Life Cycle Assessment
(LCA)

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PDS Guatemala
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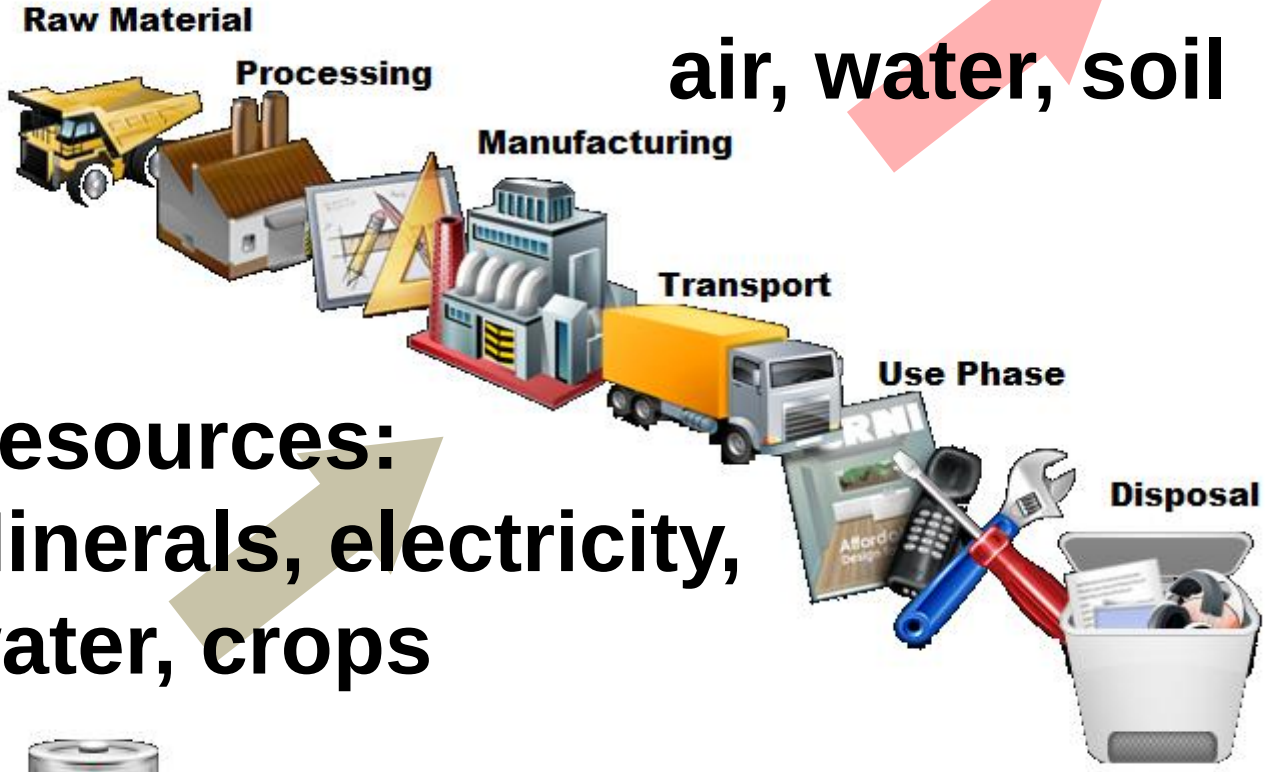
Emissions to air, water, soil

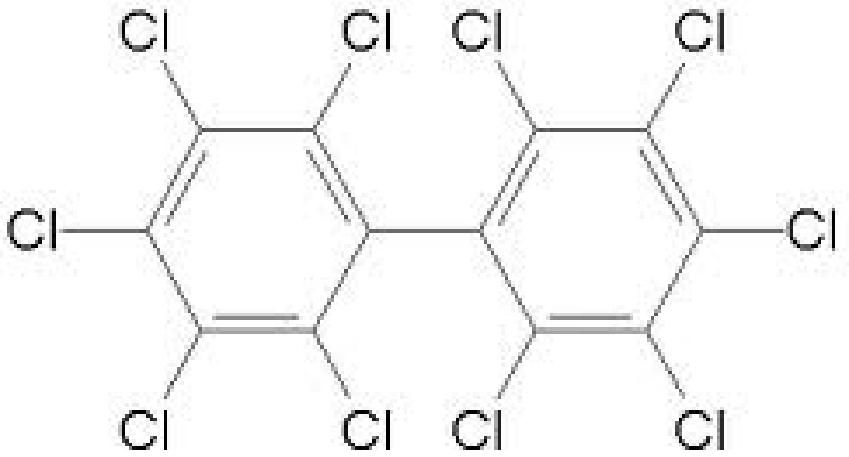


Resources: Minerals, electricity, water, crops

Adapted from: http://sustainable-graphic-design.blogspot.com

Polycarbonate biphenyls (PCBs)

PCB mass production began in 1935 by the Monsanto Corporation, and was banned in 1976



