ESD.S43 - Green Supply Chain Management

Edgar Blanco
Tony Craig
Alexis Bateman

MIT Center for Transportation & Logistics

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Learning Objectives

- Understand the steps in the LCA methodology and how it can be used by firms to make decisions around key environmental drivers, compare products, and evaluate reduction strategies

- Recognize some key LCA decisions
  - Purpose of the study
  - Setting the system boundary
  - Uncertainty in data, models and assumptions

Why measure environmental impact?

Focus / *Driver*	**Internal**	**External**
Corporate	CSR Metrics	CSR Report Government Investor Pressure
SC / Product	Supplier Selection Sourcing/Process Decisions Supply Chain/Product Design	Brand Labeling

What about products?

3.4 grams

3.4 grams,
just over
2 minutes of TV

More than
7 grams

20.14g per dry*

16.08g per dry*

8.23g per dry*

4.31g per dry*

*** CO_2 per dry. Data from Gagnon and Panertos, 2009 report – Comparative Environmental Life Cycle Assessment of Hand Drying systems, prepared for Excel Dryer, Inc. Quantis.**

What is Life Cycle Assessment?

“LCA is a technique for assessing the environmental aspects and potential impacts associated with a product by:

- compiling an inventory of relevant inputs and outputs of a product system;
- evaluating the potential environmental impacts associated with those inputs and outputs;
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.” ISO 14040

LCA takes a life cycle view of a products, from raw materials through end of life.

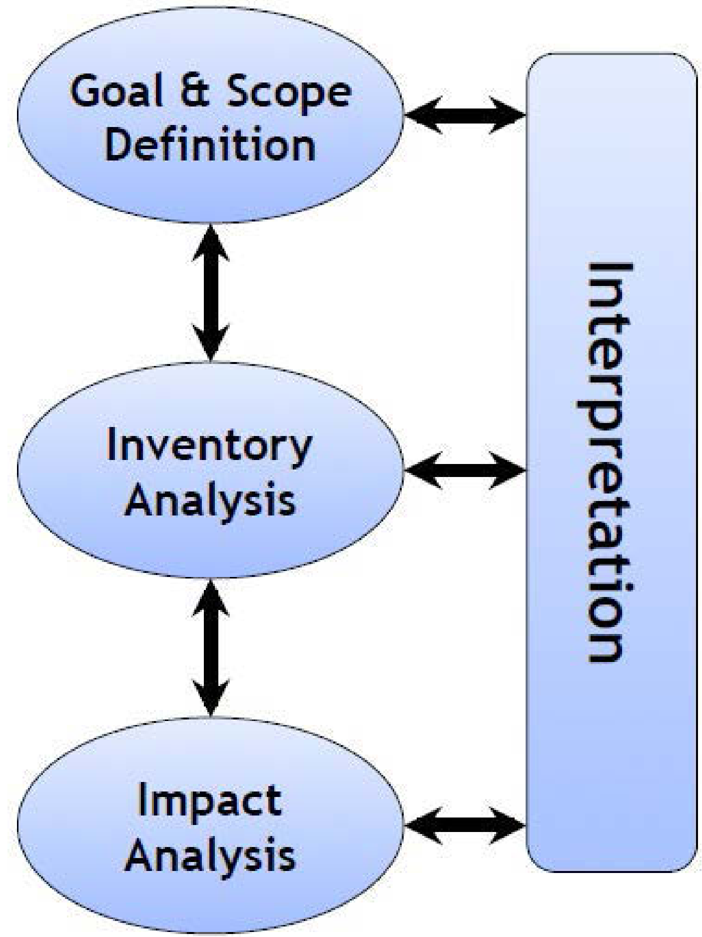
It applies to services as well as products

History of LCA

- First study credited to Coca Cola in 1969
  – Cans or glass bottles
- Rise of "hired gun" studies in the 80s
  – 11 state attorney generals recommend against using LCA for advertisements
- Move towards uniform methodologies in the 90s
  – SETAC working groups
  – ISO standards

LCA Methodology: ISO 14040 Standard

- Goal & Scope Definition
  - Unit of analysis
  - Materials, processes, or products considered
- Inventory Analysis
  - Identify & quantify
    - Energy inflows
    - Material inflows
    - Releases
- Impact Analysis
  - Relating inventory to impact on world
- Interpretation



Source: E.Olivetti MIT MSL

Goal and scope definition

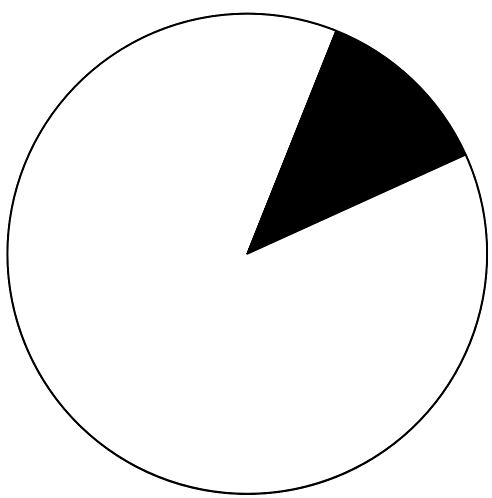
- Decide the product to be studied and the purpose of the study
  - What is the intended application of the study?
  - What is the reason for carrying it out?
  - To whom are the results to be communicated?
- Choice of functional unit
- System boundary
- Types of environmental impact
- Level of detail

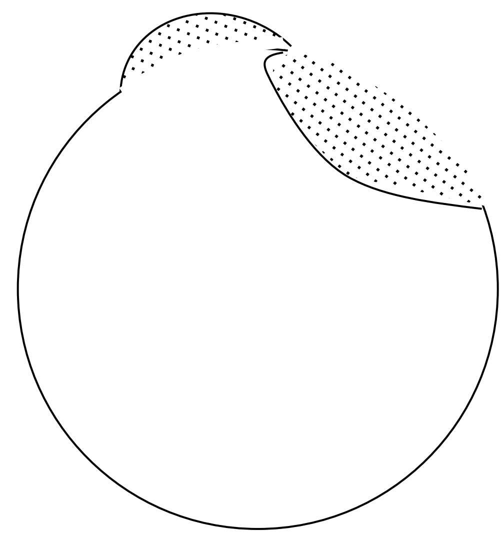
Goal

- Compare the environmental impact of hand drying systems
  - Evaluate how hand-drying systems impact the environment under different manufacturing and use scenarios
  - Identify impact drivers and ways to target those factors
  - Inform product design decisions
- Expected to be used for comparative assertions
- Internal and external audiences

Attributional vs. Consequential

Attributional	**Characteristics**	**Consequential**
Additivity Completeness	**System boundary**	Parts of system affected
Partitioning	**Allocation procedure**	System expansion
Average	**Choice of data**	Marginal





Functional Unit

- One pair of dried hands
- This requires several assumptions
  – Lifespan of dryers, waste bins, and dispensers
  – Number of hands dried during the lifespan

Scope

- Seven systems
  - Airblade (x2), Xlerator, Paper towels (x2), cotton roll towels, standard air dryer
- Cradle-to-grave
- Packaging included
- Related items
  - Waste bins and liners
  - Dispensers

