

Intended Uses and Limitations of the PAIA Model

Created by the MIT Materials Systems Laboratory (MSL)
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The Product Attribute to Impact Algorithm (PAIA), developed by the Massachusetts Institute of Technology in concert with Arizona State University, and University of California at Berkeley, is an approach to streamlined life cycle analysis (LCA) that aims to provide an efficient and cost-effective estimate of the carbon impact of a product class, including notebooks, desktops, LCD monitors, and televisions. PAIA is primarily a methodology, which as an example has been applied through models known as the PAIA tools.

In short, the intended uses of these tools are to pinpoint the impact of hotspots and to understand the impact of certain reduction strategies on those hotspots. A range of global warming potential impact can be found using these tools with the relevant uncertainty.

DETAILED ACCOUNTING OF INTENDED AND NOT INTENDED USES

Uses

PAIA is intended for use by LCA practitioners according to the following standards:

1. PAIA is first and foremost a streamlined LCA methodology. While the research team with support from its industry partners is working to gather the best data possible to populate the model, the primary focus of the research is to develop a robust methodology.
2. The current application of the method, the PAIA tools, can provide a reasonable estimate of the range of carbon impact of a product class.
3. The PAIA tools can provide the user with an estimate of the uncertainty of the results.
4. The PAIA method can be used to identify the major drivers of impact, known as hotspots, within the materials acquisition, manufacturing, and use of a generic product. Because the triage is applied from a cradle-to-grave perspective, the tools should only be used for cradle-to-grave assessments.
5. The PAIA method can be used to relate attributes of a product, such as the screen size of a television, to its environmental impact.
6. The method and tools can be used by OEMs to complete “what if” scenarios on their products, such as exploring the impact of changes to materials or processes on the product’s global warming impact. It could be used within the design phase as decision-support tool.
7. The results of the method and tools could be used to inform OEMs on areas in which to target additional data collection within the supply chain.

8. The results from the hot spot/what if analyses could be used to initiate conversations related to sustainability with suppliers or to innovate new processes/materials uses.
9. PAIA meets IEC TR 62921 requirements.

Industry partners have indicated that a typical detailed LCA is more resource intensive and expensive than this approach; and the research team members have observed that the results may still have high levels of uncertainty.

Limitations

The PAIA method and tools are not intended to be used to address the following items:

1. The results from the PAIA method and tools should be represented as a **streamlined LCA**. PAIA may not be compliant with the primary data requirements of some LCA standards depending on the definitions and interpretations of those requirements.
2. At this time, the results of the PAIA tools are not designed to differentiate between products at the SKU level. The tools can offer a high level estimate of impact along with the associated uncertainty of the results for product classes, but not for specific products.
3. At this time, the results of the PAIA tools should not be used for a regulated carbon footprint disclosure program without further discussion with the research team.
4. In the case of a major shift in technology or improvement in manufacturing, the PAIA tools may need to be reconfigured (as would any study based on extant data).
5. As is typically found in any LCA, data within the tools are of varying quality (age, source, sample size, etc.). The quality of data should be examined in the context of the requirements of each tool use.
6. The results of the PAIA tools are not intended to be applied to cradle-to-gate or component-level assessments as the triage was applied at the cradle-to-grave level and the level of detail made in each tool was made accordingly.
7. **The results from the PAIA tools are liable to change over time as the methodology is improved and data is updated.**

USING INFORMATION FROM PAIA

Single Value

Numerical results from the PAIA tools should be primarily reported as a 95th percentile number with a subsequent explanation or an accessible footnote which notes:

- a) “All estimates of environmental impact and/or carbon footprint are uncertain”
- b) The mean estimate
- c) The standard deviation of the estimate

For example, a carbon footprint could be stated as: “An industry-average notebook with a 12-inch screen used in the EU has an estimated impact of no more than 780 kg CO₂e[†] (where the “†” is a pointer to a footnote) over the course of its life cycle.” An example footnote text is “†All estimates of carbon footprint are uncertain. [Reporting organization] reports the 95th percentile of the carbon footprint estimate to reflect that uncertainty. For this product, that estimate has a mean of 700 kg of CO₂-e and standard deviation of 50 kg of CO₂-e. Other organizations might report this value as 700 +/- 50 kg of CO₂-e.”