Electric cars

BIOPLASTICS

Transport

Water

Electricity

Fertilizer, Pesticides

Natural gas

Equipment

Additives

Water

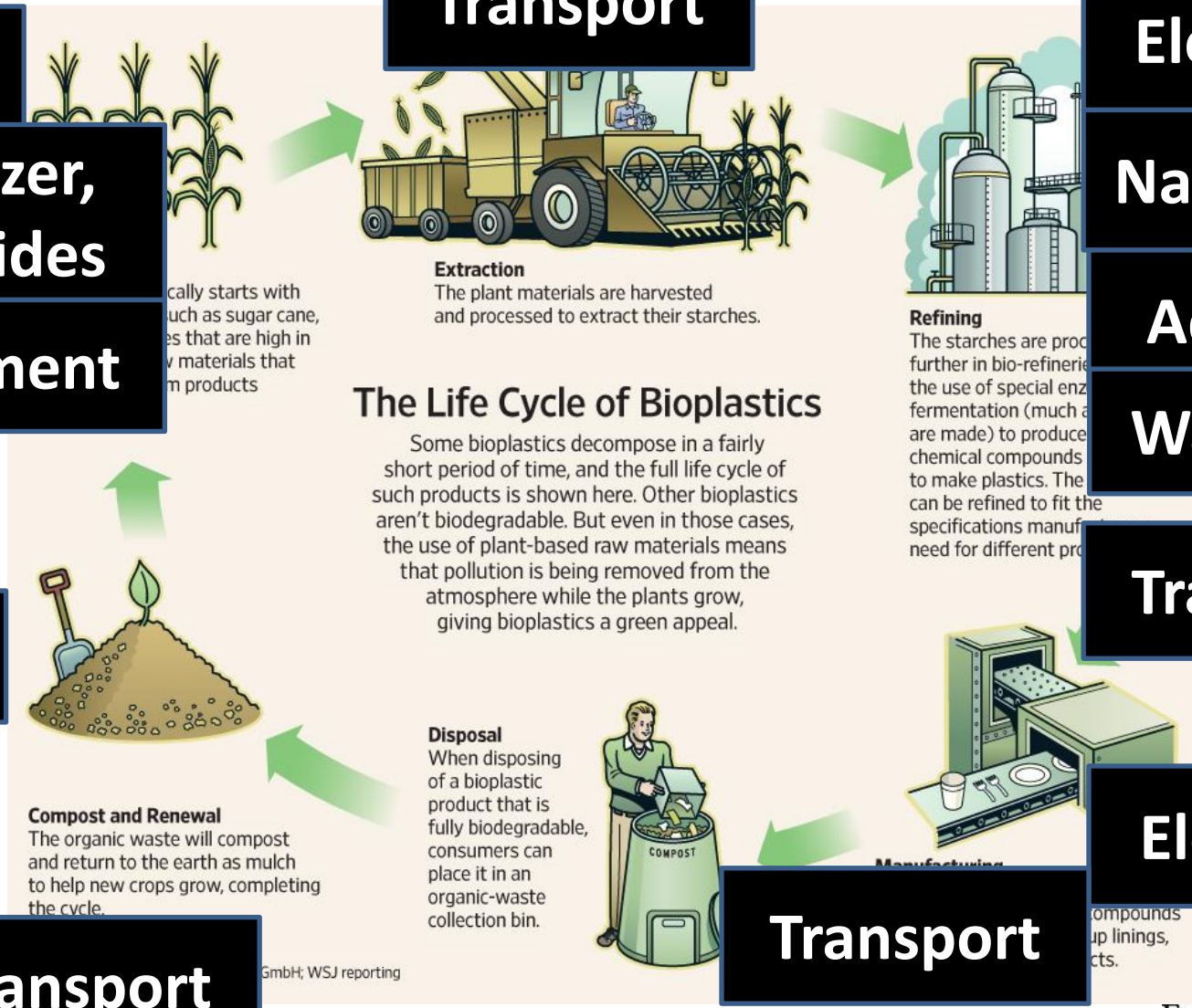
Land

Transport

Electricity

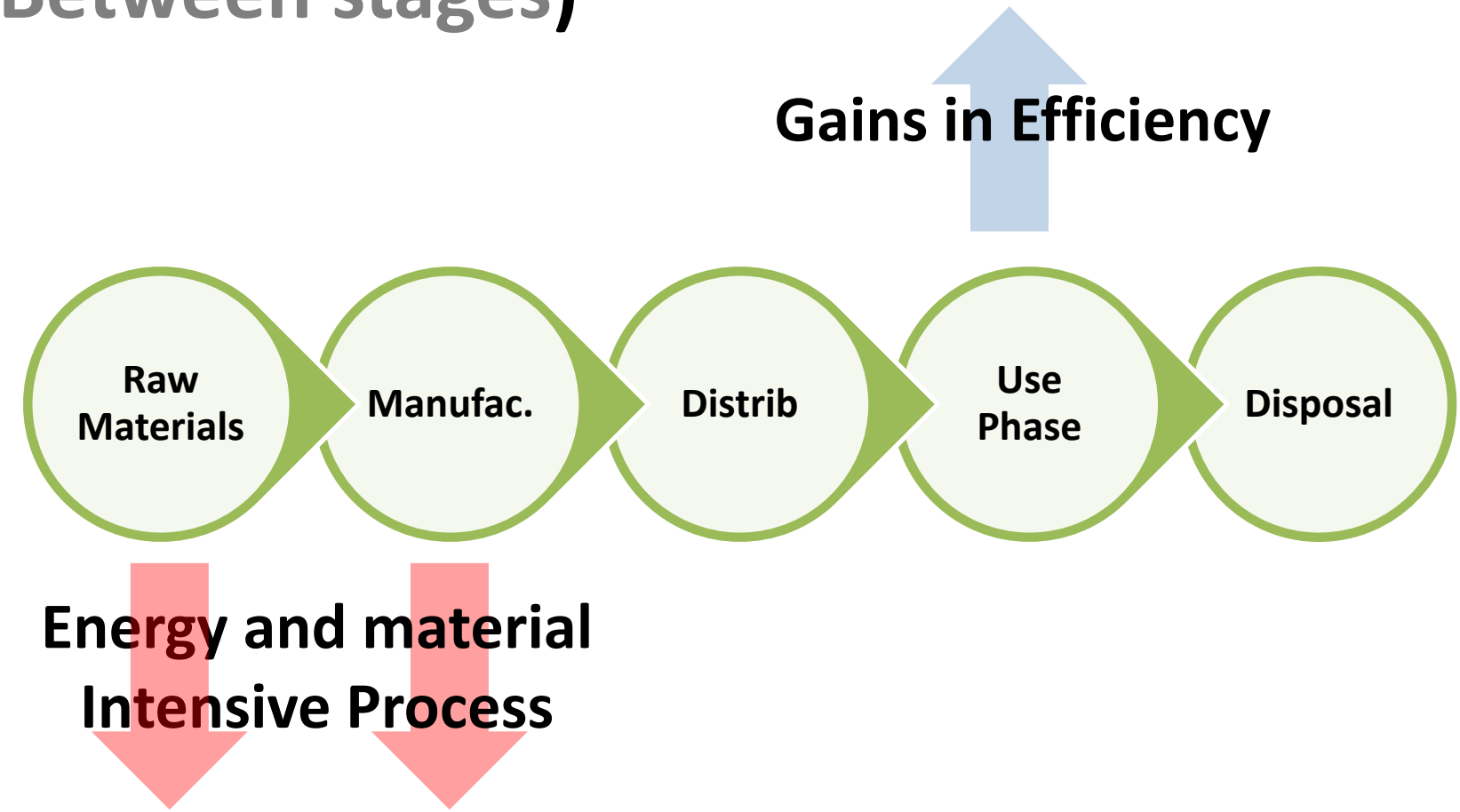
Transport

Transport

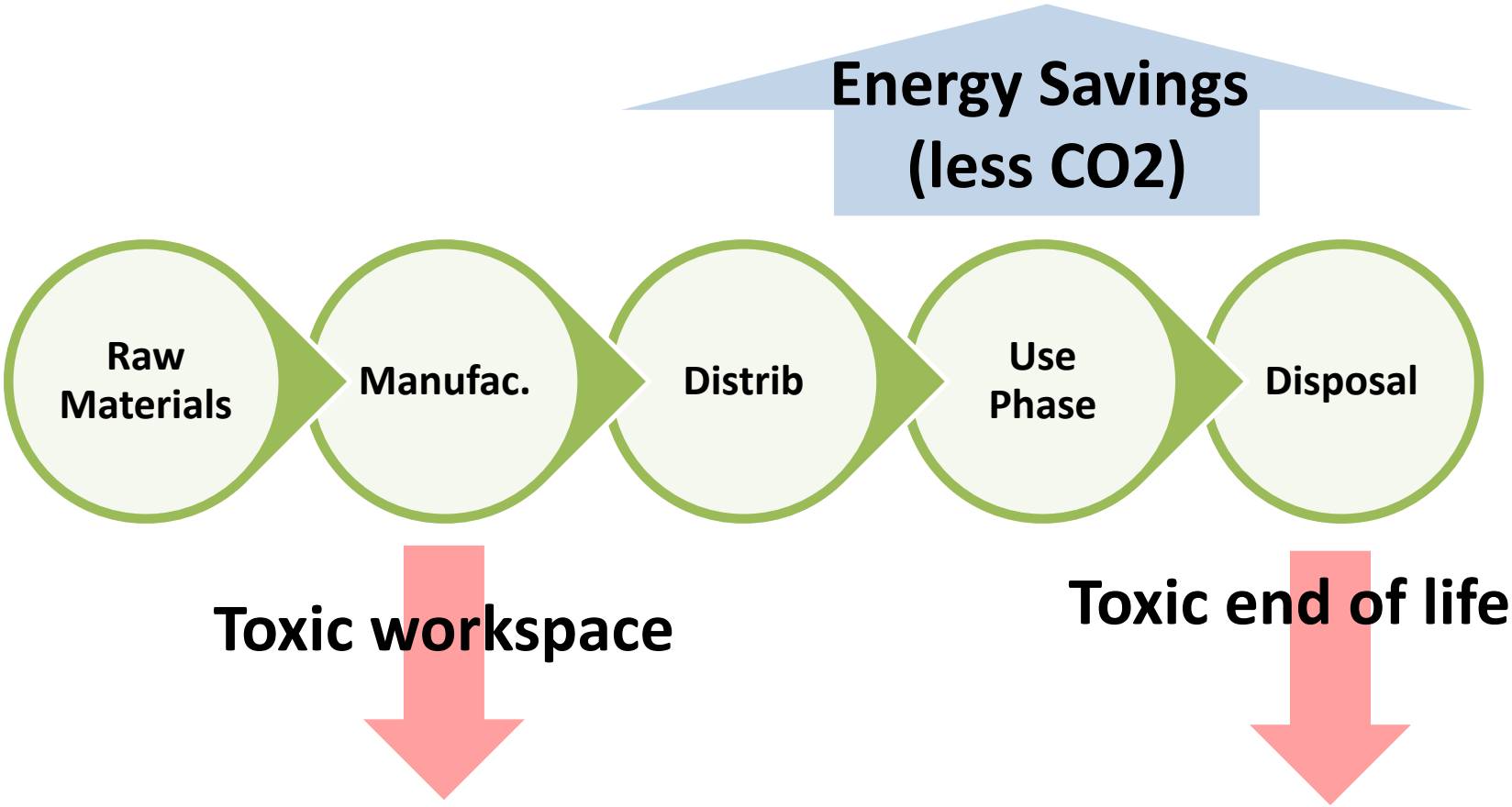


EarthShift
Changing the way we look at natural resources

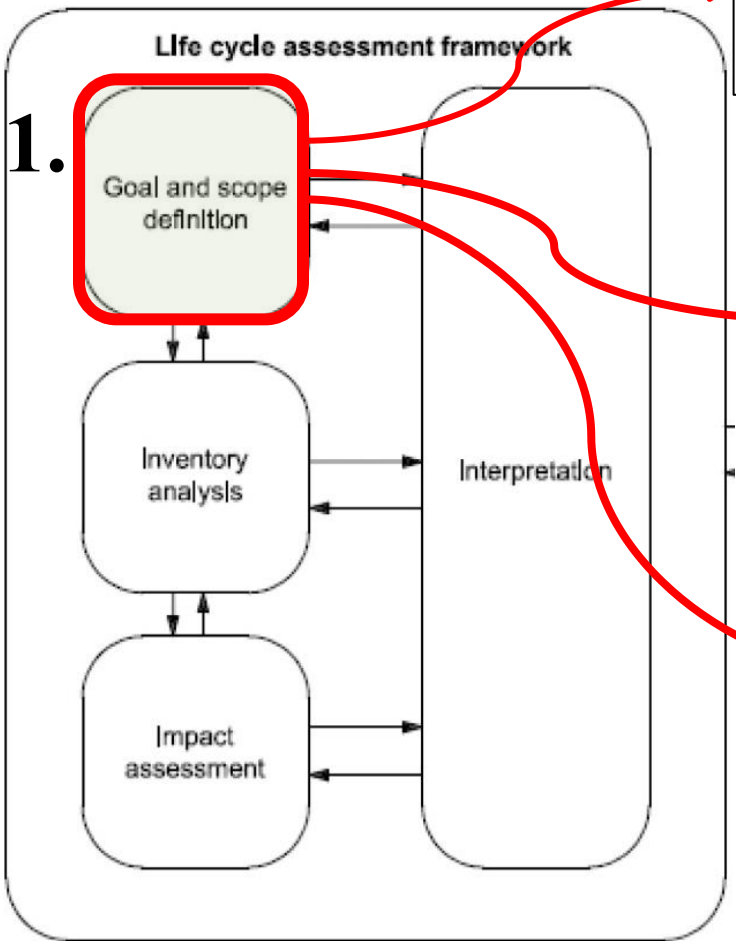
1. Problem *Shifting*
(Between stages)



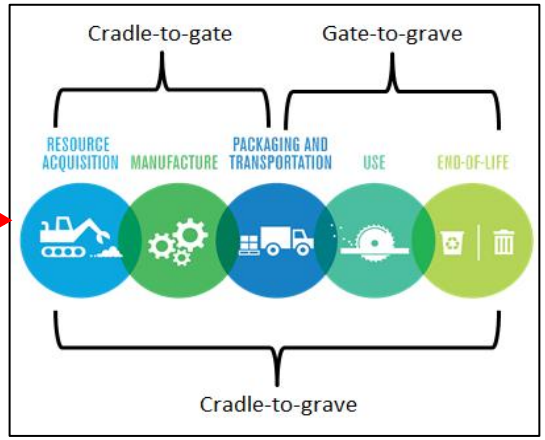
2. Problem *Shifting*