System Boundary

- Allocation vs. System Expansion
  - End-of-life
  - Co-products
- Cutoff rules
  - Mass, energy, estimated impact
  - Less than 1% individually, less than 5% sum

94

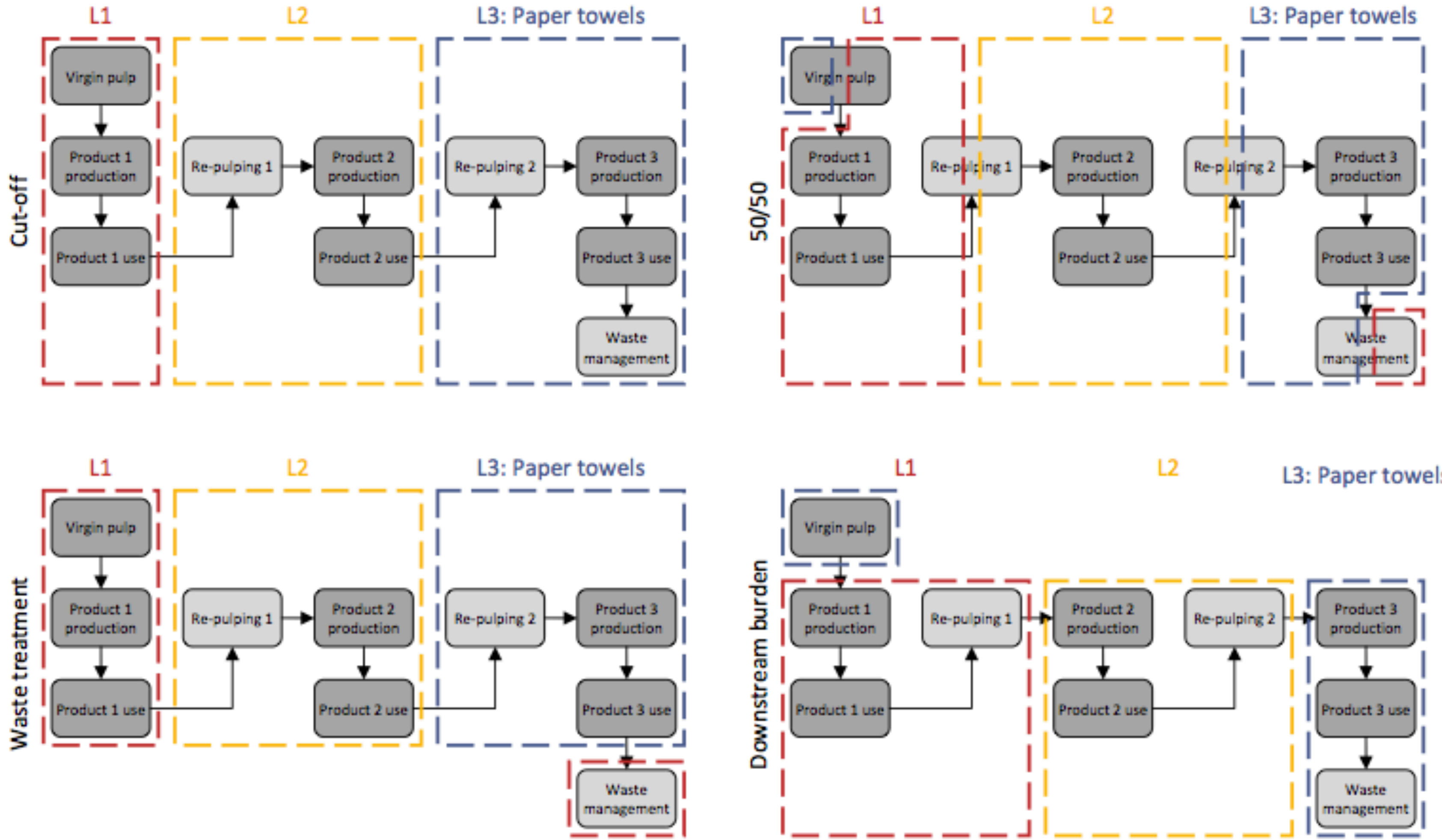


Figure 36 Allocation schemes for recycled content [60].

Courtesy of Gregory, J., R. Kirchain, and T. Montalbo, Materials Systems Laboratory, MIT. Used with permission.

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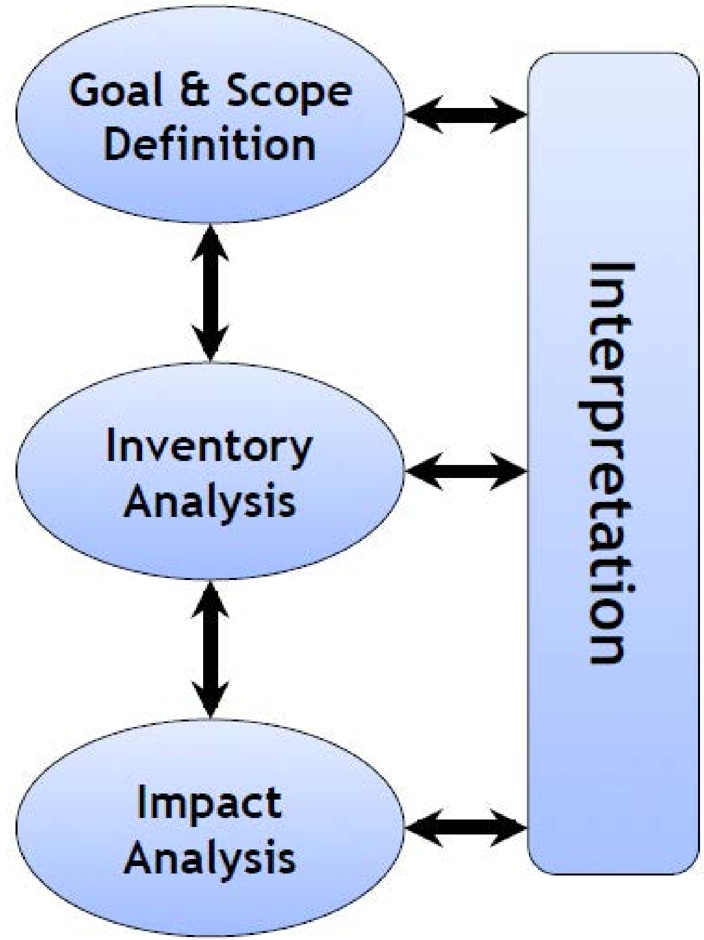
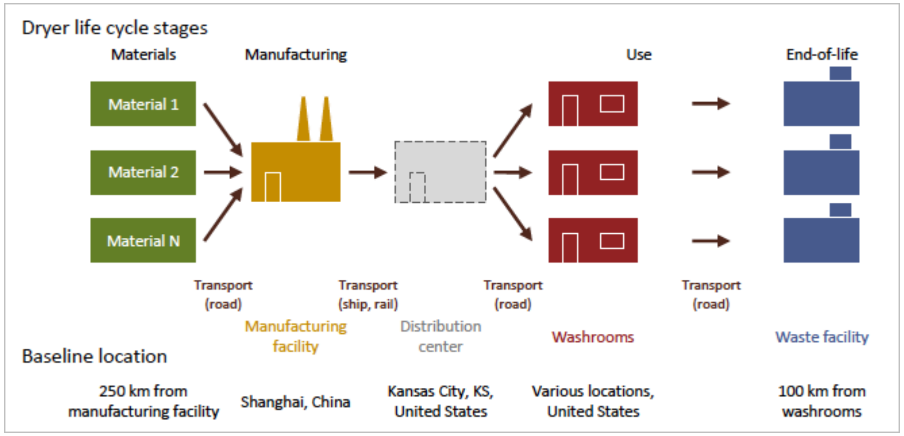