RANGE OF VALUES

It is also acceptable to report the numerical results from the PAIA tools in terms of a range. To be consistent with single value reporting it is recommended that firms report the range as the 5th to 95th percentile of the results with a subsequent explanation or an accessible footnote that covers the same points as above.

For example, a carbon footprint could be stated as: “An industry-average notebook with a 12-inch screen used in the EU has an estimated impact of between 620 and 780 kg CO₂-e[†] (where the “†” is a pointer to a footnote) in the course of its life cycle.” An example footnote text is “†All estimates of carbon footprint are uncertain. [Reporting organization] reports the 5th and 95th percentile of the carbon footprint estimate to reflect that uncertainty. For this product, that estimate has a mean of 700 kg of CO₂-e and standard deviation of 50 kg of CO₂-e. Other organizations might report this value as 700 +/- 50 kg of CO₂-e.”

GENERAL

The units for global warming potential are in kgCO₂-equivalent.

The other key attributes from the inputs page should also be listed beyond e.g., screen size depending on where specificity has been added by the user.

To cite a value generated by the PAIA tools, please use the following: the Product Attribute to Impact Algorithm model, Version [DATE], copyright by the ICT Benchmarking collaboration including the Massachusetts Institute of Technology’s Materials Systems Laboratory and partners.

To cite the PAIA method directly, please use the following: the Product Attribute to Impact Algorithm method, developed by the Massachusetts Institute of Technology’s Materials Systems Laboratory and partners.

When reporting results for the server tool, datacenter energy consumption should be reported separately from the hardware energy consumption.

It is especially important to list key product attributes and assumptions when reporting results from the server tool. This is because:

- a. The server tool's results are driven almost entirely by use stage (comprised of server hardware energy consumption as well as datacenter energy consumption) which are highly variable and are user input-dependent, and
- b. The tool permits highly variable material and component configurations, which are also based on user input.

Therefore, carbon footprint estimates from the server tool (reported either as a single value or a range, as described above) shall be qualified with the following information:

- Server type: tower, rack or blade
- Shared resources:
 - Encasement/mount:
 - If the server type is rack, indicate the number of servers sharing a rack mount
 - If server type is blade, indicate the number of servers sharing the enclosure
 - PSUs and fans:
 - If the server type is rack, indicate whether the PSU and fan quantities indicated are dedicated to the server or shared among multiple servers
 - If the server type is blade, indicate the quantity of PSUs and fans used by the entire blade enclosure
 - If the server type is tower, indicate the quantity of PSUs and fans used by the tower server.
- Number of CPUs used by the server
- Number of HDDs used by the server
- Number of SSDs used by the server
- Location of server use
- Lifetime of server
- Annual typical energy consumption of the server hardware system
- Datacenter and hardware energy consumption assumptions should be documented.

Please qualify the results from the network switch tool with the following information:

- "The scope of the analysis is a single network switch product, which is defined to exclude storage array and server. The scope includes the rack or blade chassis, which are allocated equally to the number of switches sharing the rack or blade chassis."
- Count of mainboards
- Count of PSUs
- Location of use
- Useful lifetime (years)

- Annual typical energy consumption for the switch
- Use stage considers only the energy demands of the network switch equipment, and therefore excludes datacenter and other hardware draws.

COMPARING PAIA RESULTS

The PAIA tools were not developed to support comparisons. As is discussed below, comparisons of LCA results generally, particularly those developed separately are fraught with challenges. As such, we do not recommend that PAIA results be used comparatively.

ISSUES IN LCA COMPARISON

**Note: In the following discussion, frequent reference is made to analysis or results used to support meaningful decisions. Here, meaningful decisions are those where the selected alternative is in fact superior (or, more precisely, the superior alternative is identified with a tolerably low error rate).*

As life cycle analysis becomes more prevalent, its metrics are used to support an increasing number of decisions, including those that involve comparisons. Unfortunately, comparing the results of two life cycle assessments can be misleading.