(Between impacts)



LCA Framework



Improvement Assessment
Or
Comparison



Functional Unit (FU):
-One load of laundry
-A sheet of paper
-1 kg of corn

ISO guidelines 14044: 2006

Goal & Scope: Motive

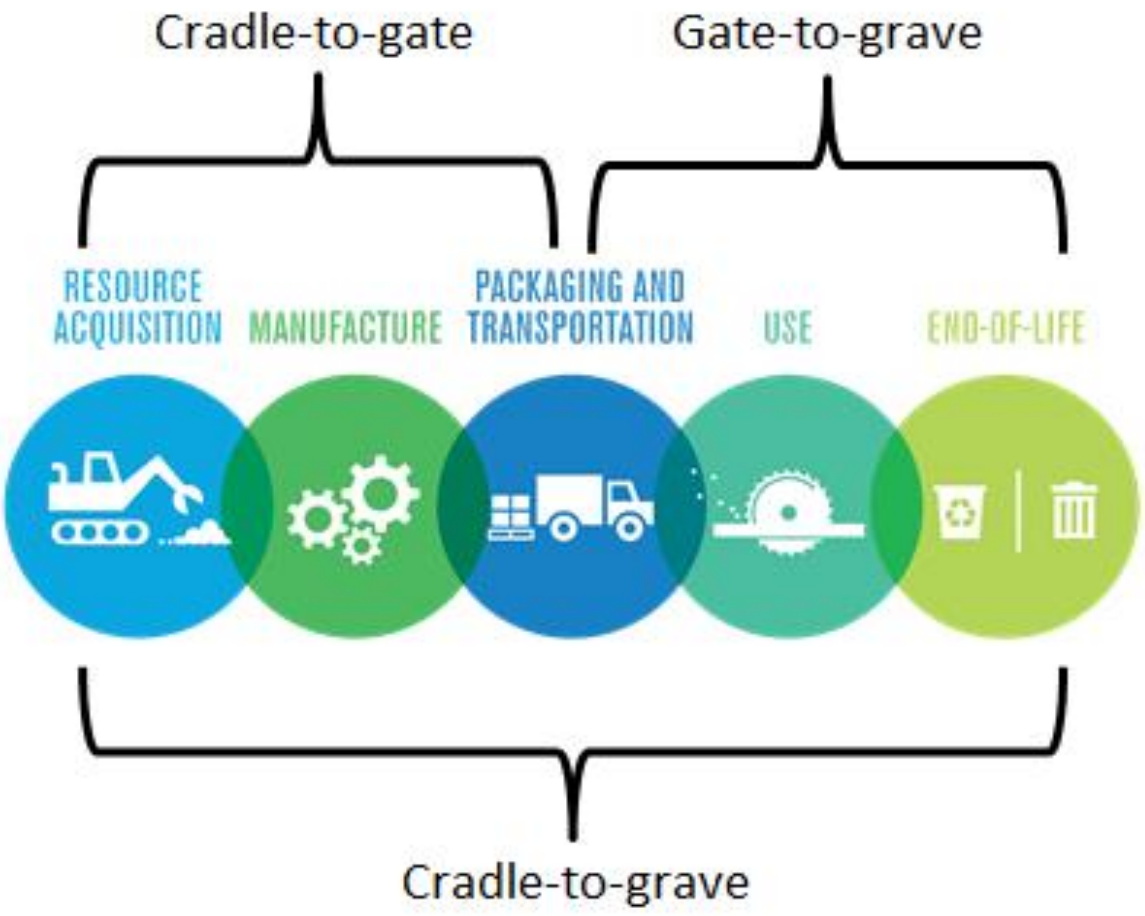
Improvement Assessment

Magnitude of Impact

Comparative Assessment

Trade-off

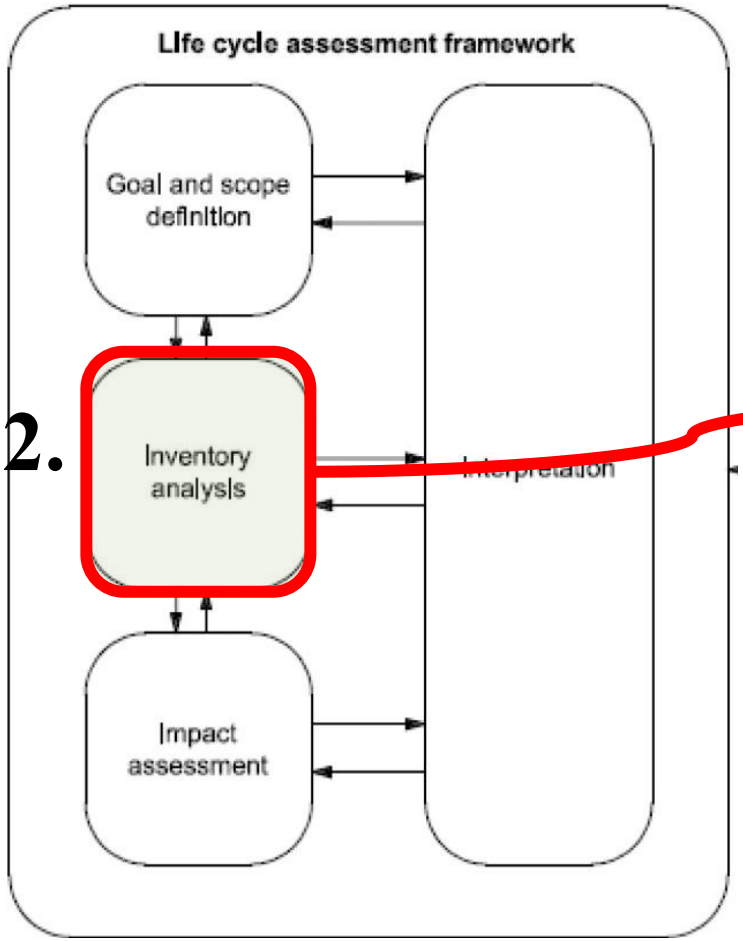
Goal & Scope: System Boundaries



- **Environmental concerns**
- **Stakeholder identification**

Goal & Scope: Functional Unit

LCA Framework



2.