Source: E.Olivetti MIT MSL

Inventory Analysis

- Build a model of the system
- Identify inputs and outputs
  - Raw materials, energy, products
  - Emissions to air, water, and waste



Courtesy of Gregory, J., R. Kirchain, and T. Montalbo, Materials Systems Laboratory, MIT. Used with permission.

Life Cycle Inventories

- Most time consuming part of the LCA
- Third party sources of data
  - Provide life cycle inventories for common products and processes

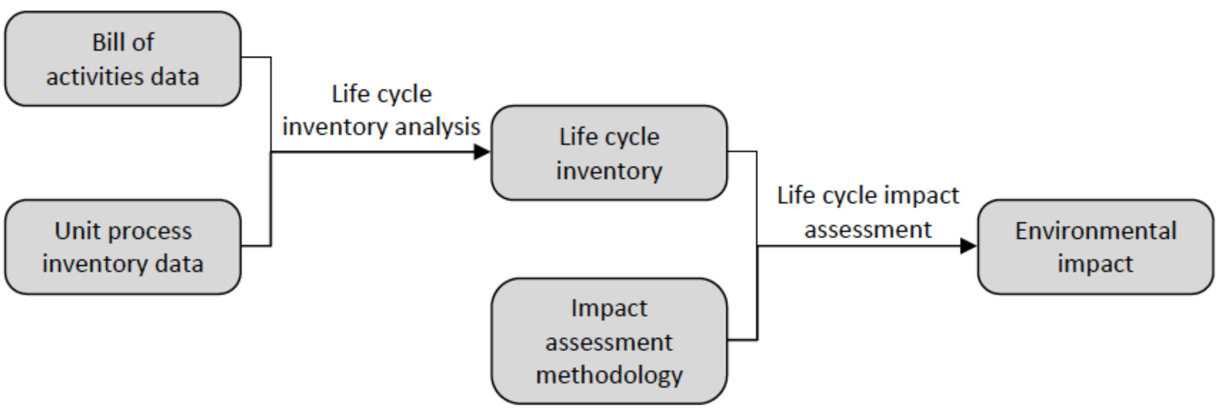


Figure 3 Steps to convert bill of activities data to environmental impact.

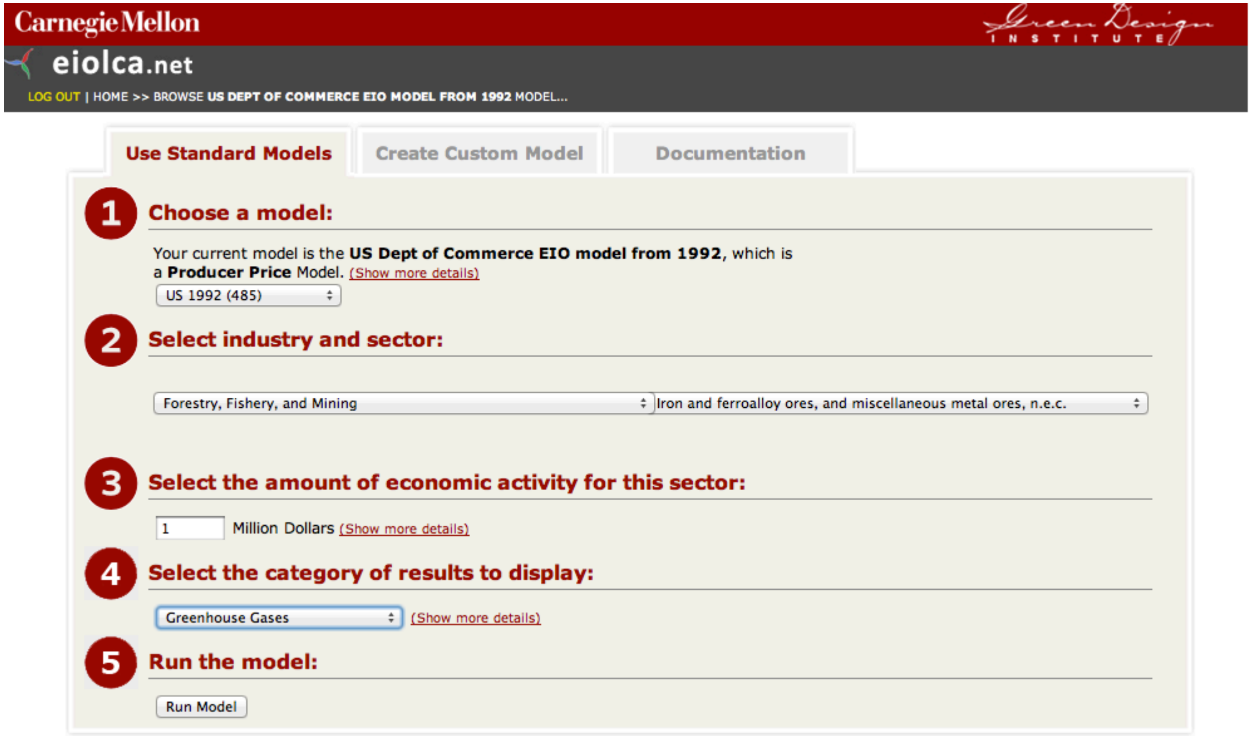
Courtesy of Gregory, J., R. Kirchain, and T. Montalbo, Materials Systems Laboratory, MIT. Used with permission.

Table 3 Assumptions used to generate hand-drying system life cycle inventories for the baseline analysis.

