	RAM cover, plastic, PC+ABS	009-Plastic - ABS + PC blend	Mass (g)	28
Casing	Metal screws	002-Metal - steel (screws)	Mass (g)	4.2
Casing	HD cover, plastic PC+ABS	009-Plastic - ABS + PC blend	Mass (g)	28
Casing	Backplate, PC/ABS plastic 35x26cm	009-Plastic - ABS + PC blend	Mass (g)	231
Casing	Frontplate, PC/ABS plastic,	009-Plastic - ABS + PC blend	Mass (g)	38

	34x5cm			
Casing	Frontplate, PC/ABS plastic	009-Plastic - ABS + PC blend	Mass (g)	215
Casing	ABS housing for speakers	009-Plastic - ABS + PC blend	Mass (g)	3.2
Casing	Brackets main hinge - "Mg alloy" - 2x6.3g	001-Metal - steel (sheet)	Mass (g)	13
Casing	Front frame - PC-ABS plastic	009-Plastic - ABS + PC blend	Mass (g)	40
Casing	Metal screws	002-Metal - steel (screws)	Mass (g)	4.2
Casing	Backplate PC-ABS plastic	009-Plastic - ABS + PC blend	Mass (g)	240
Casing	Display frame - steel clamps	001-Metal - steel (sheet)	Mass (g)	60
Subtotal: Casing			Mass (g)	904
Daughtercards	Small daughtercard: 13x77mm 6 layer, negligible IC's	021-Electronics - PCB (6 layer, bare)	Mass (g)	2.7
Daughtercards	Small daughtercard: 25x35mm, 4 layer	020-Electronics - PCB (4 layer, bare)	Mass (g)	2.5
Daughtercards	On-board connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	3.0
Mainboard	Main logic board 15x19+11x6cm, 6 layer	021-Electronics - PCB (6 layer, bare)	Mass (g)	102
Mainboard	Plastic spill guard	011-Plastic - LPDE (plastic wrap)	Mass (g)	5.8
Mainboard	3V CR2032 Li battery	056-Battery - CR2032 3V Li-Ion (CMOS)	Mass (g)	2.9
Mainboard	Heatsink - copper bar (heat conductor)	007-Metal - copper heatsink	Mass (g)	17
Mainboard	Heatsink - fins (non-magnetic)	006-Metal - aluminum heatsink	Mass (g)	4.0
Mainboard	Heatsink - heat spreader (non-magnetic)	006-Metal - aluminum heatsink	Mass (g)	16
Mainboard	PCMCIA card port	079-Electronics - connectors - PCI-type slot	Mass (g)	17
Mainboard	RAM slots, 2x5g each, 6.5cm	077-Electronics - connectors - laptop-size RAM slot	Mass (g)	10
Mainboard	Ethernet port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	2.7
Mainboard	Voice data port	073-Electronics - ports - small metal (USB, firewire,	Mass (g)	1.8

		ethernet)		
Mainboard	USB port, 2x2g each	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	4.0
Mainboard	VGA port	072-Electronics - ports - video multi-pin	Mass (g)	3.8
Mainboard	Stereo mini port, 2x1g each	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	1.9
Mainboard	Power port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	1.5
Mainboard	Misc. connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	8.1
Mainboard	CPU - large metal heat spreader, non-magnetic	006-Metal - aluminum heatsink	Mass (g)	8.8
Mainboard	CPU - plastic socket	080-Electronics - connectors - CPU socket	Mass (g)	5.7
Mainboard	CPU - Intel 1.83/2M/667 398-pin bare die; 35x35mm, 8x11mm die	033-Electronics - IC, large BGA (mounted bare die, 672 pin)	Mass (g)	6.2
Mainboard	CPU unmarked 1469-pin bare die 37x37mm PBC 11x11mm die	033-Electronics - IC, large BGA (mounted bare die, 672 pin)	Mass (g)	4.7
Mainboard	Silicon die, exposed	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	209
Mainboard	CPU Intel NH82820 652-pin mounted package 31x31cm PCB 25x25mm package	027-Electronics - IC, large BGA (mounted, plastic package, 672 pin)	Mass (g)	3.5
Mainboard	128-pin SMT 21x21mm	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	1.4
Mainboard	128-pin SMT 15x15mm	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	0.5
Mainboard	72-pin DIP 17x7mm	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	0.3
Mainboard	48-pin DIP 16x7mm	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0.7
Mainboard	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	119
Mainboard	Small IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	3.3
Mainboard	Small inductors	048-Electronics - Inductor, chip (small box)	Mass (g)	11
Mainboard	Small caps	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	2.5
Mainboard	Misc. connectors	081-Electronics - connectors - misc. on-board plugs	Mass (g)	6.0

		and connectors		
Mainboard	Misc. tiny bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	7.2
Mainboard	Small CPU fan, 5x6cm	065-Electronics - components - small CPU fan	Mass (g)	0.0
Daughterboards	Wireless antenna - wires	084-Electronics - cables - small cables and wires	Mass (g)	6.6
Daughterboards	Wireless antenna - metal, non-magnetic	005-Metal - aluminum (solid)	Mass (g)	4.3
Daughterboards	Small PWB, 1x10cm	019-Electronics - PCB (2 layer, bare)	Mass (g)	8.0
RAM	RAM PCB, 2x, each 30x67mm 6-layer	021-Electronics - PCB (6 layer, bare)	Mass (g)	5.7
RAM	16X RAM IC's, each 84-pin 0.2g, 12x10mm (64MB)	037-Electronics - IC, packaged RAM chip	Mass (g)	3.2
RAM	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	150
Daughterboards	Wireless board - PCB 5x3cm, 4 layer	020-Electronics - PCB (4 layer, bare)	Mass (g)	3.6
Daughterboards	Wireless board - metal shield, magnetic	001-Metal - steel (sheet)	Mass (g)	1.2
Daughterboards	Wireless board - large IC 225-pin packaged BGA SMT	035-Electronics - IC, large BGA SMT, no PCB (256 pin)	Mass (g)	0.3
Daughterboards	Silicon die, by mass ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	5.5
Daughterboards	Wireless board small IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	0.4
Subtotal: Circuit boards (total)			Mass (g)	302
Subtotal: Circuit boards (excluding IC's)			Mass (g)	281
Display	LCD module 36x21.5cm	058-Display - LCD module	Mass (g)	540
Display	Display, reflective backplate, flexible plastic tape	011-Plastic - LPDE (plastic wrap)	Mass (g)	13
Subtotal: Display			Mass (g)	553
Power supply	Power cable	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	160
Power supply	Power cord	082-Electronics - cables - power cords, thick cables	Mass (g)	64

		and cords		
Power supply	Plastic casing	008-Plastic - ABS	Mass (g)	58
Power supply	Bare PCB 2-layer 5x11cm	019-Electronics - PCB (2 layer, bare)	Mass (g)	17
Power supply	Cylindrical electrolytic caps	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	12
Power supply	Ceramic caps	045-Electronics - Capacitor, ceramic (button)	Mass (g)	3
Power supply	Coils - large cylindrical wound	049-Electronics - Inductor, large cylindrical wound	Mass (g)	53
Power supply	Coils - toroidal	047-Electronics - Inductor, toroidal	Mass (g)	6
Power supply	Capacitor - box (film)	046-Electronics - Capacitor, polyester film (box)	Mass (g)	6
Power supply	Power plug	075-Electronics - ports - AC power plug	Mass (g)	11
Power supply	Metal frame, aluminum	003-Metal - aluminum (sheet)	Mass (g)	31
Power supply	Power transistors	042-Electronics - Transistor, large/power	Mass (g)	5
Power supply	LED	052-Electronics - LED	Mass (g)	0
Power supply	Power resistors	051-Electronics - Resistor, large (power)	Mass (g)	1
Power supply	Fuse	050-Electronics - Diode, large (power)	Mass (g)	1
Power supply	Rubbery coatings	012-Plastic - silicone rubber	Mass (g)	2
Power supply	Small transistors	041-Electronics - Transistor, small	Mass (g)	0
Power supply	Small diodes	050-Electronics - Diode, large (power)	Mass (g)	0
Power supply	Small IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	0
Power supply	Small metal brackets, magnetic	001-Metal - steel (sheet)	Mass (g)	1
Power supply	Small plastic bits	008-Plastic - ABS	Mass (g)	1
Subtotal: Power supply				433
Interior parts	DVD-RW drive, 180g, 13x12.1x1.3cm	061-Electronics - components - DVD drive	Mass (g)	180
Keyboard	Keys, PC/ABS plastic	009-Plastic - ABS + PC blend	Mass (g)	25
Keyboard	Plastic bumpers (white plastic)	009-Plastic - ABS + PC blend	Mass (g)	10
Keyboard	Metal brackets -steel	001-Metal - steel (sheet)	Mass (g)	1
Keyboard	Rubber/silicone bumpers	012-Plastic - silicone rubber	Mass (g)	3

Keyboard	Papery film layer	018-Paper	Mass (g)	4
Keyboard	Flexible circuit board - 30.5x10.5cm	013-Plastic - polystyrene film (flex circuit board)	Mass (g)	8
Keyboard	Metal backplate - non-magnetic	005-Metal - aluminum (solid)	Mass (g)	45
Interior parts	Stickers on wireless chip	018-Paper	Mass (g)	0
Interior parts	HD carriage, metal, magnetic	001-Metal - steel (sheet)	Mass (g)	34
Keyboard	Trackpad - Metal plate, non-magnetic	003-Metal - aluminum (sheet)	Mass (g)	9
Keyboard	Trackpad - Sticker	018-Paper	Mass (g)	1
Keyboard	Trackpad - Small PCB - 7.5g , 7 x 5cm	019-Electronics - PCB (2 layer, bare)	Mass (g)	8
Interior parts	Speakers	071-Electronics - components - speaker	Mass (g)	3
Interior parts	PCMCIA card tray - PC/ABS plastic	009-Plastic - ABS + PC blend	Mass (g)	6
Subtotal: Other			Mass (g)	334
Subtotal: IC's (packaged)			Mass (g)	21
Subtotal: IC's (die)			Area (mm^2)	483
Total			Mass (g)	2770