Inputs per FU:

- 3 kWh Electricity
- 15 gallons of water
- 40 m2 of land
- 10 gallons of diesel
- 50 lbs of plastic

Process A

Outputs per FU:

- 4 kg of CO2 to air
- 15 gallons of contaminated water
- 3 grams of particulate matter
- 5g of dioxins

Inventory: Sources

- Measurements
- Publications
- NREL - US LCI
- Ecoinvent
- Input/Output
- GREET

Inventory

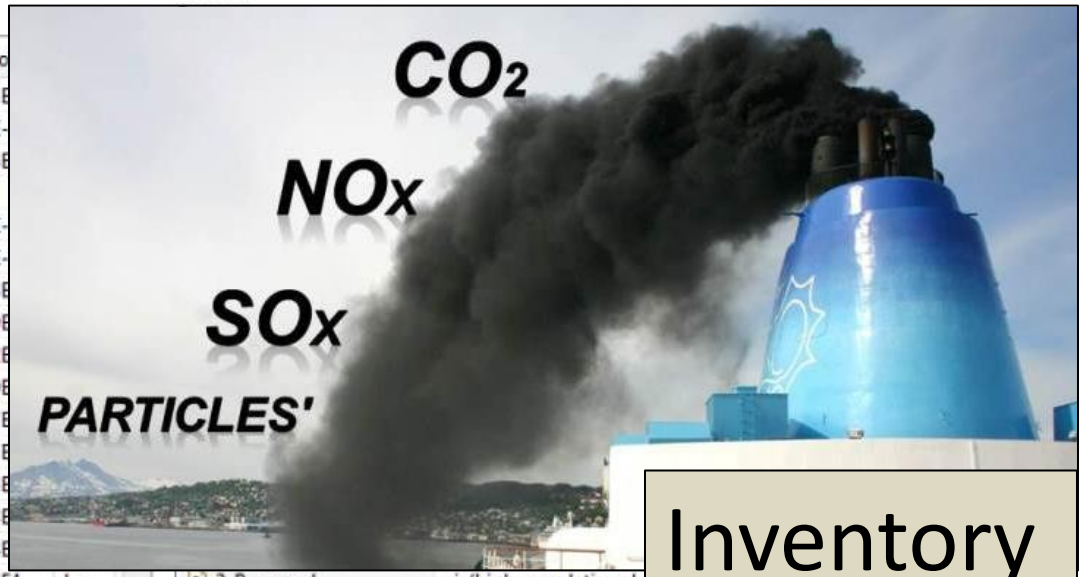
Park, remodelled | Park, remodelled - CML 2001

Life cycle inventory of Park, remodelled (ecoinvent_Fallstudien)

Inputs

Flow	Category	Flow property	Amo		
Aluminium, 24% in bauxite, 11...	resource/in ground	Mass	3.31E		
Anhydrite, in ground	resource/in ground	Mass	5.6E-		
Barite, 15% in crude ore, in gro...	resource/in ground	Mass	1.48E		
Basalt, in ground	resource/in ground	Mass	3.4		
Borax, in ground	resource/in ground	Mass	2.1E-		
Bromine, 0.0023% in water	resource/in water	Mass	7.1E-		
Cadmium, 0.30% in sulfide, Cd ...	resource/in ground	Mass	6.98E		
Calcite, in ground	resource/in ground	Mass	2.09E		
Carbon dioxide, in air	resource/in air	Mass	1.82E		
Carbon, in organic matter, in soil	resource/in ground	Mass	4.19E		
Chromium, 25.5% in chromite, ...	resource/in ground	Mass	1.27E		
Chrysotile, in ground	resource/in ground	Mass	1.31E		
Cinnabar, in ground	resource/in ground	Mass	1.18E		
Clay, bentonite, in ground	resource/in ground	Mass	4.33E		
Clay, unspecified, in ground	resource/in ground	Mass	5.18E		
Coal, brown, in ground	resource/in ground	Mass	1.13E4	kg	
Coal, hard, unspecified, in grou...	resource/in ground	Mass	8.1E3	kg	
Cobalt, in ground	resource/in ground	Mass	4.5E-4	kg	
Colemanite, in ground	resource/in ground	Mass	0.1	kg	
Copper, 0.99% in sulfide, Cu 0.3...	resource/in ground	Mass	1.26	kg	
Copper, 1.18% in sulfide, Cu 0.3...	resource/in ground	Mass	6.96	kg	
Copper, 1.42% in sulfide, Cu 0.8...	resource/in ground	Mass	1.85	kg	
Copper, 2.19% in sulfide, Cu 1.8...	resource/in ground	Mass	9.18	kg	
Diatomite, in ground	resource/in ground	Mass	3.54E-5	kg	
Dolomite, in ground	resource/in ground	Mass	4.8	kg	
Energy, gross calorific value, in ...	resource/biotic	Energy	2.0E6	MJ	
Energy, gross calorific value, in ...	resource/biotic	Energy	2.9	MJ	
Energy, kinetic (in wind), conve...	resource/in air	Energy	4.64E3	MJ	

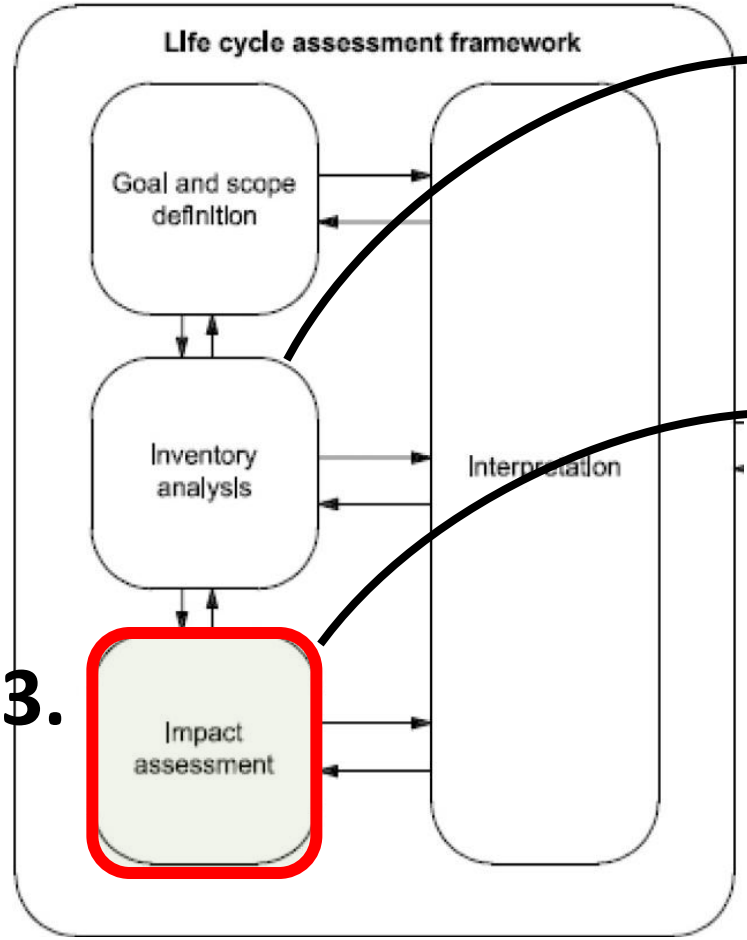
2-Propanol	air/high population de	Mass		
4-Methyl-2-pentanone	water/unspecified	Mass	1.11E-8	kg
Acenaphthene	air/low population density	Mass	1.36E-8	kg
Acenaphthene	water/river	Mass	8.15E-6	kg
Acenaphthene	air/unspecified	Mass	2.54E-11	kg
Acenaphthene	air/high population density	Mass	8.97E-8	kg
Acenaphthene	water/ocean	Mass	3.64E-6	kg
Acenaphthylene	water/ocean	Mass	2.28E-7	kg
Acenaphthylene	water/river	Mass	5.1E-7	kg
Acetaldehyde	air/high population density	Mass	1.01E-2	kg
Acetaldehyde	air/unspecified	Mass	0.49	kg
Acetaldehyde	water/river	Mass	8.79E-5	kg
Acetaldehyde	air/low population density	Mass	1.03E-4	kg