It is difficult to draw meaningful conclusions when comparing two life cycle assessment results for two fundamental reasons. First, LCA results are strongly influenced by the assumptions made by the analyst; if those assumptions are inconsistent, comparisons are not likely meaningful. Secondly, LCA results have a high degree of inherent uncertainty and that uncertainty would not be expected to be statistically independent across a set of alternatives being compared.

With regard to the application of the PAIA tools, analytical assumptions manifest as input values. Obviously, when comparing two alternative products, some inputs will be different. Such differences, however, should be strictly limited to inputs which represent characteristics of the alternatives. Conversely, ALL inputs which are NOT driven by characteristics of the alternatives must be consistent to support meaningful comparisons.

The second issue that confounds comparison of LCA results is a statistical phenomenon called correlation. First, we restate a point made throughout this document: LCA results exhibit a high degree of uncertainty. Interestingly, though, the uncertainty in LCA results for two (or multiple) alternatives being compared is generally partially correlated. By this we mean, that if the result for one alternative is actually at the higher end of the uncertainty range, the result for the other alternative has a better than even chance of also being at the higher end of its range. The existence of correlation among the LCA

results of alternatives means that simple statistical evaluations (such as comparing two reported ranges) will generally understate the resolvability of the two alternatives.

Because of the importance of assumptions and the prevalence of correlation, accurate comparisons of LCA results require that all alternatives be simultaneously simulated. Based on simultaneous simulations, it is possible to generate a distribution of the differences in results (or ratios of results) among the alternatives. This distribution of differences can be evaluated for statistical significance.

Because the PAIA tools are not configured to allow for simultaneous simulation, it is not recommended that PAIA results be used in comparisons.

STATEMENT ON DATA QUALITY

As with any LCA model, the results are only as good as the data employed in the calculations. Primary data is preferred; however the level of effort expended to gather data was prioritized based on the results of the PAIA method's impact screening technique. As such, additional care is taken to gather information where it will have the most potential impact on creating a more accurate number. That said, all data employed by PAIA conform to the ISO 14064¹ statement on data quality:

The project proponent shall establish and apply quality management procedures to manage data and information, including the assessment of uncertainty, relevant to the project and baseline scenario. The project proponent should reduce, as far as is practical, uncertainties related to the quantification of GHG emission reductions or removal enhancements.

As shown in Appendix I, the quality of each data source has been classified as high, medium, low and very poor based on the following criteria:

- Source: The data within PAIA come from a number of sources: industry-aggregated primary data, commercially available LCA databases, technical specifications, published reports and studies. Primary data were collected from PAIA partners as well as relevant industry groups. The source for each element is listed in the Data Attribute tables within the model as well as in the Appendix II below.
- Temporal: When the data was collected and over what amount of time was it aggregated affects the relevance and accuracy of the model's results. As such, newer data is preferred, and employed when available.

¹ International Standards Organization. Greenhouse Gases. In *Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements*, ISO copyright office: Geneva, 2006; Vol. 14064-2.

- Representativeness: Wherever possible, data have been collected that provide a representative picture of the relevant supply chains within the electronics industry.
- Geographic: Geographic uncertainty is made explicit by offering options for transport from various production locations and use phase impact for various regions.

The research team continues to gather additional data to improve the robustness of the dataset. As the PAIA models transition to other agencies for administration, so will the responsibility to maintain a relevant and accurate database. Data updates for the most significant components will aim to occur annually, based on availability of relevant industry association data and relevant energy mix data.

STATEMENT ON UNCERTAINTY

One of the core aims of PAIA is to represent uncertainty within the data used to make carbon impact calculations. Data uncertainty in any LCA can be due to a number of factors, such as measurement inaccuracies, allocation inconsistencies, outdated or obsolete data sources, human bias, error, etc. Data related to IT products are particularly prone to uncertainty because of the high speed of evolution within both the technology and its manufacture. Geographic uncertainty is also an issue, related to both where a product is produced as well as where it is used.