Table S6-X: Full bill of materials, laptop

F. Netbook

This product is an HP Mini 110-1030CA netbook-style laptop, circa 2009 manufacture, with dimensions 26cm x 17cm x 3cm, and total mass 1.34kg, excluding external packaging, but including a 297g external power supply.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply	Mass (g)	297	8	151
Casing	Mass (g)	265	2	39
Circuit boards (excl. IC's)	Mass (g)	127	9	161
IC's (packages)	Mass (g)	17	12	245
IC's (die)	Area (mm ²)	463	20	294
Battery	Mass (g)	178	0.9	18
Display	Mass (g)	204	7	101
Other	Mass (g)	250	3	54
Transport	Mass (g)	1337	0.3	5
Assembly	Products	1	1	19
Total	Mass(g)	1337	62	1088

Table S6-XI: Summary of bill of materials, netbook

Subsystem	Description	Process (best fit)	Unit	Measurement
Assembly	Assembly	098-Assembly - large component or medium product	Products	1
Transport	Transport to regional assembly	087-Transport - SE Asia to regional assembly (per g)	Mass (g)	1337
Battery	Battery - Li-Ion Cell 10.8V, 2420mAh	054-Battery - Li-Ion 32 Whr (Laptop)	Mass (g)	178
Display	Display - thin metal layer	003-Metal - aluminum (sheet)	Mass (g)	5.3
Display	LCD module, 22.5x12.7cm	058-Display - LCD module	Mass (g)	107

Subsystem	Description	Process (best fit)	Unit	Measurement
Display	Glass plate, 23x13.8cm	059-Display - Glass	Mass (g)	92
	Subtotal: Display		Mass (g)	204
Casing	Backplate - PC+ABS plastic, 25.5X15cm	009-Plastic - ABS + PC blend	Mass (g)	120
Casing	Display plastic frame PC+ABS	009-Plastic - ABS + PC blend	Mass (g)	15
Casing	Display plastic frontplate PC+ABS	009-Plastic - ABS + PC blend	Mass (g)	105
Casing	Metal hinge brackets, magnetic, 2x12.5g each	001-Metal - steel (sheet)	Mass (g)	25
	Subtotal: Casing		Mass (g)	265
Daughtercards	Small daughtercard - 5.5x2cm, 4 layer	019-Electronics - PCB (2 layer, bare)	Mass (g)	3.3
Daughtercards	USB port 1x	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	1.4
Daughtercards	Stereo mini port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	1.6
Daughtercards	Ribbon connector	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	0.5
Daughtercards	Small IC devices	040-Electronics - IC, tiny < 0.1g	Mass (g)	0.2
Daughtercards	Small daughtercard - 2.5x3.5cm+1x5cm	020-Electronics - PCB (4 layer, bare)	Mass (g)	5.6
Daughtercards	Small power adapter plug	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	1.5
Daughtercards	Small wire	084-Electronics - cables - small cables and wires	Mass (g)	0.9
Daughtercards	Small ribbon connector	084-Electronics - cables - small cables and wires	Mass (g)	0.9
Daughtercards	Small SMT IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	1.5
Daughtercards	Small inductor	048-Electronics - Inductor, chip (small box)	Mass (g)	1.5
RAM	RAM stick PCB 6.7x3cm (laptop RAM), 8 layer	022-Electronics - PCB (8 layer, bare)	Mass (g)	6.3
RAM	8X RAM chips, 10x14mm 108 pin	037-Electronics - IC, packaged RAM chip	Mass (g)	1.6

Subsystem	Description	Process (best fit)	Unit	Measurement
	0.2g each			
RAM	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	87
Mainboard	Battery - CR 2016 Li 3V	056-Battery - CR2032 3V Li-Ion (CMOS)	Mass (g)	1.8
Mainboard	Intel CPU 652-pin packaged/PCB BGA 30x30mm	027-Electronics - IC, large BGA (mounted, plastic package, 672 pin)	Mass (g)	4.0
Mainboard	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	70
Mainboard	Intel 1.60Ghz 227pin bare die/PCB; 24x24mm PCB 7x7mm die.	032-Electronics - IC, large BGA (mounted bare die, 256 pin)	Mass (g)	3.0
Mainboard	Bare die 1001-pin 26x26mm package 11x11mm die	033-Electronics - IC, large BGA (mounted bare die, 672 pin)	Mass (g)	1.2
Mainboard	Silicon die, exposed	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	170
Mainboard	108-pin SMT 13x13mm	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	0.6
Mainboard	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	13
Mainboard	Mid-size SMT IC's	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	4.8
Mainboard	Silicon die, by mass ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	88
Mainboard	Small inductors	048-Electronics - Inductor, chip (small box)	Mass (g)	3.8
Mainboard	Small on-board batteries, 2X 1.2g each	057-Battery - small on-board	Mass (g)	2.4
Mainboard	Ethernet port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	2.8
Mainboard	2X USB port 1.8g each	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	3.6
Mainboard	VGA port	072-Electronics - ports - video multi-pin	Mass (g)	3.0
Mainboard	Misc. on-board connectors and plugs	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	12
Mainboard	Main logic board - 23.5*6.6 + 4.3x5cm, 8 layer	022-Electronics - PCB (8 layer, bare)	Mass (g)	59
Daughterboards	Small PCB for WLAN - 3x2.3cm	019-Electronics - PCB (2 layer, bare)	Mass (g)	2.3

Subsystem	Description	Process (best fit)	Unit	Measurement
Daughtercards	Small BGA Broadcom 120-pin 10x10mm	034-Electronics - IC, large BGA SMT, no PCB (144 pin)	Mass (g)	0.2
Daughtercards	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	7.8
Daughtercards	Small RF shield magnetic	001-Metal - steel (sheet)	Mass (g)	1.0
Daughtercards	Display controller PCB 21x3.5cm	019-Electronics - PCB (2 layer, bare)	Mass (g)	11
Daughtercards	Small SMT IC's	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	1.4
Daughtercards	Silicon die, by mass ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	26
Subtotal: Circuit boards (total)			Mass (g)	144
Subtotal: Circuit boards (excluding IC's)			Mass (g)	127
Power supply	42W external power supply (AC/DC converter)			
Power supply	Power cord (AC side)	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	88
Power supply	Power cord (DC side)	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	51
Power supply	2-layer PCB 9.5x5.5cm	019-Electronics - PCB (2 layer, bare)	Mass (g)	20
Power supply	Plastic casing	008-Plastic - ABS	Mass (g)	37
Power supply	Metal frame (aluminum)	005-Metal - aluminum (solid)	Mass (g)	13
Power supply	Electrolytic caps	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	14
Power supply	Ceramic caps	045-Electronics - Capacitor, ceramic (button)	Mass (g)	3
Power supply	Coil large cylindrical	049-Electronics - Inductor, large cylindrical wound	Mass (g)	32
Power supply	Coil toroidal	047-Electronics - Inductor, toroidal	Mass (g)	6
Power supply	Power transistors	042-Electronics - Transistor, large/power	Mass (g)	10
Power supply	Resistors	051-Electronics - Resistor, large (power)	Mass (g)	1
Power supply	Small diodes	050-Electronics - Diode, large (power)	Mass (g)	0

Subsystem	Description	Process (best fit)	Unit	Measurement
Power supply	20mm fuse	050-Electronics - Diode, large (power)	Mass (g)	2
Power supply	Metal screws	002-Metal - steel (screws)	Mass (g)	1
Power supply	Small copper piece	004-Metal - copper (sheet)	Mass (g)	2
Power supply	Small aluminum pieces	005-Metal - aluminum (solid)	Mass (g)	3
Power supply	AC power plug	075-Electronics - ports - AC power plug	Mass (g)	4
Power supply	Clear rubbery plastic	012-Plastic - silicone rubber	Mass (g)	7
Power supply	Stiff clear plastic pieces	010-Plastic - PC	Mass (g)	3
Subtotal: Power supply			Mass (g)	297
Keyboard	Plastic plating - PC-ABS	009-Plastic - ABS + PC blend	Mass (g)	60
Keyboard	Trackpad - Plastic plating PC-ABS	009-Plastic - ABS + PC blend	Mass (g)	4
Keyboard	Trackpad - Small PCB 6x3.4cm	019-Electronics - PCB (2 layer, bare)	Mass (g)	5
Keyboard	Trackpad - Tiny SMT components	040-Electronics - IC, tiny < 0.1g	Mass (g)	0
Keyboard	Plastic keys - PC-ABS	009-Plastic - ABS + PC blend	Mass (g)	20
Keyboard	Plastic bumpers - unknown white plastic	009-Plastic - ABS + PC blend	Mass (g)	10
Keyboard	Rubber bumpers	012-Plastic - silicone rubber	Mass (g)	2
Keyboard	Flexible printed circuit , 25x10cm	013-Plastic - polystyrene film (flex circuit board)	Mass (g)	8
Interior parts	Metal plating, non-magnetic	003-Metal - aluminum (sheet)	Mass (g)	70
Interior parts	Hard drive cover - non-magnetic metal	003-Metal - aluminum (sheet)	Mass (g)	14
Interior parts	Small flat ribbon cable 9cm	083-Electronics - cables - large ribbon cables	Mass (g)	0
Interior parts	Copper heat spreader (flat)	004-Metal - copper (sheet)	Mass (g)	15
Interior parts	Small CPU fan 4x4cm	065-Electronics - components - small CPU fan	Mass (g)	13
Interior parts	Speakers	049-Electronics - Inductor, large cylindrical wound	Mass (g)	11
Interior parts	Display cable	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	6