Drying system	Airblade™ (high-speed hands-in dryer)	XLERATOR® (high-speed hands-under dryer)	Standard warm air dryer	Cotton roll towels	Paper towels
Functional unit	1 pair of dry hands				
Lifetime usage	350,000 pairs of dry hands over 5 years [26, 27]				
Mass (+ manufacturing scrap) per dryer or towel	Al: 14.8 kg (1.43 kg) Pl: 9.9 kg (2.16 kg) [27]	9.4 kg (1.12 kg) [14]	6.4 kg (0.9 kg) [14]	16.2 g (2.2 g) [12]	1.98 g (0.08 g) [14]
Manufacturing location	China	China	China	China	US
Manufacturing energy per dryer or towel	146 MJ electricity [27]	156 MJ electricity [14]	156 MJ electricity [14]	431 kJ electricity 507 kJ gas [12]	14.7 kJ electricity 24.4 kJ gas [14]
Use location	US				
Use intensity	12 sec @ 1,400 W + 0 sec @ 0 W + 439 sec @ 1 W	20 sec @ 1,500 W + 1.5 sec @ 750 W + 429 sec @ 1 W	31 sec @ 2,300 W + 1.5 sec @ 1,150 W + 406 sec @ 0.4 W	1 towel (pull) + laundry	2 towels
End-of-life scenario	76.7% of cardboard recycled 19% of remaining waste incinerated with energy recovery 81% of remaining waste landfilled with methane capture and conversion to electricity [30, 31]				
Transportation					
Raw material to plant	250 km via truck				
Plant to warehouse	10,500 km via ocean freighter + 2,600 km via freight train + 24 km via truck (excl. paper towels)				
Warehouse to washroom	1,760 km via truck				
Washroom to laundry and back	100 km via truck (cotton towels only)				
Washroom to waste facility	100 km via truck				
Additional lifecycles	Packaging	Packaging	Packaging	Packaging, dispenser	Packaging, dispenser, waste bin, bin liners
Packaging per dryer or towel	2.94 kg cardboard [27]	0.27 kg cardboard [14]	0.45 kg cardboard [14]	0.08 g polyethylene	0.18 g cardboard [14]

Economic Input-Output Environmental Estimation

- A big matrix. For every sector in the economy …
  - Map $$$ to environmental impact



Economic Input-Output Environmental Estimation

Sector #50001: Iron and ferroalloy ores, and miscellaneous metal ores, n.e.c.
Economic Activity: $1 Million Dollars
Displaying: Greenhouse Gases
Number of Sectors: Top 10

Change Inputs (Click here to view greenhouse gases, air pollutants, etc...)

Documentation:
The sectors of the economy used in this model.
The environmental, energy, and other data used and their sources.
Frequently asked questions about EIO-LCA.

This sector list was contributed by Green Design Initiative.

	Sector	GWP MTCO2E	CO2 MTCO2E	CH4 MTCO2E	N2O MTCO2E	CFCs MTCO2E
	Total for all sectors	*4290*	*3870*	*64.5*	*355.*	*3.14*
680100	Electric services (utilities)	2370	2120	0.471	248.0	0
50001	Iron and ferroalloy ores, and miscellaneous metal ores, n.e.c.	1420	1340	0.785	75.0	0
70000	Coal	66.9	3.78	62.8	0.276	0
370101	Blast furnaces and steel mills	62.6	58.1	0.028	4.53	0
650301	Trucking and courier services, except air	54.8	49.2	0.094	5.44	0
270100	Industrial inorganic and organic chemicals	45.5	40.2	0.023	2.47	2.81
310102	Lubricating oils and greases	39.3	37.9	0.021	1.40	0
310101	Petroleum refining	36.9	35.4	0.021	1.42	0.086
680202	Natural gas distribution	24.0	22.9	0.015	1.14	0
650100	Railroads and related services	23.6	21.9	0.016	1.72	0

Economic Input-Output LCA

- Advantages
  - Speed
  - Completeness
- Disadvantages
  - Aggregation
  - Limited impact categories
  - Cradle-to-gate

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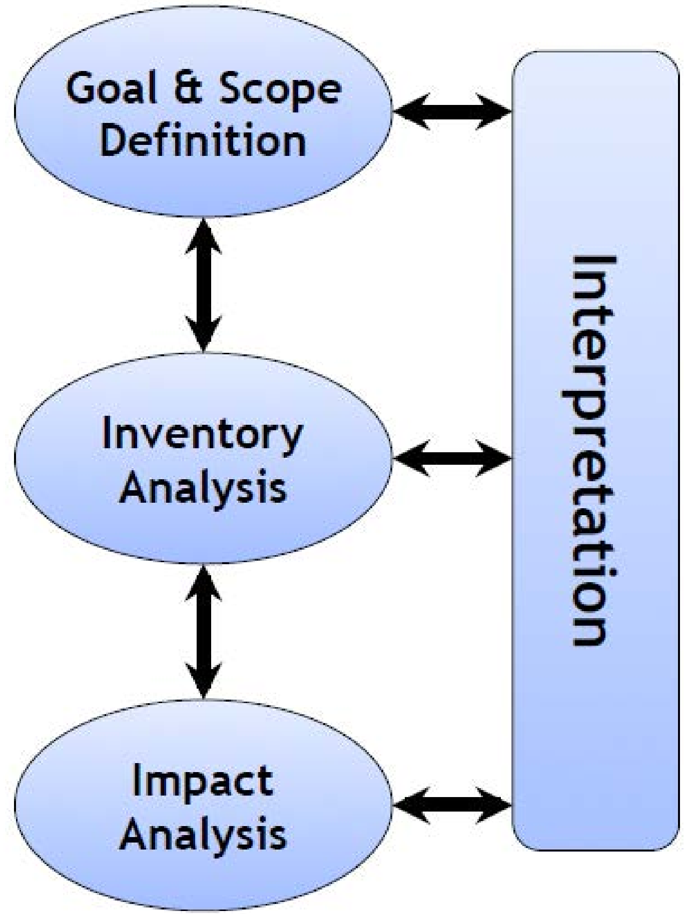

Source: E.Olivetti MIT MSL

Impact Assessment

- Describes the impacts of the inventory analysis
- Two steps:
  - Classification sorts the inventory parameters based on the type of environmental impact they contribute to
  - Characterization calculates the contribution of the emissions and resources for each type of environmental impact