In most cases, it is not feasible to eliminate the uncertainty; therefore PAIA aims to provide a structural mechanism to account for and manage uncertainty in the areas with the most impact. As suggested by Weber (2012), determining which approach to take depends on the number of data points available. Briefly, where one data point is available, the pedigree matrix is applied to quantitatively estimate qualitative uncertainty (Frischknecht et al. 2007). When multiple data points are available, simple distributions are used to model uncertainty structure, where possible. If no central tendency is apparent a uniform distribution is used (versus normal, lognormal or triangular if a central tendency is apparent). If too few data points are available, the pedigree approach may also be used in cases of multiple data points. For the impact data, this method uses an approach termed probabilistic underspecification for the emissions factors associated with materials, electronics and energy, etc. The essence of this approach is to describe materials at a less specific level than at the individual life cycle inventory level so as to a) avoid bias where individual entries are not applicable, b) focus the data gathering effort and c) structure the uncertainty associated with emissions factors.

To describe the pedigree matrix and probabilistic underspecification in a bit more detail the following are offered:

1. The pedigree matrix or data quality indicator: Pedigree matrices are used to create a framework to quantitatively assess qualitative factors when appropriate data is not available (Frischknecht et al 2007). In this case, data quality is assessed based on a number of factors, including reliability, completeness, temporal correlation, geographical correlation, and technological correlation. Depending on the score assigned for each category, indicator scores are assigned, providing a variance (σ^2) of the underlying normal distribution.
2. Probabilistic Underspecification:
Probabilistic underspecification allows the practitioner to broadly define a material or process category depending on its contribution to the total uncertainty. Many times, it is unclear when performing an LCA whether a specific process is appropriate for the system being studied, or if the appropriate process is even available. As a result, the practitioner uses proxy data, such as from an LCA database, as a best guess. By instead categorizing all the inventories within a given materials (or process) type and statistically sampling within the desired level of the hierarchy, a descriptive probability distribution can be determined for a given category. The categories are defined at different levels of specification according to different material or process characteristics, ranging from the least specified (such as high level categories of metals or chemicals) to highly specified (such as the exact chemical being analyzed). As the levels become more specific, their associated uncertainty decreases and the range of values becomes smaller. Please see the following for more information: <http://pubs.acs.org/doi/abs/10.1021/es3042934>

REPRESENTATIVENESS OF TOOLS

Tablet tool

The tablet tool is intended to be used for tablets with the option to input or choose default values for the following form factors: screen size, screen resolution, production release year, 2-in-1 accessories, and other features. Users are also able to specify the information for PWB area, IC die area, packaging, transportation, use and EoL.

The following are the key measurements of the information used for creating the tool:

- Range of products: teardown data from 25 tablets were used from 2010 and 2013
- Component data: integrated circuit data and display data (Scope 1 and 2 emissions per area) updated annually; other small electronics are modeled in terms of density based on data from 2008-2012.

Notebook tool

The notebook tool is intended to be used for notebook computers with the option to input or choose default values for the following form factors: product weight; screen size, resolution and design; chassis materials; number of hard drives and optical drives, characteristics of the motherboard and other boards including area and chip sizes; number of battery cells; wattage of power supply; and other features. The users are also able to specify information for packaging, transportation, use and EoL.

The following are the key measurements of the information used for creating the tool:

- Range of products: teardown data from notebooks ranging from 10.1 to 17.3" screen sizes from production years ~2005-2010.
- Component data: integrated circuit data and display data (Scope 1 and 2 emissions per area) updated annually; other small electronics are modeled in terms of density based on data from 2008-2012.

Desktop tool

The desktop tool is intended to be used for desktop computers in tiny/mini, small/medium, and tower/large form factors with the option to input or choose default values for the following additional form factors: product weight, chassis dimensions, hard drive size and quantity, optical size and quantity, power supply wattage, mainboard and other board area and characteristics, and integrated circuit area, among other features. The users are also able to specify the information for packaging, transportation, use and EoL.

The following are the key measurements of the information used for creating the tool:

- Range of products: teardown data from 10 desktop computers were used from 2005-2011
- Component data: integrated circuit data and display data (Scope 1 and 2 emissions per area) updated annually; other small electronics are modeled in terms of density based on data from 2008-2012.