Subsystem	Description	Process (best fit)	Unit	Measurement
Interior parts	Long thin wire for wireless (50cm)	084-Electronics - cables - small cables and wires	Mass (g)	3
Interior parts	Display cable	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	6
Interior parts	Long thin wire for wireless (50cm)	084-Electronics - cables - small cables and wires	Mass (g)	3
Subtotal: Other			Mass (g)	250
Subtotal: IC's (packaged)			Mass (g)	17
Subtotal: IC's (die)			Area (mm^2)	463
Total			Mass (g)	1337

Table S6-XII: Full bill of materials, netbook

G. Apple iPad

This product is an Apple iPad 8Gb WIFI 1st gen, circa 2009 manufacture, with dimensions 24cm x 19cm x 1cm, and total mass 777g, excluding external packaging, but including an 89g external power supply.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply	Mass (g)	89	2.3	42.2
Casing	Mass (g)	151	1.3	21.8
Circuit boards (excl. IC's)	Mass (g)	30	1.7	32.0
IC's (packages)	Mass (g)	1.8	1.3	25.1
IC's (die)	Area (mm ²)	170	7.3	108.1
Battery	Mass (g)	129	0.7	13.0
Display	Mass (g)	342	9.9	148.4
Other	Mass (g)	34	0.1	3.3
Transport	Mass (g)	777	0.2	3.1
Assembly	Products	1	0.6	12.7
Total	Mass(g)	777	25.5	409.6

Table S6-XIII: Summary of bill of materials, iPad

Subsystem	Description	Process (best fit)	Unit	Measurement
Assembly	Assembly	097-Assembly - subcomponent or small product	Pieces	1
Transport	Transport to regional assembly	087-Transport - SE Asia to regional assembly (per g)	Mass (g)	777
Battery	2X Li-ion 24.8Whr 3.75V battery	053-Battery - Li-Ion 24.8 Whr (iPad)	Mass (g)	129
Display	LCD module 21x16.5 cm	058-Display - LCD module	Mass (g)	154
Display	Glass and small plastic frame 18.5x24cm	059-Display - Glass	Mass (g)	188
Subtotal: Display			Mass (g)	342
Casing	Backplate, metal 19x24cm non-	003-Metal - aluminum (sheet)	Mass (g)	136

Subsystem	Description	Process (best fit)	Unit	Measurement
	magnetic			
Casing	Metal screws	002-Metal - steel (screws)	Mass (g)	2.1
Casing	Metal and plastic tabs	001-Metal - steel (sheet)	Mass (g)	1.0
Casing	Metal and plastic tabs	008-Plastic - ABS	Mass (g)	1.0
Casing	Bottom plate light plastic	008-Plastic - ABS	Mass (g)	11
Subtotal: Casing			Mass (g)	151
Mainboard	Main logic board, 10 layer, approx. 5x11cm	023-Electronics - PCB (10 layer, bare)	Mass (g)	12
Mainboard	2X solid state memory, 8GB each, 52-pin 14x18mm 0.3g each	037-Electronics - IC, packaged RAM chip	Mass (g)	0.6
Mainboard	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	39
Mainboard	A4 processor; 14x14mm package; chip 7x7mm; 551-pin; SMT package	036-Electronics - IC, large BGA SMT, no PCB (672 pin)	Mass (g)	0.6
Mainboard	Silicon die, exposed	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	49
Mainboard	Silicon die, 2X stacked memory (via 3rd party teardown)	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	71
Mainboard	Small coils (box-type)	048-Electronics - Inductor, chip (small box)	Mass (g)	1.9
Mainboard	Medium IC's: 2x100pin; 2x121pin; 1x 64pin; 0.5g total	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	0.5
Mainboard	Silicon die, by mass ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	9.2
Mainboard	Small IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	1.6
Mainboard	Misc. on-board connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	1.2
Mainboard	RF shielding - magnetic metal	001-Metal - steel (sheet)	Mass (g)	9.2
Mainboard	Wireless assembly -small logic board 25x10mm	019-Electronics - PCB (2 layer, bare)	Mass (g)	0.8
Mainboard	Chip - bare die mounted, very small	035-Electronics - IC, large BGA SMT, no PCB (256 pin)	Mass (g)	0.1
Mainboard	Silicon die, by mass ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	1.8

Subsystem	Description	Process (best fit)	Unit	Measurement
Mainboard	Metal shield	001-Metal - steel (sheet)	Mass (g)	0.2
Mainboard	Connector port for main plug cable	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	2.4
Subtotal: Circuit boards (total)			Mass (g)	32
Subtotal: Circuit boards (excluding IC's)			Mass (g)	30
Power supply	PC plastic casing	010-Plastic - PC	Mass (g)	17
Power supply	AC plug with plastic coating	075-Electronics - ports - AC power plug	Mass (g)	18
Power supply	Plastic piece	010-Plastic - PC	Mass (g)	3.4
Power supply	Metal piece (non-magnetic)	003-Metal - aluminum (sheet)	Mass (g)	3.4
Power supply	Power connector	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	4.1
Power supply	Tiny power supply mainboard (5x2.5cm)	019-Electronics - PCB (2 layer, bare)	Mass (g)	1.5
Power supply	Tiny IC's and SMT components	040-Electronics - IC, tiny < 0.1g	Mass (g)	2.0
Power supply	USB port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	2.1
Power supply	Cylindrical electrolytic caps	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	4.6
Power supply	Coils, large wound	049-Electronics - Inductor, large cylindrical wound	Mass (g)	10
Power supply	Ceramic caps	045-Electronics - Capacitor, ceramic (button)	Mass (g)	1.2
Power supply	Plastic bits	008-Plastic - ABS	Mass (g)	1.0
Power supply	Other bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	1.0
Power supply	USB cable	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	20
Subtotal: Power supply			Mass (g)	89
Interior parts	Plastic/rubber strip	012-Plastic - silicone rubber	Mass (g)	4.4

Subsystem	Description	Process (best fit)	Unit	Measurement
Interior parts	Connector	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	1.5
Interior parts	Speakers 2x3g	071-Electronics - components - speaker	Mass (g)	6.0
Interior parts	Antenna	084-Electronics - cables - small cables and wires	Mass (g)	1.1
Interior parts	Shield for antenna - thin metal foil, non-magnetic	003-Metal - aluminum (sheet)	Mass (g)	1.2
Interior parts	Plastic housing for battery	008-Plastic - ABS	Mass (g)	20
Subtotal: Other			Mass (g)	34
Subtotal: IC's (packages)			Mass (g)	1.8
Subtotal: IC's (die)			Area (mm^2)	170
Total			Mass (g)	777

Table S6-XIV: Full bill of materials, iPad

H. Apple iPod Touch

This product is an Apple iPod touch 8gb. 3rd generation, circa 2009 manufacture, with dimensions 11cm x 6cm x 0.5cm, and total mass 198g, excluding external packaging, but including an 89g external power supply.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply	Mass (g)	89	2.3	42.2
Casing	Mass (g)	49	0.4	7.2
Circuit boards (excl. IC's)	Mass (g)	6.0	0.4	7.0
IC's (packages)	Mass (g)	0.8	0.6	11.1
IC's (die)	Area (mm ²)	52	2.2	33.0
Battery	Mass (g)	16	0.1	1.6
Display	Mass (g)	35	0.8	11.4
Other	Mass (g)	2.8	0.0	0.3
Transport	Mass (g)	198	0.0	0.8
Assembly	Products	1	0.6	12.7
Total	Mass(g)	198	7.5	127.1

Table S6-XV: Summary of bill of materials, iPod touch

Subsystem	Description	Process (best fit)	Unit	Measurement
Assembly	Assembly	097-Assembly - subcomponent or small product	Products	1
Transport	Transport to regional assembly	087-Transport - SE Asia to regional assembly (per g)	Mass (g)	198
Battery	Li-ion polymer battery 3.7V 2.83Whr	055-Battery - Li-Ion 2.83 Whr (iPod touch)	Mass (g)	16

Subsystem	Description	Process (best fit)	Unit	Measurement
Casing	Backplate - non-magnetic metal	003-Metal - aluminum (sheet)	Mass (g)	33
Casing	Interior metal plating, non-magnetic	003-Metal - aluminum (sheet)	Mass (g)	15
Casing	Metal screws	002-Metal - steel (screws)	Mass (g)	0.4
Subtotal: Casing			Mass (g)	49
Display	Front glass	059-Display - Glass	Mass (g)	24
Display	LCD module 55x83mm	058-Display - LCD module	Mass (g)	11
Subtotal: Display			Mass (g)	35
Mainboard	Mainboard 42x27mm 2 layer	019-Electronics - PCB (2 layer, bare)	Mass (g)	1.9
Mainboard	RF shielding - light magnetic metal	001-Metal - steel (sheet)	Mass (g)	1.3
Mainboard	Ribbon connector	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	0.7
Mainboard	Apple ARM CPU 12x12mm 333 pin plastic package	035-Electronics - IC, large BGA SMT, no PCB (256 pin)	Mass (g)	0.3
Mainboard	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	11
Mainboard	Silicon die, 2X stacked memory (via 3rd party teardown)	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	16
Mainboard	Samsung RAM 52pin 14x19mm	037-Electronics - IC, packaged RAM chip	Mass (g)	0.3
Mainboard	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	21
Mainboard	Small IC	040-Electronics - IC, tiny < 0.1g	Mass (g)	0.3
Mainboard	Small IC's and tiny bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	0.3
Daughtercards	Bottom assembly - small printed circuit 3cm^2	019-Electronics - PCB (2 layer, bare)	Mass (g)	0.5
Daughtercards	Bottom assembly - small IC memory type 50-pin	037-Electronics - IC, packaged RAM chip	Mass (g)	0.2
Daughtercards	Silicon die, by mass ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	3.7
Daughtercards	Bottom assembly - RF shield - non-magnetic metal	003-Metal - aluminum (sheet)	Mass (g)	0.1
Daughtercards	Bottom assembly - plastic piece	008-Plastic - ABS	Mass (g)	0.5