Single Issue Indicators

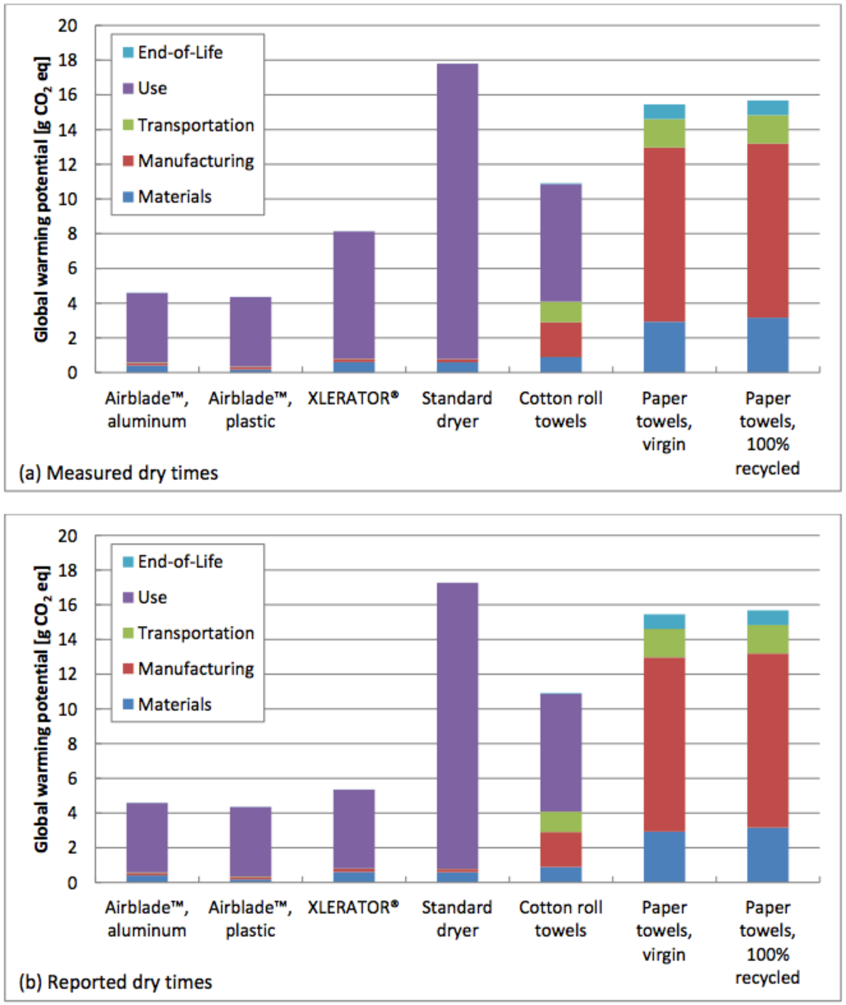

Figure 5 Global warming potential associated with drying a single pair of hands.

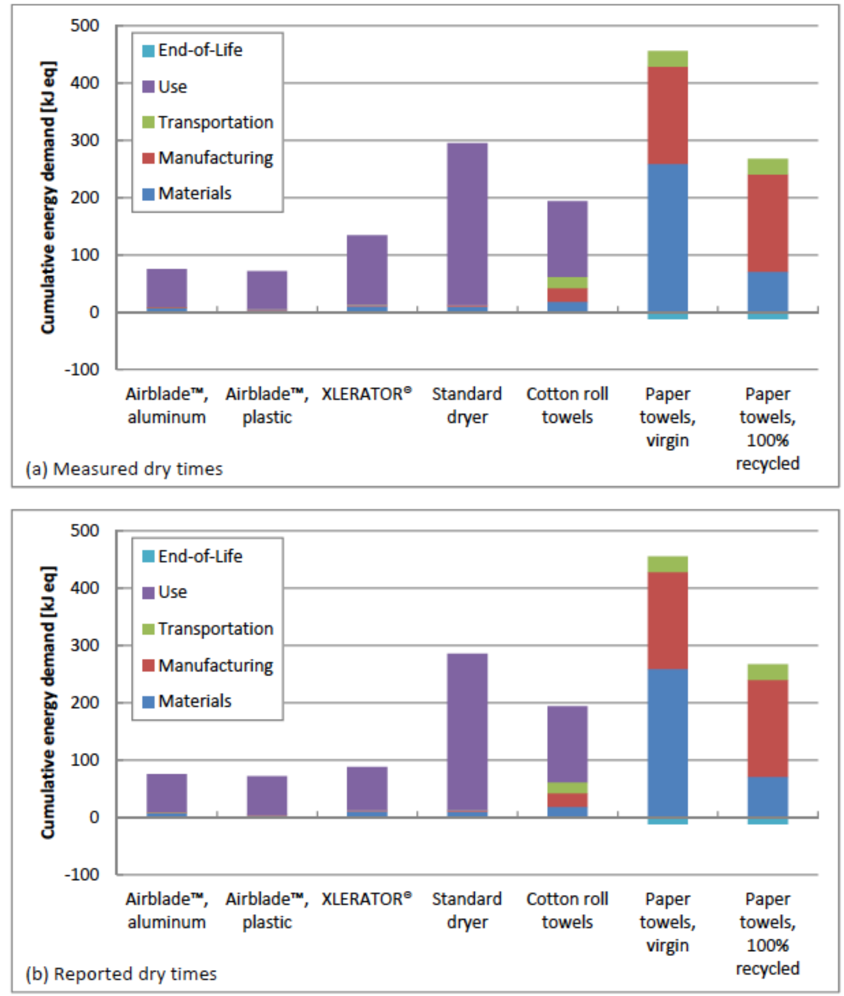

Figure 7 Cumulative energy demand associated with drying a single pair of hands, assuming (a) measured dry times and (b) reported dry times.