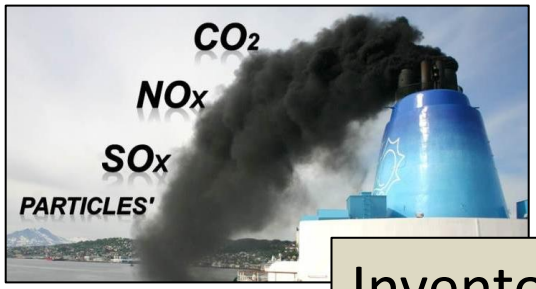


Inventory

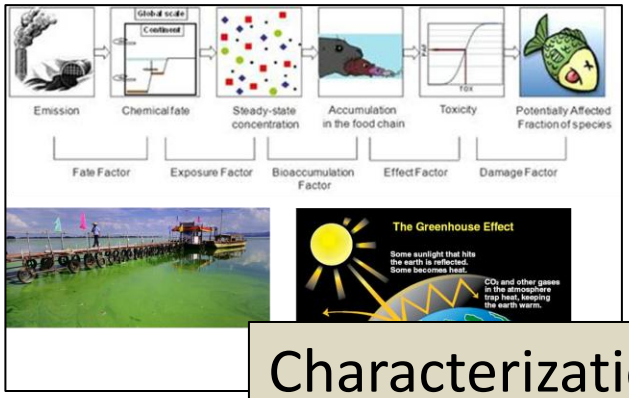
General information | Life cycle inventory | Characterization

Impact Assessment



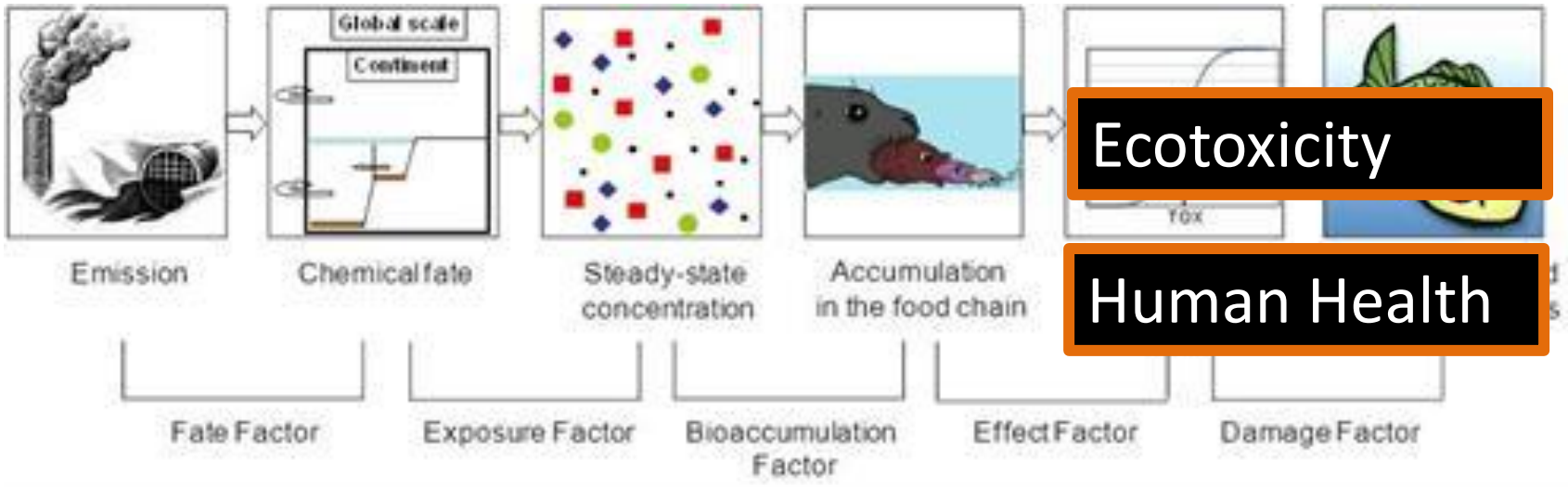


Inventory



Characterization

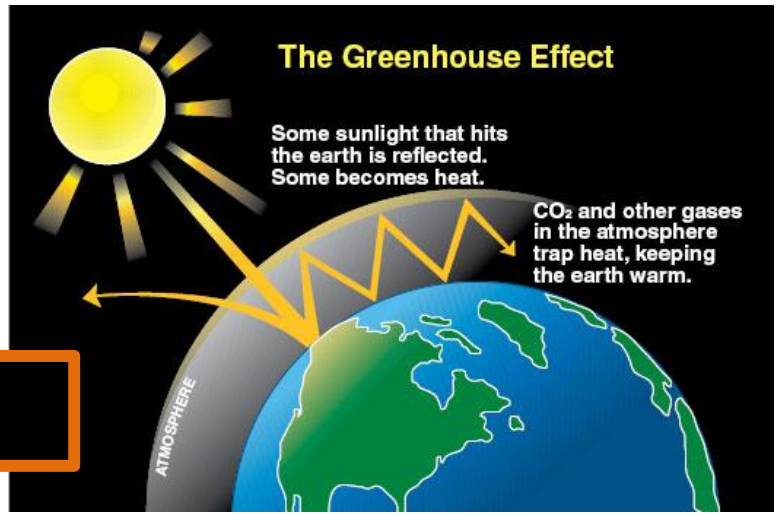
Characterization



Ecotoxicity

Human Health

Eutrophication



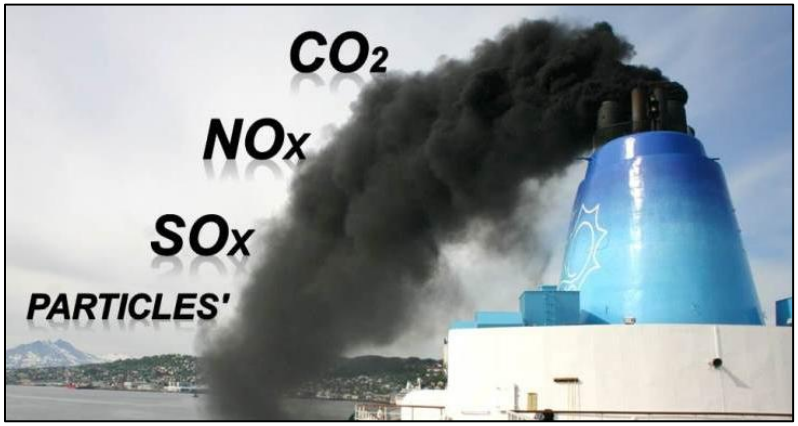
Global Warming

www.ru.nl, www.ecy.wa.gov

Selecting indicators

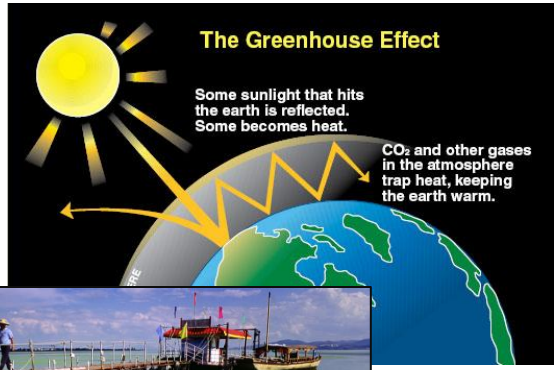
Select specific emissions:

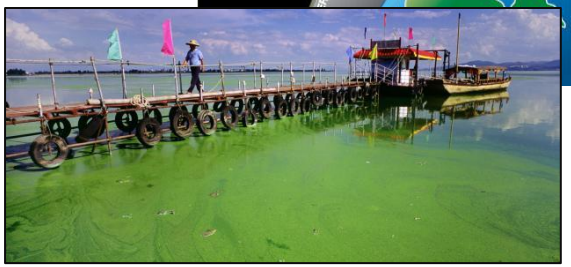
CO2
CH4
VOC
NOx
SOx
PM



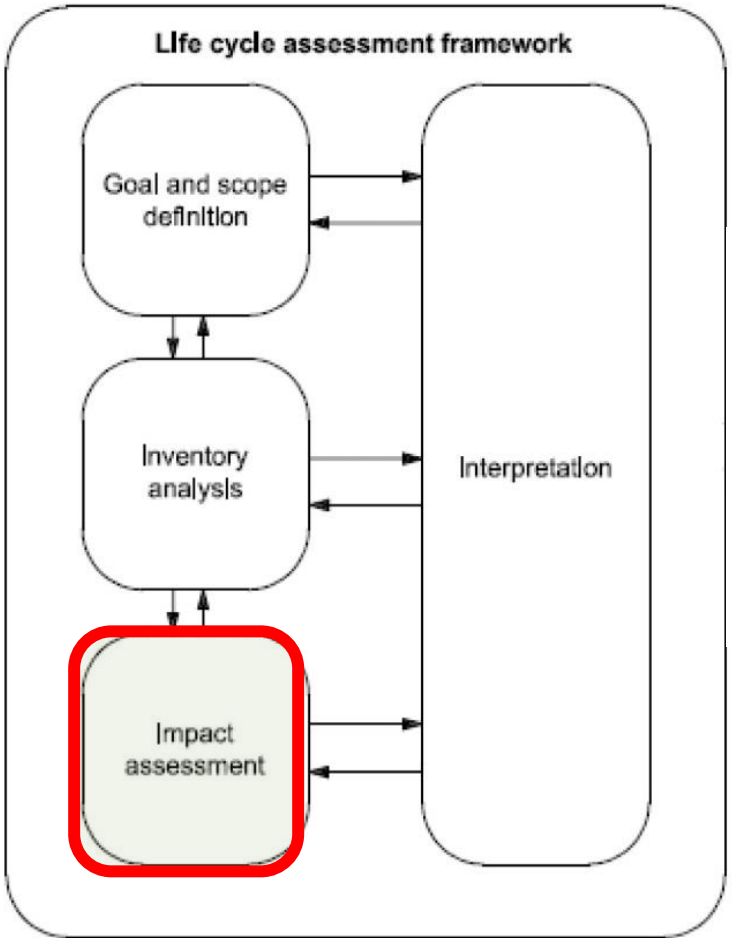
Characterization:

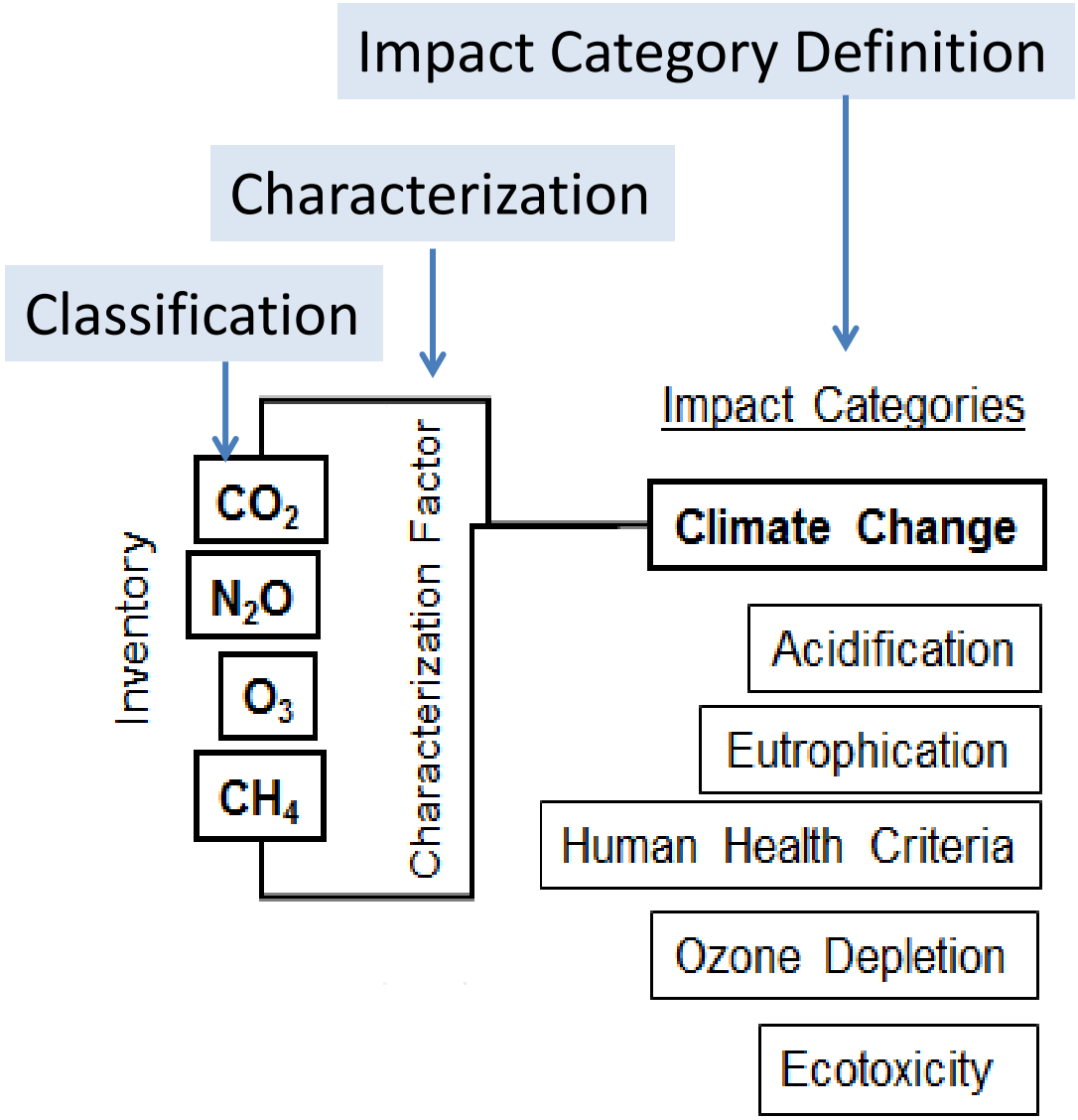
Global Warming Potential
Eutrophication
Acidification
Human Toxicity
…