Subsystem	Description	Process (best fit)	Unit	Measurement
Daughtercards	Bottom assembly - small speaker	071-Electronics - components - speaker	Mass (g)	0.4
Subtotal: Circuit boards (total)			Mass (g)	7
Subtotal: Circuit boards (excluding IC's)			Mass (g)	6
Power supply	PC plastic casing	010-Plastic - PC	Mass (g)	17
Power supply	AC plug with plastic coating	075-Electronics - ports - AC power plug	Mass (g)	18
Power supply	Plastic piece	010-Plastic - PC	Mass (g)	3.4
Power supply	Metal piece (non-magnetic)	003-Metal - aluminum (sheet)	Mass (g)	3.4
Power supply	Power connector	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	4.1
Power supply	Tiny power supply mainboard (5x2.5cm)	019-Electronics - PCB (2 layer, bare)	Mass (g)	1.5
Power supply	Tiny IC's and SMT components	040-Electronics - IC, tiny < 0.1g	Mass (g)	2.0
Power supply	USB port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	2.1
Power supply	Cylindrical electrolytic caps	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	4.6
Power supply	Coils, large wound	049-Electronics - Inductor, large cylindrical wound	Mass (g)	10
Power supply	Ceramic caps	045-Electronics - Capacitor, ceramic (button)	Mass (g)	1.2
Power supply	Plastic bits	008-Plastic - ABS	Mass (g)	1.0
Power supply	Other bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	1.0
Power supply	USB cable	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	20
Subtotal: Power supply			Mass (g)	89
Interior parts	Flexible printed ribbon cable	013-Plastic - polystyrene film (flex circuit board)	Mass (g)	1.5
Interior parts	Small black plastic internal framing	008-Plastic - ABS	Mass (g)	0.8
Interior parts	Silicone rubber piece	012-Plastic - silicone rubber	Mass (g)	0.5
Subtotal: Other			Mass (g)	2.8

Subsystem	Description	Process (best fit)	Unit	Measurement
	Subtotal: IC's (packages)		Mass (g)	0.8
	Subtotal: IC's (die)		Area (mm^2)	52
	Total		Mass (g)	198

Table S6-XVI: Full bill of materials, iPod touch

I. Amazon Kindle

This product is an Amazon Kindle 3rd generation Wi-Fi model, circa 2010 manufacture, with dimensions 19cm x 12.5cm x 0.5cm, and total mass 312g, excluding external packaging, but including an 89g external power supply.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply	Mass (g)	89	2.3	42.2
Casing	Mass (g)	59	0.5	7.9
Circuit boards (excl. IC's)	Mass (g)	33	2.4	44.8
IC's (packages)	Mass (g)	1.6	1.2	22.3
IC's (die)	Area (mm ²)	66	3.6	53.0
Battery	Mass (g)	51	0.3	5.1
Display	Mass (g)	34	2.0	29.8
Other	Mass (g)	45	0.3	6.0
Transport	Mass (g)	312	0.1	1.2
Assembly	Products	1	0.6	12.7
Total	Mass(g)	312	13.3	225.1

Table S6-XVII: Summary of bill of materials, Amazon Kindle

Subsystem	Description	Process (best fit)	Unit	Measurement
Assembly	Assembly	097-Assembly - subcomponent or small product	Products	1
Transport	Transport to regional assembly	087-Transport - SE Asia to regional assembly (per g)	Mass (g)	312
Battery	Li-ion battery 7x10cm 3.7V 6.5Wh minimum capacity	053-Battery - Li-Ion 24.8 Whr (iPad)	Mass (g)	51
Display	E-ink display module, 10x14cm	060-Display - E-ink module	Mass (g)	34
Casing	Plastic backplate "PC CM-10 2" plastic	010-Plastic - PC	Mass (g)	36
Casing	Plastic frontplate "PC CM-10 2" plastic	010-Plastic - PC	Mass (g)	21

Subsystem	Description	Process (best fit)	Unit	Measurement
Casing	Metal screws, magnetic	002-Metal - steel (screws)	Mass (g)	1.5
Subtotal: Casing			Mass (g)	59
Mainboard	Mainboard - 6 layer bare PCB 7x19.5 + 4x4cm	021-Electronics - PCB (6 layer, bare)	Mass (g)	21
Mainboard	16x16mm flat package 400-pin BGA	035-Electronics - IC, large BGA SMT, no PCB (256 pin)	Mass (g)	0.7
Mainboard	18x14mm flat package 188-pin BGA (Samsung)	034-Electronics - IC, large BGA SMT, no PCB (144 pin)	Mass (g)	0.3
Mainboard	12x12mm flat package 188-pin BGA	034-Electronics - IC, large BGA SMT, no PCB (144 pin)	Mass (g)	0.3
Mainboard	12x8mm Samsung RAM-type 90-pin	037-Electronics - IC, packaged RAM chip	Mass (g)	0.1
Mainboard	10x10mm 144-pin BGA	034-Electronics - IC, large BGA SMT, no PCB (144 pin)	Mass (g)	0.2
Mainboard	Silicon die, by area ratio	096-Silicon die - 2010 process (45 nm)	Area (mm^2)	66
Mainboard	Small connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	1.3
Mainboard	Tiny bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	2.0
Mainboard	RF shielding, non-magnetic metal	003-Metal - aluminum (sheet)	Mass (g)	9.0
Subtotal: Circuit boards (total)			Mass (g)	35
Subtotal: Circuit boards (excluding IC's)			Mass (g)	33
Power supply	PC plastic casing	010-Plastic - PC	Mass (g)	17
Power supply	AC plug with plastic coating	075-Electronics - ports - AC power plug	Mass (g)	18
Power supply	Plastic piece	010-Plastic - PC	Mass (g)	3.4
Power supply	Metal piece (non-magnetic)	003-Metal - aluminum (sheet)	Mass (g)	3.4
Power supply	Power connector	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	4.1
Power supply	Power supply mainboard (5x2.5cm)	019-Electronics - PCB (2 layer, bare)	Mass (g)	1.5
Power supply	Tiny IC's and SMT components	040-Electronics - IC, tiny < 0.1g	Mass (g)	2.0
Power supply	USB port	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	2.1

Subsystem	Description	Process (best fit)	Unit	Measurement
Power supply	Cylindrical electrolytic caps	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	4.6
Power supply	Coils, large wound	049-Electronics - Inductor, large cylindrical wound	Mass (g)	10
Power supply	Ceramic caps	045-Electronics - Capacitor, ceramic (button)	Mass (g)	1.2
Power supply	Plastic bits	008-Plastic - ABS	Mass (g)	1.0
Power supply	Other bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	1.0
Power supply	USB cable	082-Electronics - cables - power cords, thick cables and cords	Mass (g)	20
Subtotal: Power supply			Mass (g)	89
Interior parts	Metal internal backplate (non-magnetic)	003-Metal - aluminum (sheet)	Mass (g)	25
Interior parts	ABS plastic pieces	008-Plastic - ABS	Mass (g)	16
Interior parts	Flexible rubber keyboard	012-Plastic - silicone rubber	Mass (g)	3.3
Interior parts	Connector	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	1.0
Subtotal: Other			Mass (g)	45
Subtotal: IC's (packages)			Mass (g)	1.6
Subtotal: IC's (die)			Area (mm^2)	66
Total			Mass(g)	312

Table S6-XVIII: Full bill of materials, Amazon Kindle

J. Dell rack server

This product is Dell PowerEdge rack server, model EMU 3710P71, circa 2005 manufacture, with dimensions 44cm x 76.5cm x 4.5cm, and total mass 15471g, excluding external packaging.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply	Mass (g)	2911	89.3	1653.4
Casing	Mass (g)	8767	18.5	302.4
Circuit boards (excl. IC's)	Mass (g)	2199	128.8	2407.3
IC's (packages)	Mass (g)	88	50.8	1008.2
IC's (die)	Area (mm ²)	1683	72.4	961.0
Battery	Mass (g)	0	0.0	0.0
Display	Mass (g)	0	0.0	0.0
Other	Mass (g)	1506	18.2	341.9
Transport	Mass (g)	15471	3.9	61.7
Assembly	Products	1	1.2	25.3
Total	Mass(g)	15471	383.1	6761.1

Table S6-XIX: Summary of bill of materials, rack server

Subsystem	Description	Process (best fit)	Unit	Measurement
Assembly	Assembly	099-Assembly - large product	Products	1
Transport	Transport to regional assembly	087-Transport - SE Asia to regional assembly (per g)	Mass (g)	15471
Casing	Bottom plate - magnetic	001-Metal - steel (sheet)	Mass (g)	2190
Casing	Main internal frame - magnetic	001-Metal - steel (sheet)	Mass (g)	6550
Casing	Screws	002-Metal - steel (screws)	Mass (g)	27
Subtotal: Casing			Mass (g)	8767
Power supply 1	Metal casing - magnetic	001-Metal - steel (sheet)	Mass (g)	200
Power supply 1	Metal casing - magnetic	001-Metal - steel (sheet)	Mass (g)	360