Display tool

The display tool is intended to be used for displays spanning 15-65" (either monitors or TVs) with the option to input or choose default values for the following form factors: monitor or TV; screen size; resolution; LCD panel design (light type and lighting configuration); housing materials; and characteristics of boards, integrated circuits and power supply. Users are also able to specify information for packaging, transportation, use and EoL.

The following are the key measurements of the information used for creating the tool:

- Range of products: teardown data from 5 monitors from 2008-2011 and 4 TVs from 2009-2012.
New Egg samples (~80 for TVs and several hundred for monitors) were used to develop relationships for weight and dimensions. Data were extrapolated to accommodate an expansion of the model to larger display sizes (around 65").
- Component data: integrated circuit data and display data (Scope 1 and 2 emissions per area) updated annually; other small electronics are modeled in terms of density based on data from 2008-2012. Quantity of LEDs in edge and direct design displays was based on aggregated member feedback. PWB area estimated based on member feedback.

All-in-One tool

The all-in-one (AiO) tool is intended to be used for AiOs with the option to input or choose default values for the following form factors: product weight, screen size, release date, portability, number of fans, HDD quantity, optical drive quantity, battery cells and characteristics of boards, integrated circuits and power supply. Users are also able to specify information for packaging, transportation, use and EoL.

The following are the key measurements of the information used for creating the tool:

- Range of products: teardown data from 7 AiOs were used from 2010-2014.
- Component data: integrated circuit data and display data (Scope 1 and 2 emissions per area) updated annually; other small electronics are modeled in terms of density based on data from 2008-2012.

Thin Client tool

The thin client tool has been built to represent thin clients, and not similar products such as zero clients and mobile clients. With regard to data inputs expected from the user, the following inputs are mandatory, i.e., there are no default data available: thin client dimensions, thin client weight, product shipping weight, storage type (HDD or SSD), assembly location, year of IC Scope 1 and 2 data, and product use parameters of product lifetime, yearly typical energy consumption and use location. Other requested inputs are optional, i.e., default assumptions are available: motherboard PWB area, CPU area, memory area, other ICs area, number of ICs on the motherboard, RAM, storage size, transport modes, and EoL fate.

The following are the key measurements of the information used for creating the tool:

- Range of products: teardown data from seven thin clients from three manufacturers were used. In addition, New Egg data for approximately 50 diverse thin client products was used to characterize product weight, dimensions (and by association motherboard area), CPU types and their package and die area, chipset types and die area.
- Component data: integrated circuit Scope 1 and 2 emissions per area are updated annually; integrated circuit area estimated based on product specs from New Egg samples; motherboard area estimated from thin client length and width from New Egg samples; other small electronics are modeled in terms of density based on the teardown data described above; enclosure material types and quantities based on teardown data; SSD info based on teardowns.
- Other data: assembly efforts are assumed to be close to those for desktops (based on PAIA member feedback)

Server tool

The server tool is intended to represent tower, rack and blade servers manufactured between 2013 and 2016. Because of the highly variable nature of server configurations, quite a lot of input about the server configuration is required to be specified by the user: server type, quantity of slots in the enclosure/mount, quantity of slots occupied, number of PSUs and fans either used by the server or shared among all servers in the enclosure/mount, server weight, assembly location, motherboard PWB area, DRAM

capacity, mainboard assembly location, quantity of SSDs, HDDs, ODDs, transport distances and modes, hardware annual typical energy consumption, datacenter PUE (or datacenter size as a proxy), server lifetime, server use location, and end of life fate.

- Range of products: teardown data were supplied by three manufacturers for at least six products.
- Component data: integrated circuit Scope 1 and 2 emissions per area are updated annually; integrated circuit area estimated based on product specs from New Egg samples; other small electronics are modeled in terms of density based on the teardown data collected for prior tools; enclosure material types and quantities based on teardown data; SSD info based on teardowns.

As is the case with all the PAIA tools, but especially for the server tool, the intended use is for cradle to grave assessments, as this is how the triage has been applied. In other words, the screening triage for server products identified use stage to dominate, so not much detail was built around other server aspects such as component materials, manufacturing, etc. Therefore, if a user intends to report cradle to gate footprints or component-level footprint, a different tool is needed.