Impact Assessment

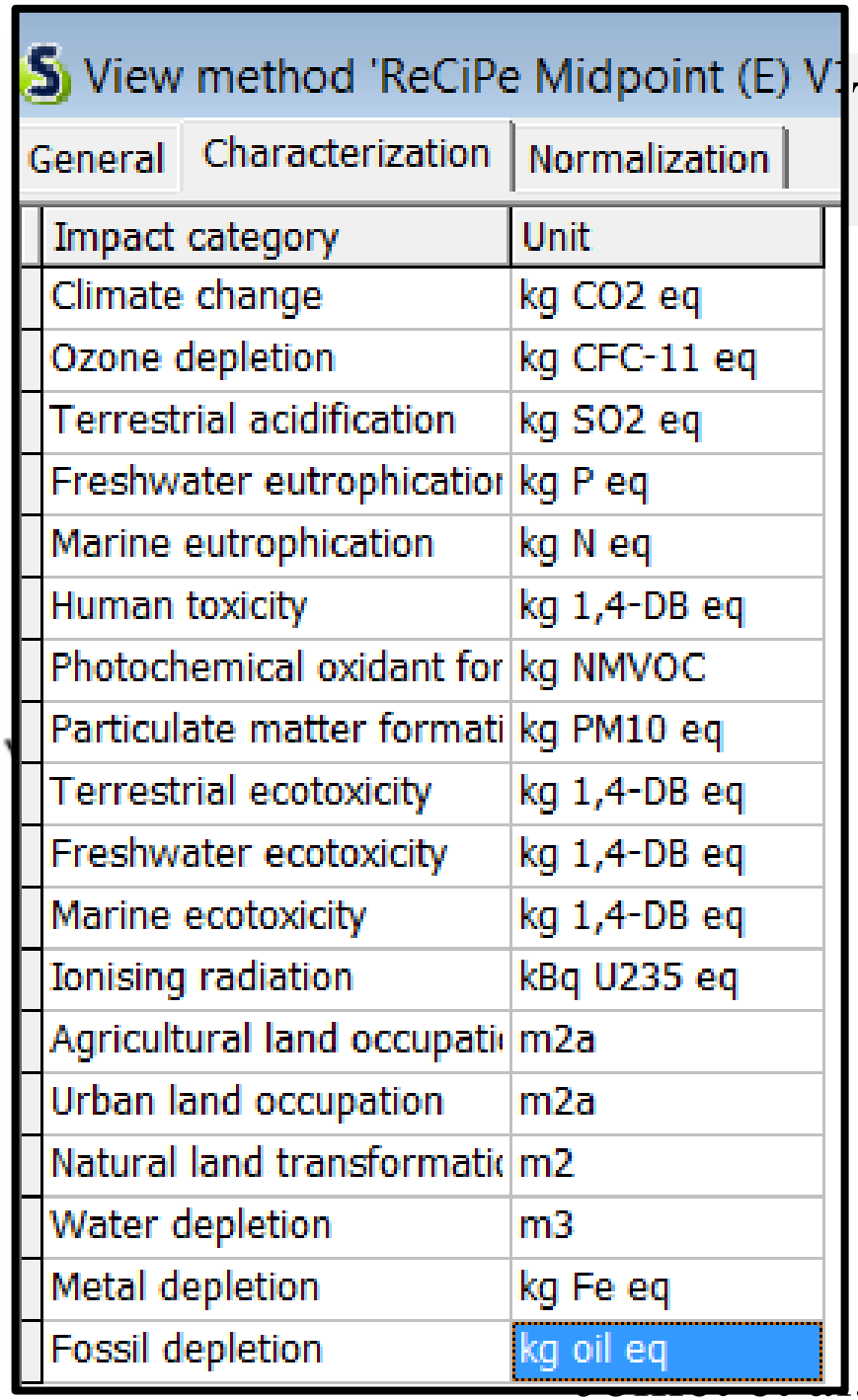




ISO guidelines 14044: 2006

LCIA Methods

- CML 2001
- Eco-Indicator 99
- IMPACT 2002+
- ReCiPe
- TRACI



TRACI

Tool for the Reduction and Assessment Of Chemical and Other Environmental Impacts

General | Characterization | Normalization

Impact category	Unit
Ozone depletion	kg CFC-11 eq
Global warming	kg CO2 eq
Smog	kg O3 eq
Acidification	kg SO2 eq
Eutrophication	kg N eq
Carcinogenics	CTUh
Non carcinogenics	CTUh
Respiratory effects	kg PM2.5 eq
Ecotoxicity	CTUe
Fossil fuel depletion	MJ surplus

http://www.epa.gov/nrmrl/std/traci/traci.html

Characterization Factors

- **Global Warming Potential (kg CO2 eq)**
  - Infra-red absorbing efficiency, decay (time)

- **Acidification (H+ eq)**

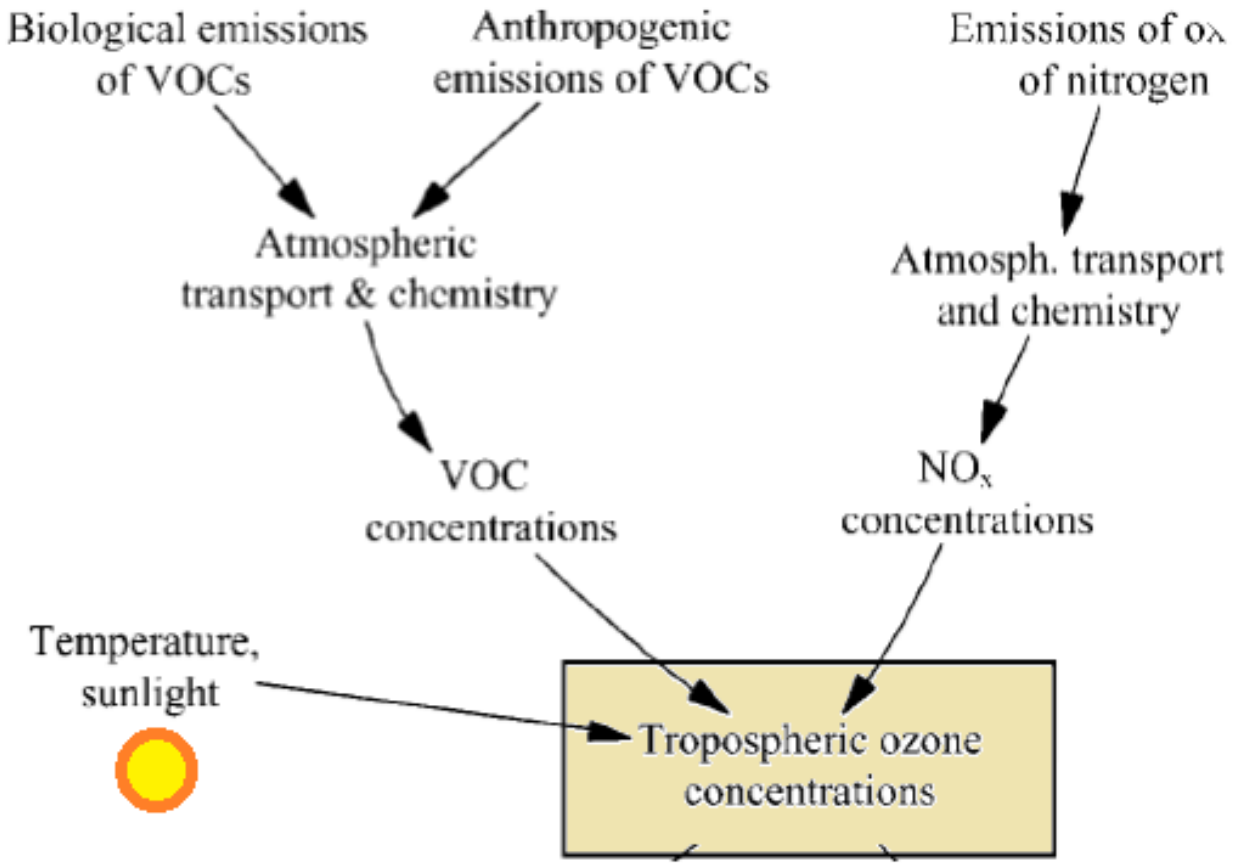
  -Air emissions and deposit (rain, snow, dry)

  -sulphur dioxide, nitrogen oxides, ammonia

- **Eutrophication**
  - Runoff(Terrain, precipitation, volatilization)

Characterization Factors

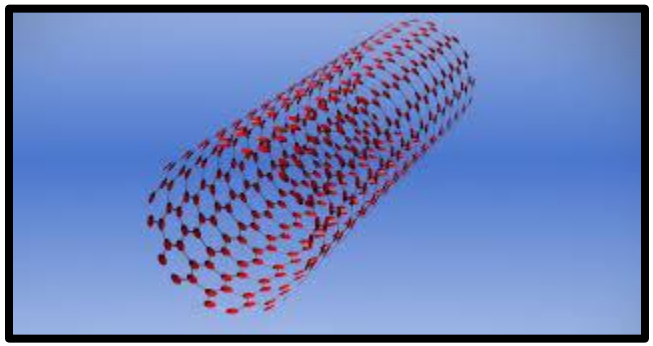
- Smog (O3 eq)
  - Ground level ozone



http://www4.ncsu.edu/~richardv/documents/Lecture11TRACIAssessment.pdf

Challenges/Limitations

- Uncertainty
- CF for emerging materials
- Accounting of long term emissions
- Regional differences
  - Preexisting conditions
  - Buffering capacities