Subsystem	Description	Process (best fit)	Unit	Measurement
Power supply 1	Papery housing	018-Paper	Mass (g)	16
Power supply 1	Fan - double CPU fan	065-Electronics - components - small CPU fan	Mass (g)	90
Power supply 1	Metal screws and bolts	002-Metal - steel (screws)	Mass (g)	21
Power supply 1	Copper plates	004-Metal - copper (sheet)	Mass (g)	210
Power supply 1	PCB, 8-layer, 26x7.6cm	022-Electronics - PCB (8 layer, bare)	Mass (g)	91
Power supply 1	Coils, large wound	049-Electronics - Inductor, large cylindrical wound	Mass (g)	246
Power supply 1	Caps, electrolytic	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	115
Power supply 1	Metal plate, non-magnetic	003-Metal - aluminum (sheet)	Mass (g)	6.6
Power supply 1	Power transistors	042-Electronics - Transistor, large/power	Mass (g)	46
Power supply 1	Connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	29
Power supply 1	Misc. bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	25
Power supply 2	Metal casing - magnetic	001-Metal - steel (sheet)	Mass (g)	200
Power supply 2	Metal casing - magnetic	001-Metal - steel (sheet)	Mass (g)	360
Power supply 2	Papery housing	018-Paper	Mass (g)	16
Power supply 2	Fan - double CPU fan	065-Electronics - components - small CPU fan	Mass (g)	90
Power supply 2	Metal screws and bolts	002-Metal - steel (screws)	Mass (g)	21
Power supply 2	Copper plates	004-Metal - copper (sheet)	Mass (g)	210
Power supply 2	PCB, 8-layer, 26x7.6cm	022-Electronics - PCB (8 layer, bare)	Mass (g)	91
Power supply 2	Coils, large wound	049-Electronics - Inductor, large cylindrical wound	Mass (g)	246
Power supply 2	Caps, electrolytic	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	115
Power supply 2	Metal plate, non-magnetic	003-Metal - aluminum (sheet)	Mass (g)	6.6

Subsystem	Description	Process (best fit)	Unit	Measurement
Power supply 2	Power transistors	042-Electronics - Transistor, large/power	Mass (g)	46
Power supply 2	Connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	29
Power supply 2	Misc. bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	25
Subtotal: Power supply			Mass (g)	2911
Mainboard	Main logic board - 14-layer, 15*41 + 48*25cm	024-Electronics - PCB (12 layer, bare)	Mass (g)	760
Mainboard	Connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	250
Mainboard	Large caps	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	86
Mainboard	Large coils	049-Electronics - Inductor, large cylindrical wound	Mass (g)	52
Mainboard	Battery CR2032 3V	056-Battery - CR2032 3V Li-Ion (CMOS)	Mass (g)	2.8
Mainboard	Small on-board batteries	057-Battery - small on-board	Mass (g)	2.3
Mainboard	Tiny IC's and little bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	18
Mainboard	Large IC 1077-pin mounted bare die, PCB 42x42mm, die 11x9mm	033-Electronics - IC, large BGA (mounted bare die, 672 pin)	Mass (g)	7.9
Mainboard	Silicon die	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	99
Mainboard	Large IC 569-pin mounted bare die, PCB 31x31mm, die 7x8mm	033-Electronics - IC, large BGA (mounted bare die, 672 pin)	Mass (g)	3.3
Mainboard	Large IC 460-pin mounted package, PCB 31x31mm, package 25mm	027-Electronics - IC, large BGA (mounted, plastic package, 672 pin)	Mass (g)	3.3
Mainboard	Silicon die, via area ratio	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	49
Mainboard	Large IC multi-chip package, 169-pin, 2 packaged IC's 29x17mm, 12x12mm, PCB	026-Electronics - IC, large BGA (mounted, plastic package, 256 pin)	Mass (g)	2.8

Subsystem	Description	Process (best fit)	Unit	Measurement
	31x31mm			
Mainboard	Silicon die, via area ratio	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	50
Mainboard	196-pin mounted package, 15x15mm, 14x14 package	025-Electronics - IC, large BGA (mounted, plastic package, 144 pin)	Mass (g)	0.4
Mainboard	Silicon die, via area ratio	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	15
Mainboard	196-pin mounted package, 15x15mm, 14x14 package	025-Electronics - IC, large BGA (mounted, plastic package, 144 pin)	Mass (g)	0.4
Mainboard	Silicon die, via area ratio	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	15
Mainboard	136-pin SMT	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	0.4
Mainboard	136-pin SMT	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	
Mainboard	128-pin SMT	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	0.4
Mainboard	100-pin SMT	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	0.4
Mainboard	40-pin SMT	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0.4
Mainboard	44-pin SMT	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0.4
Mainboard	48-pin SMT	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0.4
Mainboard	Silicon die, via mass ratio	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	94
Mainboard	Small heatsinks, non-magnetic	006-Metal - aluminum heatsink	Mass (g)	20
Mainboard	Small PCBs	019-Electronics - PCB (2 layer, bare)	Mass (g)	40
Mainboard	Heat sink - copper body with aluminum fins - aluminum component	006-Metal - aluminum heatsink	Mass (g)	180
Mainboard	Heat sink - copper body with aluminum fins - copper	007-Metal - copper heatsink	Mass (g)	45

Subsystem	Description	Process (best fit)	Unit	Measurement
	component			
Mainboard	Main CPU, Intel Xeon - mounted with heat spreader. 604-pin, heat spreader 7.4g, PCB 43x43mm, bare die 11x11mm	030-Electronics - IC, large BGA (with heat spreader, 672 pin)	Mass (g)	22
Mainboard	Silicon die, via bare die	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	121
RAM	RAM #1 PCB: 6 layer, 3 x 13cm	021-Electronics - PCB (6 layer, bare)	Mass (g)	13
RAM	RAM IC's: 60-pin 8x12mm 18X @ 0.16g each	037-Electronics - IC, packaged RAM chip	Mass (g)	2.9
RAM	RAM: Other IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	0.4
RAM	RAM # 2 PCB: 6 layer, 3 x 13cm	021-Electronics - PCB (6 layer, bare)	Mass (g)	13
RAM	RAM IC's: 60-pin 8x12mm 18X @ 0.16g each	037-Electronics - IC, packaged RAM chip	Mass (g)	2.9
RAM	RAM: Other IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	0.4
RAM	RAM # 3 PCB: 6 layer, 3 x 13cm	021-Electronics - PCB (6 layer, bare)	Mass (g)	13
RAM	RAM IC's: 60-pin 8x12mm 18X @ 0.16g each	037-Electronics - IC, packaged RAM chip	Mass (g)	2.9
RAM	RAM: Other IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	0.4
RAM	RAM # 4 PCB: 6 layer, 3 x 13cm	021-Electronics - PCB (6 layer, bare)	Mass (g)	13
RAM	RAM IC's: 60-pin 8x12mm 18X @ 0.16g each	037-Electronics - IC, packaged RAM chip	Mass (g)	2.9
RAM	RAM: Other IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	0.4
RAM	RAM # 5 PCB: 6 layer, 3 x 13cm	021-Electronics - PCB (6 layer, bare)	Mass (g)	13
RAM	RAM IC's: 60-pin 8x12mm 18X @ 0.16g each	037-Electronics - IC, packaged RAM chip	Mass (g)	2.9
RAM	Silicon die, via area ratio	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	674
RAM	RAM: Other IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	0.4
Daughtercards	Daughtercard PCB - 8 layer -	022-Electronics - PCB (8 layer, bare)	Mass (g)	26

Subsystem	Description	Process (best fit)	Unit	Measurement
	5x14cm			
Daughtercards	Large ribbon cable	083-Electronics - cables - large ribbon cables	Mass (g)	29
Daughtercards	Connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	17
Daughtercards	Small IC's	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	17
Daughtercards	Silicon die, via mass ratio	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	313
Daughtercards	Tiny IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	1.0
Daughtercards	Small PCB	019-Electronics - PCB (2 layer, bare)	Mass (g)	4.4
Daughtercards	Daughtercard PCB - 8layer, 15*19 + 5*15cm	022-Electronics - PCB (8 layer, bare)	Mass (g)	189
Daughtercards	Connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	145
Daughtercards	Tiny PCB's	019-Electronics - PCB (2 layer, bare)	Mass (g)	15
Daughtercards	Caps, electrolytic	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	15
Daughtercards	Small IC's and bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	8.0
Daughtercards	48-pin SMT	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0.5
Daughtercards	32-pin SMT	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0.9
Daughtercards	Silicon die, via mass ratio	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	26
Daughtercards	Large IC, 832-pin, mounted bare die, 37x37mm PCB, 10x10mm die	033-Electronics - IC, large BGA (mounted bare die, 672 pin)	Mass (g)	5.8
Daughtercards	Silicon die, via direct measurement	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	100
Daughtercards	Large IC, 141-pin, mounted package, 35x35mm PCB 28x28mm package	025-Electronics - IC, large BGA (mounted, plastic package, 144 pin)	Mass (g)	4.2

Subsystem	Description	Process (best fit)	Unit	Measurement
Daughtercards	Silicon die, via area ratio	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	61
Daughtercards	PCB, 6 layer, 96+36+78+50cm^2	021-Electronics - PCB (6 layer, bare)	Mass (g)	98
Daughtercards	Connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	55
Daughtercards	Plastic piece, PC+ABS	009-Plastic - ABS + PC blend	Mass (g)	25
Daughtercards	Sticker labels	018-Paper	Mass (g)	5.0
Daughtercards	Large cable - connectors	081-Electronics - connectors - misc. on-board plugs and connectors	Mass (g)	28
Daughtercards	large cable	083-Electronics - cables - large ribbon cables	Mass (g)	10
Daughtercards	Large LEDs 2X @ 1.7g each	052-Electronics - LED	Mass (g)	3.4
Daughtercards	Small IC's	040-Electronics - IC, tiny < 0.1g	Mass (g)	1.7
Daughtercards	144-pin 20x20mm SMT	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	1.4
Daughtercards	100-pin 15x15mm SMT	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	0.7
Daughtercards	48-pin 12x19mm SMT	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	0.5
Daughtercards	Silicon die, via area ratio	094-Silicon die - 2004 process (90 nm)	Area (mm^2)	67
Subtotal: Circuit boards (total)			Mass (g)	2287
Subtotal: Circuit boards (excluding IC's)			Mass (g)	2199
Interior parts	Floppy disk drive 3.5"	064-Electronics - components - 3.5" floppy drive	Mass (g)	185
Interior parts	DVD Rom Drive	061-Electronics - components - DVD drive	Mass (g)	227
Interior parts	Case fan - includes 2 CPU fans	065-Electronics - components - small CPU fan	Mass (g)	86
Interior parts	Case fan - includes 2 CPU fans	065-Electronics - components - small CPU fan	Mass (g)	86
Interior parts	Case fan - includes 2 CPU fans	065-Electronics - components - small CPU	Mass (g)	86