Multi-attribute Indicators

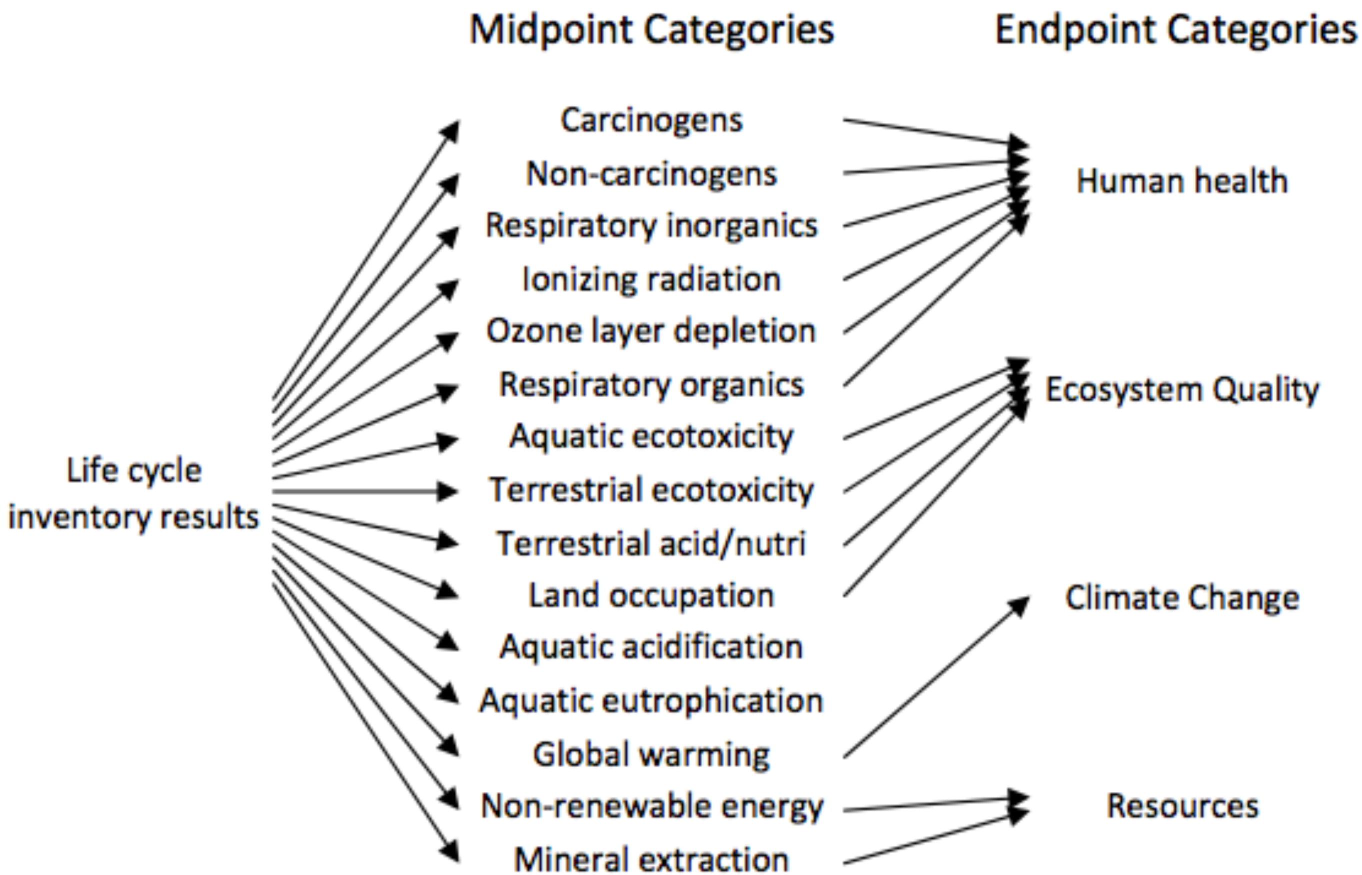

Figure 4 The 15 midpoint categories and four endpoint categories of IMPACT 2002+.

Table 8 Impact 2002+ midpoint category results for each drying system (given measured dry times).

IMPACT 2002+ midpoint categories	Units	Airblade™, aluminum	Airblade™, plastic	XLERATOR®	Standard dryer	Cotton roll towels	Paper towels, virgin	Paper towels, 100% recy.	Endpt. Category
Carcinogens	g C_2H_3Cl eq	0.277	0.272	0.486	1.111	0.205	0.525	0.525	HH
Non-carcinogens	g C_2H_3Cl eq	0.102	0.090	0.189	0.386	0.145	0.454	0.457	HH
Respiratory inorganics	g PM2.5 eq	3.63×10^{-3}	3.45×10^{-3}	6.33×10^{-3}	0.0135	8.16×10^{-3}	0.0126	0.0128	HH
Ionizing radiation	Bq C-14 eq	0.127	0.119	0.239	0.521	0.104	0.291	0.290	HH
Ozone layer depletion	g CFC-11 eq	1.43×10^{-7}	1.24×10^{-7}	2.68×10^{-7}	5.38×10^{-7}	1.03×10^{-6}	1.18×10^{-6}	1.21×10^{-6}	HH
Respiratory organics	g C_2H_4 eq	6.02×10^{-4}	5.81×10^{-4}	1.11×10^{-3}	2.27×10^{-3}	3.31×10^{-3}	4.38×10^{-3}	4.09×10^{-3}	HH
Aquatic ecotoxicity	g TEG water	486	462	1135	2197	935	1619	1628	EQ
Terrestrial ecotoxicity	g TEG soil	118	113	243	484	290	410	417	EQ
Terrestrial acid/nutri	g SO_2 eq	0.0757	0.0725	0.136	0.293	0.221	0.291	0.298	EQ
Land occupation	cm^2org.arable	0.102	0.094	0.227	0.478	22.1	45.0	21.1	EQ
Aquatic acidification	g SO_2 eq	0.0308	0.0297	0.0551	0.1210	0.0499	0.0812	0.0822	—
Aquatic eutrophication	g PO_4 P-lim	2.66×10^{-4}	2.45×10^{-4}	2.28×10^{-3}	2.80×10^{-3}	2.03×10^{-3}	4.05×10^{-3}	4.06×10^{-3}	—
Global warming	g CO_2 eq	4.44	4.19	7.85	17.2	10.2	14.6	14.8	CC
Non-renewable energy	kJ primary	72.1	69.2	130	285	171	245	247	RE
Mineral extraction	kJ surplus	0.162	0.137	0.170	0.216	0.062	0.280	0.277	RE

Endpoint categories: HH – human health; EQ – ecosystem quality; CC – climate change; RE – resources.

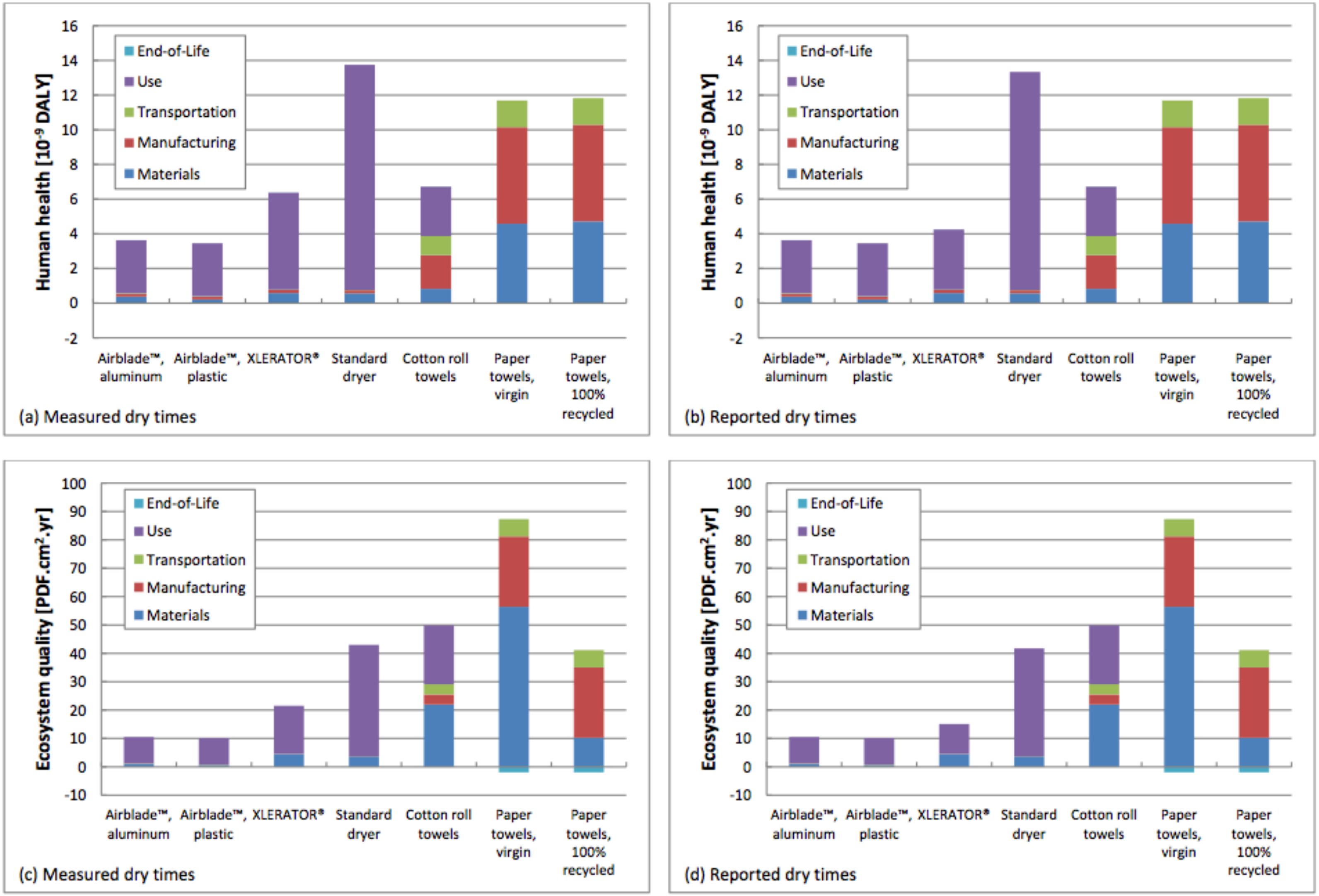

Figure 6 Impact associated with drying a single pair of hands based on impact 2002+ endpoints human health and ecosystem quality. (a) and (c) are calculated using measured dry times (in accordance with the NSF Protocol) and (b) and (d) are calculated using manufacturer reported dry times.