Network switch tool

The network switch tool was designed to evaluate and produce results for a single “rack switch” or “blade switch” network switch product, defined to exclude storage array and server components. The scope includes the rack or blade chassis and other “shared” infrastructure like shared PSUs and fans, which are allocated equally among the number of switches sharing the rack or blade chassis and infrastructure. The products represented by the network switch tool are intended to represent switches manufactured in the 2014-2017 timeframe.

Because of the highly variable nature/configurability of network switches, the user is asked to specify much information about the types and count of components included in the switch, and the user is asked to qualify the footprint results with details about the configuration being evaluated (those requested qualifications are listed earlier in this document).

- Range of products: teardown data were supplied by several manufacturers representing at least four products, including both rack and blade switches.
- Component data: integrated circuit Scope 1 and 2 emissions per area are updated annually; integrated circuit area estimated based on product specs from New Egg samples; other small electronics are modeled in terms of density based on the teardown data collected for prior tools; server data were leveraged for fan trays, PSUs, enclosure/chassis and packaging based on expert opinion/assumption that those components are either directly shared with

servers and are therefore the same, or because they are expected to be highly similar to those of a server.

Storage tool

The storage tool was designed to evaluate and produce results for a single storage array product, defined to exclude network switches, server components, and additional storage enclosures that may be present in a configuration. The scope includes the rack or blade chassis and other "shared" infrastructure like shared PSUs and fans, which are allocated equally among the number of arrays sharing the rack or blade chassis. Some server tool data was used to represent components that would likely be comparable to the server data, such as fan trays and rack and blade chassis materials.

- Range of products: teardown data were provided for three products by three manufacturers.
- Component data: integrated circuit Scope 1 and 2 emissions per area are updated annually. Some data were gathered from the New Egg website, such as RAM dimensions and characteristics.