Subsystem	Description	Process (best fit)	Unit	Measurement
		fan		
Interior parts	Case fan - includes 2 CPU fans	065-Electronics - components - small CPU fan	Mass (g)	86
Interior parts	Fan carriage - PC + ABS FR(40) plastic	009-Plastic - ABS + PC blend	Mass (g)	33
Interior parts	Misc. pieces - PC ABS	009-Plastic - ABS + PC blend	Mass (g)	154
Interior parts	HD bay - PC ABS	009-Plastic - ABS + PC blend	Mass (g)	38
Interior parts	HD bay - magnetic metal	001-Metal - steel (sheet)	Mass (g)	92
Interior parts	Misc. piece - magnetic metal	001-Metal - steel (sheet)	Mass (g)	193
Interior parts	Misc. piece - non-magnetic metal	005-Metal - aluminum (solid)	Mass (g)	136
Interior parts	Heatsinks- magnetic metal, black coating	006-Metal - aluminum heatsink	Mass (g)	74
Interior parts	Backplate - plastic, flexible	009-Plastic - ABS + PC blend	Mass (g)	1.0
Interior parts	Dell Li-Ion battery	055-Battery - Li-Ion 2.83 Whr (iPod touch)	Mass (g)	29
	Subtotal: Other		Mass (g)	1506
	Subtotal: IC's (packages)		Mass (g)	88
	Subtotal: IC's (die)		Area (mm^2)	1683
	Total		Mass (g)	15471

Table S6-XX: Full bill of materials, rack server

K. 3Com network switch

This product the 3Com 3C16464C Superstack 3 Baseline 10/100 24-port switch, circa 2003 manufacture, with dimensions 44cm x 16.5cm x 4cm, and total mass 2119g, excluding external packaging.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply	Mass (g)	193	10.8	202.7
Casing	Mass (g)	1404	3.8	57.6
Circuit boards (excl. IC's)	Mass (g)	460	25.3	479.9
IC's (packages)	Mass (g)	47	34.3	650.1
IC's (die)	Area (mm ²)	366	15.8	233.1
Battery	Mass (g)	0	0	0
Display	Mass (g)	0	0	0
Other	Mass (g)	16	0.2	3.6
Transport	Mass (g)	2119	0.5	8.5
Assembly	Products	1	1.2	25.3
Total	Mass(g)	2119	91.8	1660.8

Table S6-XXI: Summary of bill of materials, network switch

Subsystem	Description	Process (best fit)	Unit	Measurement
Assembly	Assembly	099-Assembly - large product	Products	1
Transport	Transport to regional assembly	087-Transport - SE Asia to regional assembly (per g)	Mass (g)	2119
Casing	Bottom plating - magnetic metal	001-Metal - steel (sheet)	Mass (g)	900
Casing	Top plating - magnetic metal	001-Metal - steel (sheet)	Mass (g)	104
Casing	Polycarbonate plastic	010-Plastic - PC	Mass (g)	392
Casing	Metal screws, magnetic	002-Metal - steel (screws)	Mass (g)	7.8
Subtotal: Casing			Mass (g)	1404
Power supply	88W power supply. Bare PCB, 2 layer, 14x6.5cm, 35g	019-Electronics - PCB (2 layer, bare)	Mass (g)	35

Subsystem	Description	Process (best fit)	Unit	Measurement
Power supply	Power plug	075-Electronics - ports - AC power plug	Mass (g)	22
Power supply	Power cable, internal: 6 wires and connector	084-Electronics - cables - small cables and wires	Mass (g)	6.3
Power supply	Large coil	049-Electronics - Inductor, large cylindrical wound	Mass (g)	48
Power supply	Large coil	049-Electronics - Inductor, large cylindrical wound	Mass (g)	17
Power supply	Large cap 23x30mm	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	16
Power supply	Medium caps	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	12
Power supply	Medium coils	049-Electronics - Inductor, large cylindrical wound	Mass (g)	7.4
Power supply	Small ceramic caps	045-Electronics - Capacitor, ceramic (button)	Mass (g)	2.6
Power supply	Small box coils	048-Electronics - Inductor, chip (small box)	Mass (g)	7.2
Power supply	Power transistors	042-Electronics - Transistor, large/power	Mass (g)	8.7
Power supply	Power resistors	051-Electronics - Resistor, large (power)	Mass (g)	1.5
Power supply	Small metal bits, magnetic	002-Metal - steel (screws)	Mass (g)	2.6
Power supply	Small metal bits, non-magnetic	003-Metal - aluminum (sheet)	Mass (g)	6.6
Subtotal: Power supply			Mass (g)	193
Mainboard	Main logic board, 6 layer, 15.5x31cm	021-Electronics - PCB (6 layer, bare)	Mass (g)	186
Mainboard	2X 12-port ethernet connector bank, 74g each	073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (g)	148
Mainboard	Heatsink - black-coated non-magnetic metal 3 @ 21g each	006-Metal - aluminum heatsink	Mass (g)	63
Mainboard	LED banks	052-Electronics - LED	Mass (g)	19
Mainboard	Large caps	043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (g)	16
Mainboard	Coils - small wound (several)	049-Electronics - Inductor, large cylindrical wound	Mass (g)	3.0
Mainboard	Coils - toroidal (1x)	047-Electronics - Inductor, toroidal	Mass (g)	3.0
Mainboard	Power resistors	051-Electronics - Resistor, large (power)	Mass (g)	0.8
Mainboard	Misc. connectors	081-Electronics - connectors - misc. on-board plugs	Mass (g)	14

Subsystem	Description	Process (best fit)	Unit	Measurement
		and connectors		
Mainboard	Broadcom large SMT 28x28mm, 3 @ 5.9 g each, 204-pin	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	18
Mainboard	6X 40-pin DIP, 4.6g each, 28x12mm	039-Electronics - IC, medium SMT, < 64 pin	Mass (g)	28
Mainboard	Silicon die, by area ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	341
Mainboard	2X 100-pin SMT 0.7g each	038-Electronics - IC, medium SMT, >= 64 pin	Mass (g)	1.4
Mainboard	Silicon die, by mass ratio	095-Silicon die - 2007 process (65 nm)	Area (mm^2)	26
Mainboard	2X power transistors 1.5g each	042-Electronics - Transistor, large/power	Mass (g)	3.0
Mainboard	Tiny IC's and remaining bits	040-Electronics - IC, tiny < 0.1g	Mass (g)	4.4
	Subtotal: Circuit boards (total)		Mass (g)	507
	Subtotal: Circuit boards (excluding IC's)		Mass (g)	460
Interior parts	Case fan 4x4 cm	065-Electronics - components - small CPU fan	Mass (g)	14
Interior parts	Rubber cover for power plug	012-Plastic - silicone rubber	Mass (g)	2.1
	Subtotal: Other		Mass (g)	16
	Subtotal: IC's (packages)		Mass (g)	47
	Subtotal: IC's (die)		Area (mm^2)	366
	Total		Mass (g)	2119

Table S6-XXII: Full bill of materials, network switch

L. Desktop: ecoinvent adjusted dataset

This product is a desktop PC, circa 2002 manufacture, of unknown dimensions, and total mass 11144g, excluding external packaging and cables. This dataset is an adaptation of the original dataset in ecoinvent, with modifications to adjust integrated circuit content, and to ensure consistency with other products analyzed in this study. Because the original dataset is under copyright by ecoinvent, only the summary dataset is provided.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply	Mass (g)	1463	38.2	722.9
Casing	Mass (g)	6207	13.1	214.7
Circuit boards (excl. IC's)	Mass (g)	1558	76.9	1620.9
IC's (packages)	Mass (g)	119	80.4	1778.1
IC's (die)	Area (mm ²)	2195	79.0	1222.8
Battery	Mass (g)	0	0.0	0.0
Display	Mass (g)	0	0.0	0.0
Other	Mass (g)	1796	29.9	536.0
Transport	Mass (g)	11144	2.8	44.5
Assembly	Products	1	1.2	25.3
Total	Mass(g)	11144	321.6	6165.2

Table S6-XXIII: Summary of bill of materials, desktop (adjusted ecoinvent dataset)

M. Laptop: ecoinvent adjusted dataset

This product is a laptop PC with 12" display and dock, circa 2003 manufacture, of unknown dimensions, and total mass 3350g, excluding external packaging and cables. This dataset is an adaptation of the original dataset in ecoinvent, with modifications to adjust integrated circuit content, and to ensure consistency with other products analyzed in this study. Because the original dataset is under copyright by ecoinvent, only the summary dataset is provided.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply	Mass (g)	537	2.9	53.5
Casing	Mass (g)	1413	64.4	330.2
Circuit boards (excl. IC's)	Mass (g)	345	32.0	605.6
IC's (packages)	Mass (g)	86	58.9	1259.0
IC's (die)	Area (mm ²)	1577	67.8	1002.8
Battery	Mass (g)	273	1.4	27.5
Display	Mass (g)	328	19.3	288.0
Other	Mass (g)	367	7.4	133.0
Transport	Mass (g)	3349	0.8	13.4
Assembly	Products	1	1.2	25.3
Total	Mass(g)	3350	256.2	3738.2

Table S6-XXIV: Summary of bill of materials, laptop (adjusted ecoinvent dataset)

N. LCD monitor: ecoinvent adjusted dataset

This product is a 17" LCD monitor, circa 2004 manufacture, of unknown dimensions, and total mass 5095g, excluding external packaging and cables. This dataset is an adaptation of the original dataset in ecoinvent, with modifications to adjust integrated circuit content, and to ensure consistency with other products analyzed in this study. The analysis does include a power supply, but the power supply for this product was consolidated with the mainboard, so that it is not possible to isolate power supply components. Because the original dataset is under copyright by ecoinvent, only the summary dataset is provided.