Courtesy of Gregory, J., R. Kirchain, and T. Montalbo, Materials Systems Laboratory, MIT. Used with permission.

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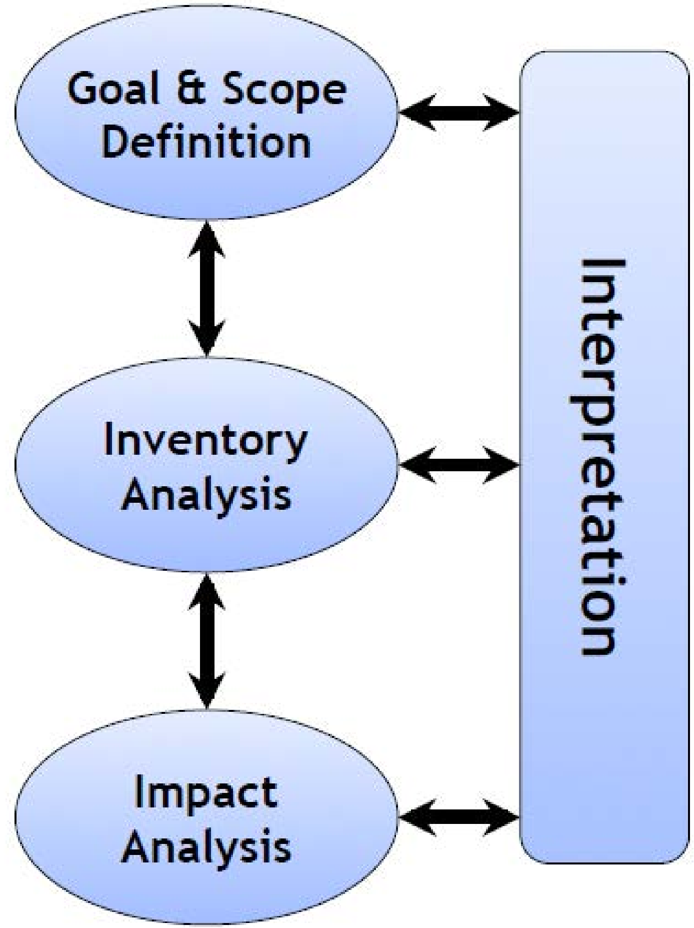

Source: E.Olivetti MIT MSL

Interpretation

- Sensitivity analysis
- Uncertainty analysis
- Bill of Activities uncertainty analysis

Sensitivity Analysis

- One factor at a time
- Tests impact of assumptions

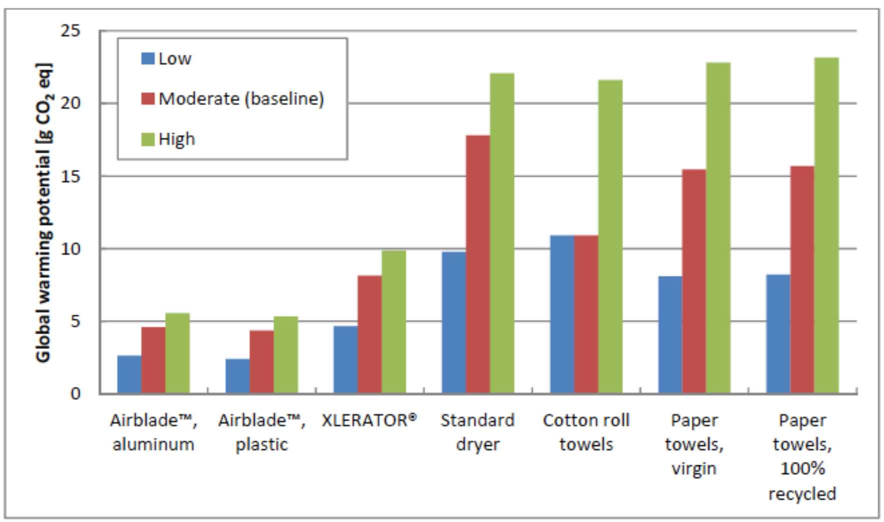

Figure 23 Effect of use intensity on drying system GWP.

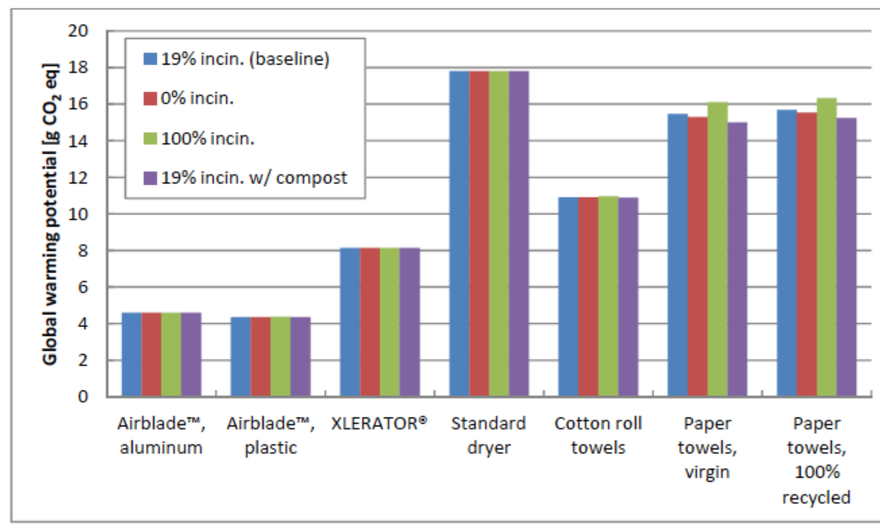

Figure 24 Effect of fraction of waste incinerated on drying system GWP.