APPENDIX I: Data quality summary

Life Cycle Phase	Used in Module	Activity	Subactivity	Data Source	Age/Year of Data	# of data points	Data Quality	
Materials & Manufacturing	Pkg	Paper & Board	Quantity Impact	Ecoinvent, Industry study, literature, company specification sheets Ecoinvent, Paper industry study	1997-2010	5	M	
	Cables, Chassis, Pkg, PSU	Thermoplastics, Rubber, Thermoset	Quantity Impact	Ecoinvent, Industry study, literature, Disassembly	1997-2010	5	L	
			Ecoinvent, Industry Association information adds some more detail		94	M		
	PSU	Glass/ Insulation	Quantity Impact	Industry study Ecoinvent	2010	1	L	
	All (except pkg)	Solder	Quantity Impact	Literature Ecoinvent	2005	1	L	
	Chassis, PSU	Ferrous Metals	Quantity Impact	Ecoinvent, Industry study, literature Ecoinvent, Industry association data	1997-2010	5	L	
	All (except pkg)	Non Ferrous Metals	Quantity Impact	Ecoinvent, Industry study, literature	1997-2010	22	M	
			Ecoinvent, Industry association data for aluminum		5	L		
	Mainboard	Precious Metals	Quantity Impact	Ecoinvent, Industry study, literature Ecoinvent	1997-2010	98	M	
	HDD, OD, Mainboard, PSU	PWB	Quantity (area of all) Impact	Teardowns, company specifications, few literature points, Industry study Ecoinvent, PE	2002-2010	3	VP	
					11	L		
	HDD, OD, Mainboard, PSU	Capacitors, Diodes, transistors, resistors	Quantity Impact	Teardowns * density conversion based on PE PE, Ecoinvent	2008	14	L	
					4	M		
	HDD, OD, Mainboard, PSU	Other ICs	Quantity Impact	(Suppl) teardown and other teardowns PE	2008	5	L	
					1	L		
	Mainboard	CPU Silicon	Die/Wafer Impact	Boyd PE, Ecoinvent, Boyd	2001-2013?	27	M	
		Chipset Silicon	Quantity (# chips, chipset) Die/Wafer Impact	On line specifications and Boyd Boyd PE, Ecoinvent, Boyd	2001-2013?	6	L	
		DRAM Silicon	Quantity (# chips) Die/Wafer Impact	Single industry study, discussions with industry Boyd PE, Ecoinvent, Boyd	2001-2013?	6	L	
		CPU, Chipset, DRAM Fabrication	Quantity (chip area) Electricity	Boyd, Specification sheets SIA	2001-2011	3	M	
		CPU, Chipset, DRAM Packaging	Quantity (chip area) Electricity	Boyd, Specification sheets Williams	2010	1	L	
		CPU, Chipset, DRAM PFCs	Impact	SIA	2001-2011	7	M	
		CPU, Chipset, DRAM Natural Gas	Natural Gas per chip area Impact	SIA IPCC	Very old	1	VP	
		CPU, Chipset, DRAM Fuel Oil	Fuel Oil per chip area Impact	SIA, IPCC Conversion Factor IPCC	2010	25	H	
		Fabrication Chemicals	% Impact Factor	By percentage contribution from literature	2006	26	L	
		Chip Packaging Materials	Impact %	By percentage contribution from literature	2008-2010	17	L	
		Low Tech Cables Processing Fuel	MJ Impact	Ecoinvent Ecoinvent	2006	1	VP	
		Cables	Assembly and Processing	Electricity	Literature, Ecoinvent	2002	2	L
			Assembly and Processing Fuel	MJ Impact	Ecoinvent Ecoinvent	2002-2005	2	L
		Chassis, HDD, OD, PSU	Board Assembly	Electricity	Ecoinvent Ecoinvent	2002	1	L
			Final Assembly	Electricity	MEEUP (calculated) Supplier survey, Ecoinvent, Industry study	2005	1	M
		MODULES INCLUDED IN NOTEBOOK						
	Materials and Manufacture	Battery	Battery	Quantity (BOA) Impact	Literature, Supplier survey, industry discussions Ecoinvent	2010	5	M
		EPS	External Power supply	Quantity (BOA) Impact	EUP lot 7, Ecoinvent, Supplier survey, Disassembly Ecoinvent	2006-2008	4	M
		LCD	LCD	Materials Quantity	Industry study, Supplier survey, Disassembly	2001-2009	4	M
		Chassis	Chassis	Electronics quantity	Industry study, Supplier survey, Disassembly Industry association data	2001-2009	M	M
	Electricity			Industry association data	2010	> 15	H	
Transportation	Use	Transportation	Quantity (product weight)	Teardowns, deriving from product dimensions and assumed thickness, Industry information As above (Ecoinvent, Industry association information on Steel and Aluminum)	2008-2010	> 15	M	
			Distance	Ecoinvent, Industry, Hikwama, Atlantic, IVF, endogenously calculated IDC (EMS locations), Wikipedia (populations), Google Maps (distances) Ecoinvent	1997-2010	5	L	
			Mode		2011	1	L	
			Yearly TEC	Energy Star v5 data set, Product specifications	2007-2008	8	M	
			Lifetime	Industry study, Literature, EPIC-ICT PE, Ecoinvent	1997-2010	183	L	
	EoL	EoL	European Grid Mix	International Energy Agency/Ecoinvent Impact	2	M	M	
			Global Grid Mix		2/1	M	M	
			Quantity (product weight)	Ecoinvent, Industry study, literature	1997-2010	5	L	
			% Landfilled	Industry study, Literature, EPIC-ICT Ecoinvent	1997-2010	6	L	
			Impact		2	L	L	
Used in several phases/modules	Recycling Manual	% Manual	Ecoinvent Ecoinvent			L		
		Impact				L		
		Recycling Shredding	Impact	Ecoinvent		1	M	
		US Grid Mix	Impact	PE, Ecoinvent, Weber article	2010	1	M	
China Grid Mix	Impact	China Electricity Council, China Electric Power Industry Statistics Analysis (2010)	2010	2	M			
	Other Grid Mixes	Impact	PE, Ecoinvent, International Energy Agency		1	L		

APPENDIX II

PAIA Bibliography

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