Category	Unit	Measurement	GHG (kg CO ₂ -eq)	Primary energy (MJ)
Power supply	Mass (g)	114	11	201
Casing	Mass (g)	862	6.8	120.8
Circuit boards (excl. IC's)	Mass (g)	94	9.6	180.4
IC's (packages)	Mass (g)	19	14.2	268.5
IC's (die)	Area (mm ²)	355	17.0	255.5
Battery	Mass (g)	0	0.0	0.0
Display	Mass (g)	4006	236.3	3518.1
Other	Mass (g)	0	0.0	0.0
Transport	Mass (g)	5096	1.3	20.3
Assembly	Products	1	1.2	25.3
Total	Mass(g)	5096	297.3	4589.5

Table S6-XXV: Summary of bill of materials, LCD monitor (adjusted ecoinvent dataset)

S7. Mapping to ecoinvent processes

All bills-of-materials in this analysis were tabulated in terms of a set of processes which was custom-created for the purposes of this project, rather than mapping directly to an established dataset such as ecoinvent. The purpose of this decision was to decouple the primary data contained in the bills-of-materials from the ecoinvent database, in order to allow the analysis to be repeated with a different or updated process database in the future. Any such updates or comparisons can be undertaken simply by altering the mapping from our process set to the new process database. These mappings are provided in this section.

In the subsequent tables, our custom process names are listed on the left, with entries in bold. The ecoinvent entries which map to that process are listed immediately above. In many cases there is a one-to-one mapping, but in some cases multiple ecoinvent processes are encapsulated in one of our processes; for example, a quantity of sheet steel in our process list maps to a raw material input (1154: steel, low-alloyed, at plant) and a processing step (1174: sheet rolling, steel). In other cases, our process list is more specific than ecoinvent's, and we use the same ecoinvent process to model several of our processes; for example, we have processes for four sizes of case fans, but all map to the same one ecoinvent process, such that our four processes are functionality identical in the current mapping. These redundant processes were not consolidated in order to allow for flexibility in future analyses if more specific process data becomes available. In such cases, the redundant process is marked "as above" to indicate that its component ecoinvent processes are identical to those of the process immediately preceding it in the listing.

The vast majority of processes are scaled by mass. Some ecoinvent processes use area as a functional unit, notably those describing circuit boards and LCD screens. In each case we converted these to mass units based on ecoinvent documentation. We express silicon die in area, but use data from Boyd (5) rather than ecoinvent; further details are provided in the appropriate section.

A. Metals

Metals typically include a raw material extraction stage and processing stage in the ecoinvent database, which we have emulated here. We did not model any metals beside the limited set here because we lacked the ability to identify exotic metals or alloys. Such materials are likely to have a higher impact than the metals listed here, so this may lead to underestimations in total impact.

Process name	Functional unit	Ecoinvent process id	Ecoinvent process name	Amount	Unit
		1154	steel, low-alloyed, at plant	1	Kg
		1174	sheet rolling, steel	1	Kg
001-Metal - steel (sheet)	Mass (kg)	(Total)		1	Kg
		1072	chromium steel 18/8, at plant	1	kg
		1165	hot rolling, steel	1	kg
002-Metal - steel (screws)	Mass (kg)	(Total)		1	kg
		1056	aluminium, production mix, at plant	1	kg
		1171	sheet rolling, aluminium	1	kg
003-Metal - aluminum (sheet)	Mass (kg)	(Total)		1	kg
		1074	copper, at regional storage	1	kg
		1173	sheet rolling, copper	1	kg
004-Metal - copper (sheet)	Mass (kg)	(Total)		1	kg
		1056	aluminium, production mix, at plant	1	kg
		1169	section bar extrusion, aluminium	1	kg
005-Metal - aluminum (solid)	Mass (kg)	(Total)		1	kg
006-Metal - aluminum heatsink	Mass (kg)	(as above)		1	kg

		1074	copper, at regional storage	1	kg
		8339	copper product manufacturing, average metal working	1	kg
007-Metal - copper heatsink	Mass (kg)		(total)		kg
		1107	magnesium-alloy, AZ91, at plant	1	kg
		1108	magnesium-alloy, AZ91, die-casting, at plant	1	kg
088-Metal - Magnesium alloy (casing)	Mass (kg)		(total)	1	kg

Table S7-I: Process ecoinvent mapping, metals

B. Plastics and paper

Most plastics have a straightforward mapping. Several ABS-polycarbonate blends were encountered in disassembly; these were assumed to require 30% polycarbonate and 70% ABS, plus an additional processing step.

Process name	Functional unit	Ecoinvent process id	Ecoinvent process name	Amount	Unit
		1817	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	1	kg
008-Plastic - ABS	Mass (kg)		(Total)	1	kg
		1826	polycarbonate, at plant	0.3	kg
		1817	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.7	kg

		1853	injection moulding	1	kg
009-Plastic - ABS + PC blend	Mass (kg)		(Total)	1	kg
		1826	polycarbonate, at plant	1	kg
010-Plastic - PC	Mass (kg)		(Total)	1	kg
		1854	packaging film, LDPE, at plant	1	kg
011-Plastic - LDPE (plastic wrap)	Mass (kg)		(Total)	1	kg
		324	silicone product, at plant	1	kg
012-Plastic - silicone rubber	Mass (kg)		(Total)	1	kg
		1836	polystyrene, general purpose, GPPS, at plant	1	kg
013-Plastic - polystyrene film (flex circuit board)	Mass (kg)		(Total)	1	kg
		11792	11792 polystyrene foam slab, 45% recycled, at plant	1	kg
014-Plastic - Styrofoam (packaging)	Mass (kg)		(Total)	1	kg
		1839	polyurethane, rigid foam, at plant	1	kg
015-Plastic - polyurethane foam (packaging)				1	kg
		1802	epoxy resin, liquid, at plant	1	kg
016-Plastic - epoxy	Mass (kg)		(Total)	1	kg
		1840	polyvinylchloride, at regional storage	1	kg
089-Plastic - PVC (polyvinylchloride)	Mass (kg)		(total)	1	kg

		1691	corrugated board, recycling fibre, double wall, at plant	1	kg
017-Cardboard	Mass (kg)		(Total)	1	kg
		1714	paper, recycling, with deinking, at plant	1	kg
018-Paper	Mass (kg)		(Total)	1	kg

Table S7-II: Process ecoinvent mapping, plastics and paper

C. Circuit boards and integrated circuits

All circuit boards are modeled using a mass functional unit which is based on the 6-layer lead-free process from ecoinvent; one kg of circuit board is assumed to be equivalent to 0.31 m² of the ecoinvent process, using the relationship provided in the ecoinvent documentation. Adjustments should ideally be made for boards with different numbers of layers as these would have differing mixtures of materials (e.g. epoxy and metal in interior layers) but we did not have enough information to construct such models. All circuit boards were stripped of parts and weighed in a depopulated state which allowed us to use a mass functional unit. In circumstances where circuit board depopulation is not possible, it would be feasible to construct approximate models of populated circuit boards including components (these do exist in ecoinvent), but we did not require this additional level of detail.

ICs are modeled differently depending on the type of package. Smaller ICs typically consist of a silicon die encased in an epoxy encapsulation which is mounted directly on the board. Larger ICs are mounted on a small board with a ball grid array of pins, and may include a bare exposed die, a die within an epoxy encapsulation, or a die within a metal heat spreader. These four types of package (encapsulation only, board + encapsulation, board + bare die, board + heat spreader) are each modeled using the ecoinvent dataset for packaged ICs (7016: integrated circuit, IC, logic type, at plant) with modifications to account for the presence or absence of an encapsulation (SiO₂ epoxy), a board (mostly copper and glass fiber), and a heat spreader (assumed to be aluminum, and accounting for about 80% of the mass of the total package), with the materials proportionally mass-scaled. We assume electricity in producing ICs is consistent, such that a collection of any type of packaged ICs requires the same electricity input, i.e. 669kWh per kg of product; as this turns out to be a major component of the impact of a package, this assumption should be explored in more detailed future studies. The silicon die are modeled separately from the packages in order to allow for the use of Boyd's (2009) data which varies depending on the year of manufacture.

Process name	Functional unit	Ecoinvent process id	Ecoinvent process name	Amount	Unit
		10995	printed wiring board, surface mount, lead-free surface, at plant	0.31	m^2
019-Electronics - PCB (2 layer, bare)	Mass (kg)		(Total)	1	Kg
020-Electronics - PCB (4 layer, bare)	Mass (kg)		(as above)	1	Kg
021-Electronics - PCB (6 layer, bare)	Mass (kg)		(as above)	1	kg
022-Electronics - PCB (8 layer, bare)	Mass (kg)		(as above)	1	kg
023-Electronics - PCB (10 layer, bare)	Mass (kg)		(as above)	1	kg
024-Electronics - PCB (12 layer, bare)	Mass (kg)		(as above)	1	kg
			Modified version of ecoinvent integrated circuit process with silicon die removed, not reproduced here due to copyright		
025-Electronics - IC, large BGA (mounted, plastic package, 144 pin)	Mass (kg)		(Total)	1	kg
026-Electronics - IC, large BGA (mounted, plastic package, 256 pin)			(as above)	1	kg
027-Electronics - IC, large BGA (mounted, plastic package, 672 pin)	Mass (kg)		(as above)	1	kg
			Modified version of ecoinvent integrated circuit process with silicon die removed and heat spreader added, not reproduced here due to copyright		
028-Electronics - IC, large BGA (with heat spreader, 144 pin)	Mass (kg)		(Total)	1	kg
029-Electronics - IC, large BGA (with heat	Mass (kg)		(as above)	1	kg

spreader, 256 pin)			
030-Electronics - IC, large BGA (with heat spreader, 672 pin)	Mass (kg)	(as above)	1 kg
Modified version of ecoinvent integrated circuit process with silicon die and encapsulation removed, not reproduced here due to copyright			
031-Electronics - IC, large BGA (mounted bare die, 144 pin)	Mass (kg)	(Total)	1 kg
032-Electronics - IC, large BGA (mounted bare die, 256 pin)	Mass (kg)	(as above)	1 kg
033-Electronics - IC, large BGA (mounted bare die, 672 pin)	Mass (kg)	(as above)	1 kg
Modified version of ecoinvent integrated circuit process with silicon die and mounting board removed, not reproduced here due to copyright			
034-Electronics - IC, large BGA SMT, no PCB (144 pin)	Mass (kg)	(Total)	1 kg
035-Electronics - IC, large BGA SMT, no PCB (256 pin)	Mass (kg)	(as above)	1 kg
036-Electronics - IC, large BGA SMT, no PCB (672 pin)	Mass (kg)	(as above)	1 kg
037-Electronics - IC, packaged RAM chip	Mass (kg)	(as above)	1 kg
039-Electronics - IC, medium SMT, < 64 pin	Mass (kg)	(as above)	1 kg
038-Electronics - IC, medium SMT, >= 64 pin	Mass (kg)	(as above)	1 kg
090-Silicon die - 1995 process (350nm)			
	Area (mm ²)	From Boyd (2009)	1 mm ²