Scenario Uncertainty Analysis

- Varies multiple parameters at a time
- Monte Carlo simulation

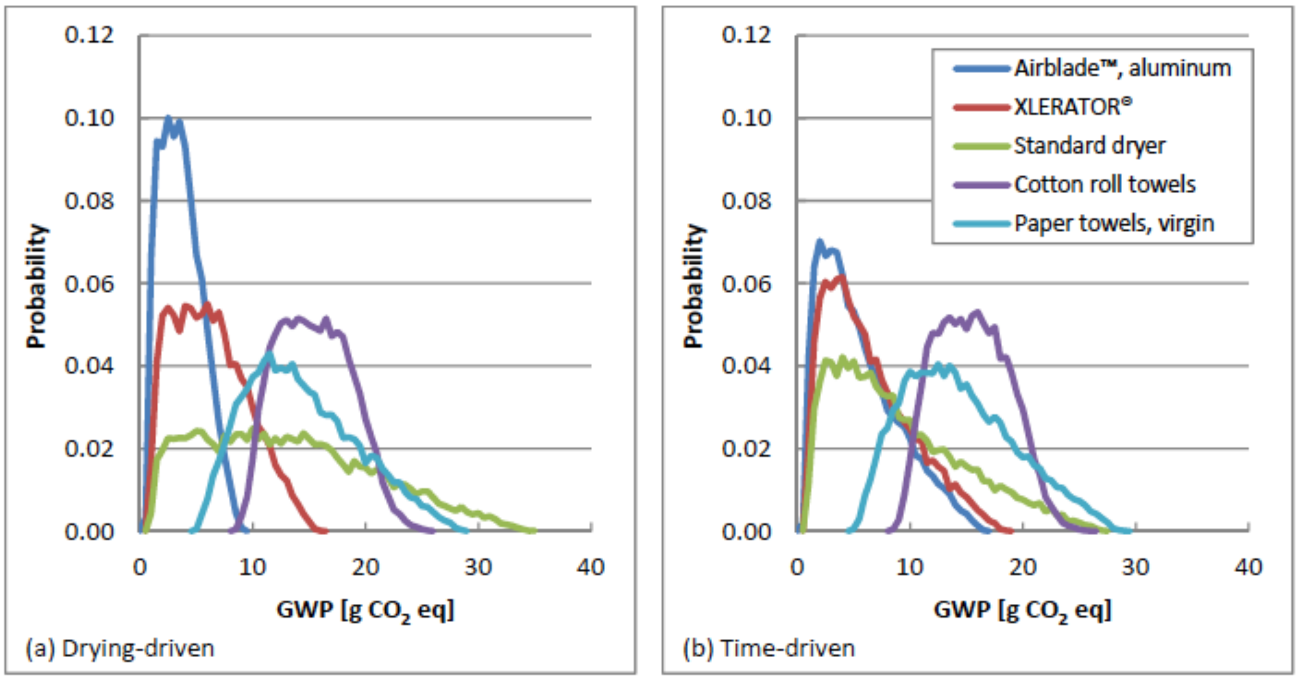

Figure 33 GWP probability distributions given (a) drying-driven and (b) time-driven usage patterns.

Courtesy of Gregory, J., R. Kirchain, and T. Montalbo, Materials Systems Laboratory, MIT. Used with permission.

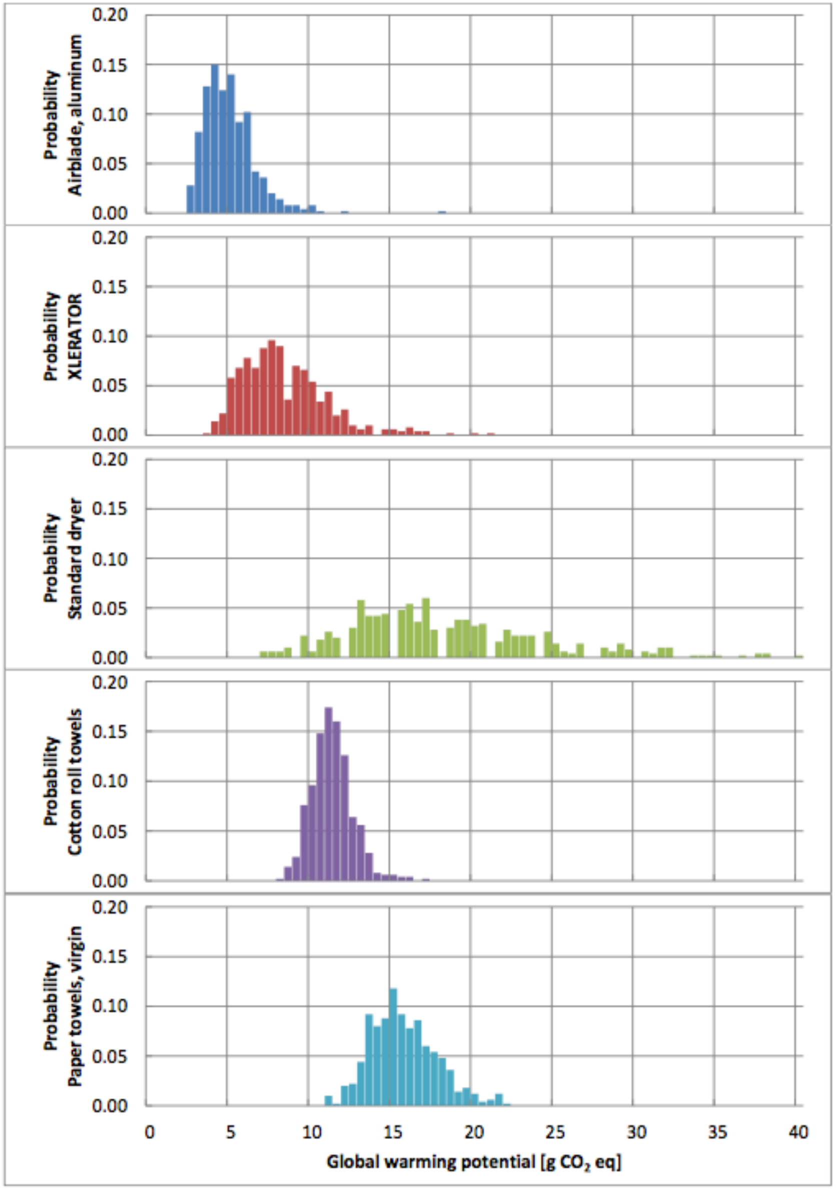

Figure 35 GWP probability distributions resulting from uncertainty in unit process inventory data. Assumes baseline scenario with measured dry times.

Courtesy of Gregory, J., R. Kirchain, and T. Montalbo, Materials Systems Laboratory, MIT Used with permission.

Study Conclusions

- Use phase is the key driver for dryers
- Electricity grid mix and use intensity are the most sensitive parameters
- Dyson Airblade shows lowest impact in general
- Recommendations
  - Reduce energy consumption in use
  - Shorten drying times
  - Switch from aluminum to other materials

LCA: Key Issues to Consider

- System boundaries
  - What will be included?
- Functional Unit
  - What is compared to what?
- Looking beyond your "walls"
  - Impacts are often elsewhere
- Allocation
  - Multiple products from one process
- Uncertainty in data, models and assumptions

Source: E.Olivetti MIT MSL

Tricks and Traps for LCA:

- Spend time defining goal and scope, understand the reason for your study
- Start with a quick estimate
  - Does my product/service use energy in the use phase?
  - Does my product/service require advanced manufacturing processes?
  - What is the bill of materials for my product or what does my service require?
- Identify major sources of impact to drive data collection priorities
- Why your study may differ from another
  - Use phase profile
  - Grid mix
  - Allocation schemes

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