091-Silicon die - 1998 process (250 nm)	Area (mm ²)	From Boyd (2009)	1 mm ²
092-Silicon die - 1999 process (180 nm)	Area (mm ²)	From Boyd (2009)	1 mm ²
093-Silicon die - 2001 process (130 nm)	Area (mm ²)	From Boyd (2009)	1 mm ²
094-Silicon die - 2004 process (90 nm)	Area (mm ²)	From Boyd (2009)	1 mm ²
095-Silicon die - 2007 process (65 nm)	Area (mm ²)	From Boyd (2009)	1 mm ²
096-Silicon die - 2010 process (45 nm)	Area (mm ²)	From Boyd (2009)	1 mm ²

Table S7-III: Processecoinvent mapping, circuit boards and integrated circuits

D. Small electronic components

This includes small board-mounted components including transistors, capacitors, resistors, diodes, and inductors. The ecoinvent dataset has a fairly broad collection of entries here and we are able to make fairly good mappings. The impacts of these parts are usually quite small, as their masses are often 10g or less, so the overall error due to a poor match with the ecoinvent process is likely very small.

Process name	Functional unit	Ecoinvent process id	Ecoinvent process name	Amount	Unit
		7065	electronic component, unspecified, at plant	1	kg
040-Electronics - IC, tiny < 0.1g	Mass (kg)		(Total)	1	kg
		7079	transistor, wired, small size, through-hole mounting, at plant	1	kg
041-Electronics - Transistor, small	Mass (kg)		(Total)	1	kg
		7113	transistor, wired, big size, through-hole mounting, at plant	1	kg
042-Electronics - Transistor, large/power	Mass (kg)		(Total)	1	kg
		7011	capacitor, electrolyte type, < 2cm height, at plant	1	kg
043-Electronics - Capacitor, electrolytic cylindrical, radial (both leads on the same side) - by mass	Mass (kg)		(total)	1	kg
		7013	capacitor, Tantalum-, through-hole mounting, at plant	1	kg

044-Electronics - Capacitor, tantalum (small/yellow)	Mass (kg)	(total)	1 kg
		7014 capacitor, unspecified, at plant	1 kg
045-Electronics - Capacitor, ceramic (button)	Mass (kg)	(total)	1 kg
		7009 capacitor, film, through-hole mounting, at plant	1 kg
046-Electronics - Capacitor, polyester film (box)	Mass (kg)	(total)	1 kg
		7067 inductor, ring core choke type, at plant	1 kg
047-Electronics - Inductor, toroidal	Mass (kg)	(total)	1 kg
		10155 inductor, miniature RF chip type, MRFI, at plant	1 kg
048-Electronics - Inductor, chip (small box)	Mass (kg)	(total)	1 kg
		10154 inductor, unspecified, at plant	1 kg
049-Electronics - Inductor, large cylindrical wound	Mass (kg)	(total)	1 kg
		7076 diode, glass-, through-hole mounting, at plant	1 kg
050-Electronics - Diode, large (power)	Mass (kg)	(total)	1 kg
		7069 resistor, metal film type, through-hole mounting, at plant	1 kg
051-Electronics - Resistor, large (power)	Mass (kg)	(total)	1 kg
		7077 light emitting diode, LED, at plant	1 kg
052-Electronics - LED	Mass (kg)	(total)	1 kg

Table S7-IV: Process ecoinvent mapping, small electronic components

E. Other electronic and electrical components

This includes larger items like batteries, drives, and displays, and miscellaneous items like connectors and ports. The e-ink display module is modeled using the same process as other LCD display modules, owing to its roughly similar composition, though there are likely to be significant differences in the manufacturing process that are not accounted for.

Process name	Functional unit	Ecoinvent process id	Ecoinvent process name	Amount	Unit
		11786	single cell, lithium-ion battery, lithium manganese oxide/graphite, at plant	1	kg
053-Battery - Li-Ion 24.8 Whr (iPad)	Mass (kg)		(total)	1	kg
054-Battery - Li-Ion 32 Whr (Laptop)	Mass (kg)		(as above)	1	kg
055-Battery - Li-Ion 2.83 Whr (iPod touch)	Mass (kg)		(as above)	1	kg
056-Battery - CR2032 3V Li-Ion (CMOS)	Mass (kg)		(as above)	1	kg
057-Battery - small on-board	Mass (kg)		(as above)	1	kg
		7000	LCD module, at plant	1	kg
058-Display - LCD module	Mass (kg)		(total)	1	kg
060-Display - E-ink module	Mass (kg)		(as above)	1	kg
		10167	LCD glass, at plant	1	kg

059-Display - Glass	Mass (kg)	(total)	1 kg
	10160	CD-ROM/DVD-ROM drive, desktop computer, at plant	1 kg
061-Electronics - components - DVD drive	Mass (kg)	(total)	1 kg
	10158	HDD, desktop computer, at plant	1 kg
062-Electronics - components - full-size hard disk	Mass (kg)	(total)	1 kg
	10159	HDD, laptop computer, at plant	1 kg
063-Electronics - components - laptop-size hard disk	Mass (kg)	(total)	1 kg
064-Electronics - components - 3.5" floppy drive	Mass (kg)	(as above)	1 kg
	10806	fan, at plant	1 kg
065-Electronics - components - small CPU fan	Mass (kg)	(total)	1 kg
066-Electronics - components - small case fan	Mass (kg)	(as above)	1 kg
067-Electronics - components - medium case fan	Mass (kg)	(as above)	1 kg
068-Electronics - components - large case fan	Mass (kg)	(as above)	1 kg
	7117	power adapter, for laptop, at plant	1 kg
069-Electronics - components - wall wart	Mass (kg)	(total)	1 kg
	10162	connector, computer, peripheral type, at plant	1 kg
072-Electronics - ports - video multi-pin	Mass (kg)	(Total)	1 kg
073-Electronics - ports - small metal (USB, firewire, ethernet)	Mass (kg)	(as above)	1 kg
074-Electronics - ports - audio	Mass (kg)	(as above)	1 kg
075-Electronics - ports - AC power plug	Mass (kg)	(as above)	1 kg

076-Electronics - connectors - full-size RAM slot	Mass (kg)	(as above)	1 kg
077-Electronics - connectors - laptop-size RAM slot	Mass (kg)	(as above)	1 kg
078-Electronics - connectors - video card slot	Mass (kg)	(as above)	1 kg
080-Electronics - connectors - CPU socket	Mass (kg)	(as above)	1 kg
081-Electronics - connectors - misc. on-board plugs and connectors	Mass (kg)	(as above)	1 kg
		7081 connector, PCI bus, at plant	1 kg
079-Electronics - connectors - PCI-type slot	Mass (kg)	(Total)	1 kg
		7017 cable, connector for computer, without plugs, at plant	1 kg
082-Electronics - cables - power cords, thick cables and cords		(total)	1 kg
084-Electronics - cables - small cables and wires		(as above)	1 kg
		7116 cable, ribbon cable, 20-pin, with plugs, at plant	1 kg
083-Electronics - cables - large ribbon cables	Mass (kg)	(total)	1 kg

Table S7-V: Process ecoinvent mapping, other electronic and electrical components

F. Non-material processes

Non-material processes include transport and assembly. All were modeled using standard ecoinvent assumptions. Transport is modeled using a mass functional unit with a fixed amount of travel per unit mass, for convenience.

Process name	Functional unit	Ecoinvent process id	Ecoinvent process name	Amount	Unit
		1983	transport, freight, rail	142	km-kg
		1943	transport, lorry >16t, fleet average	132	km-kg
		1968	transport, transoceanic freight ship	806	km-kg
086-Transport - subcomponent logistics (per mass)	Mass (kg)	(total)		1	kg
		1983	transport, freight, rail	200	km-kg
		1943	transport, lorry >16t, fleet average	100	km-kg
		1968	transport, transoceanic freight ship	21300	km-kg
087-Transport - SE Asia to regional assembly (per mass)	Mass (kg)	(total)		1	kg
		664	electricity, medium voltage, production UCTE, at grid	1.11	kWh
097-Assembly - subcomponent or small product	product	(Total)		1.00	product
		664	electricity, medium voltage, production UCTE, at grid	1.67	kWh
098-Assembly - large component or medium product	product	(Total)		1.00	product

		664	electricity, medium voltage, production UCTE, at grid	2.22	kWh
099-Assembly - large product	product		(Total)	1.00	product

Table S7-VI: Process ecoinvent mapping, non-material processes

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