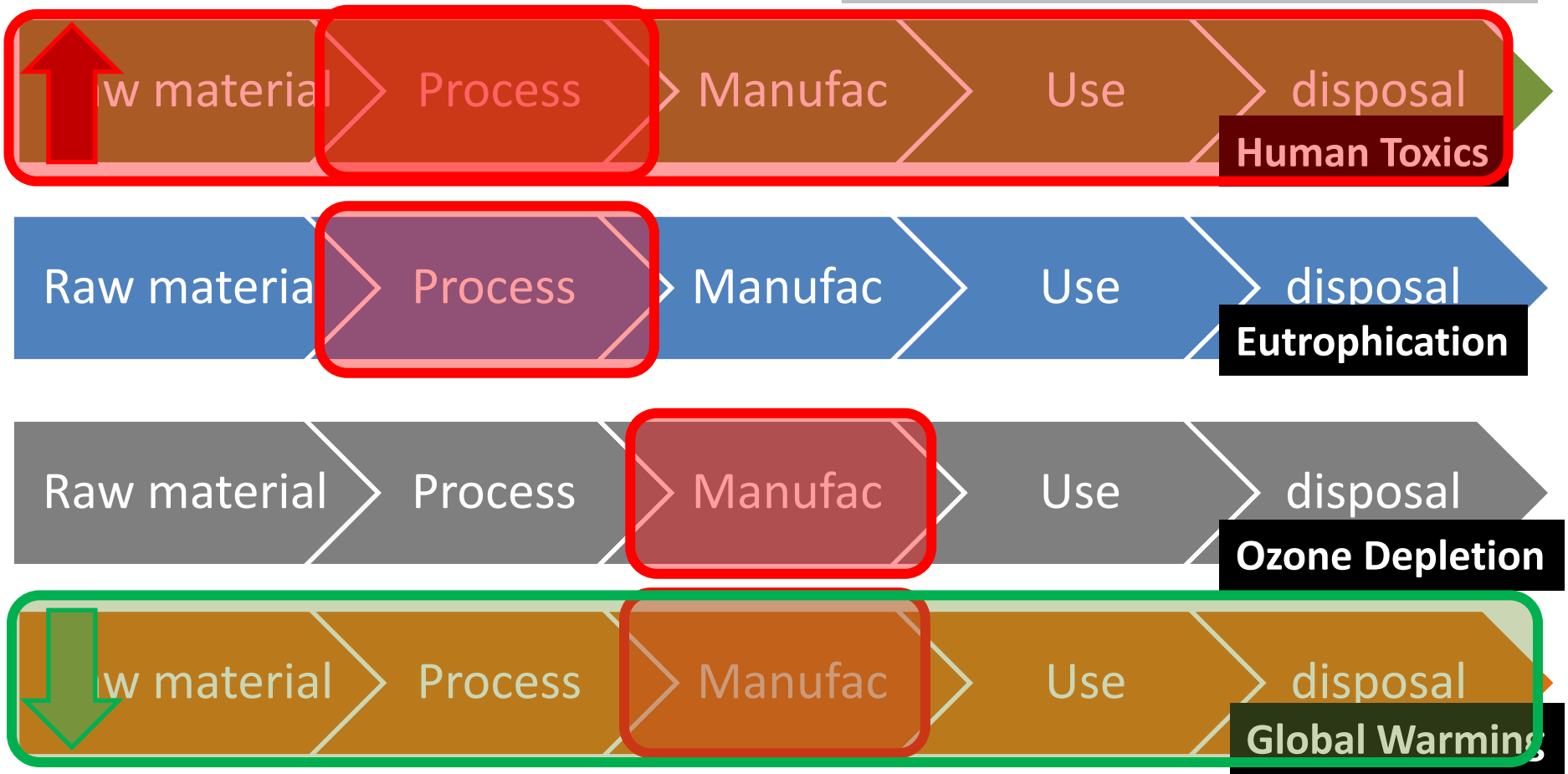
Use of Results

Improvement: (Single product)

Guide actions/Hotspots

Comparative: >1

Tradeoffs/prevents burden shifting



LCA activity

EarthShift
Building pathways to sustainability

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EarthSmart

EarthSmart is a simplified LCA tool for evaluating the environmental impacts of a Product or Service life cycle. EarthSmart is web-based, and enables teams in Product Design, Sales, Product Marketing, EH&S and others to innovate without being LCA experts.

Innovate with EarthSmart's simplified "what if..." scenario analysis

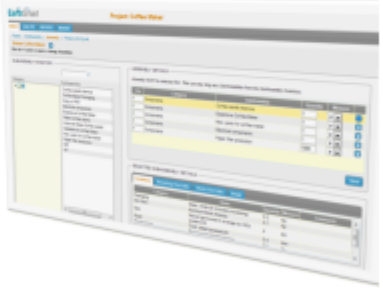
Other tools are built only for LCA experts. EarthSmart allows the LCA experts to ensure the rigor and consistency that ISO and the marketplace demands, while presenting information in an intuitive user interface that allows experts in areas other than LCA to quickly and easily ask *"What if..."*

- *What if* your sales team could show your customers a report?
- *What if* your marketing team marketed your sustainability initiatives?
- *What if* your R&D team changed a component or process in a product?
- *What if* your EH&S team used a different chemical in your product?

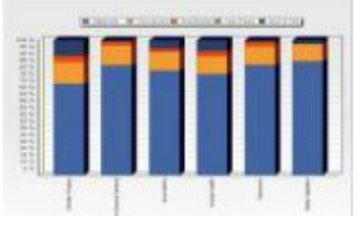
Start Your 30-day Free Trial!

EarthSmart LCA tool

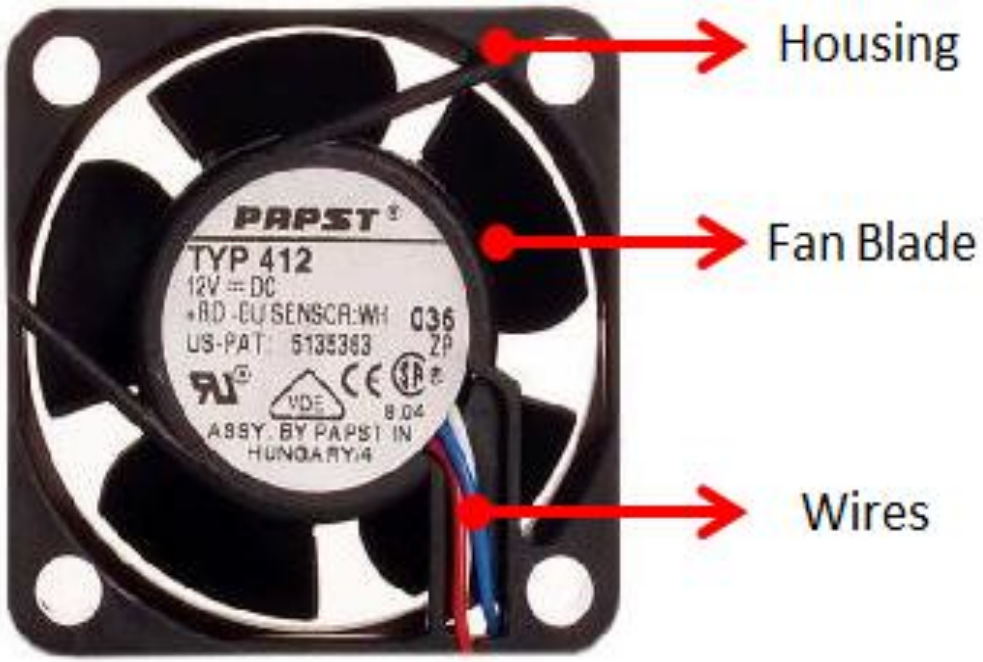
- Features
- Pricing & Order Information
- Tutorials
- Login
- Impact Assessment Method



View our Earthsmart tutorials »



Computer Fan exercise in EarthSmart



EarthShift
Changing the way we look at natural resources

2. New Project & Save

EarthSmart

BUILD | ANALYZE | REPORTS | MANAGE

Project | Component/Activity | Product Life Cycle

PROJECTS

Please select or create a new Project.

Project	Method	Normalization	EOL Scenario
Plastic vs Wood Decking	ES Method	World ReCiPe H/A	Waste scenario 2010/US US-EI S
Practical LCA Course - Crane Truck	ES Method	World ReCiPe H/A	Waste scenario 2010/US US-EI S
Computer Fan	ES Method	World ReCiPe H/A	Waste scenario 2010/US US-EI S

PROJECT DETAILS

To create a new project, click New, enter all the necessary information and click Save. The newly created project will appear at the bottom of the Projects table.

Project: Computer Fan

Description: Modeling of 3 design choices for a computer fan

Impact Assessment Method: ES Method

Normalization/Weighting: World ReCiPe H/A

End of Life (EOL) Scenario: Waste scenario 2010/US US-EI S

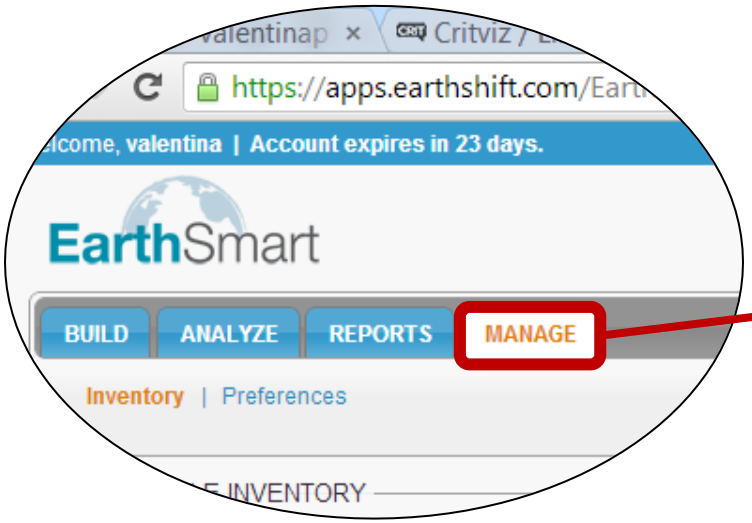
Fill in the form

New | Select | Save | Delete

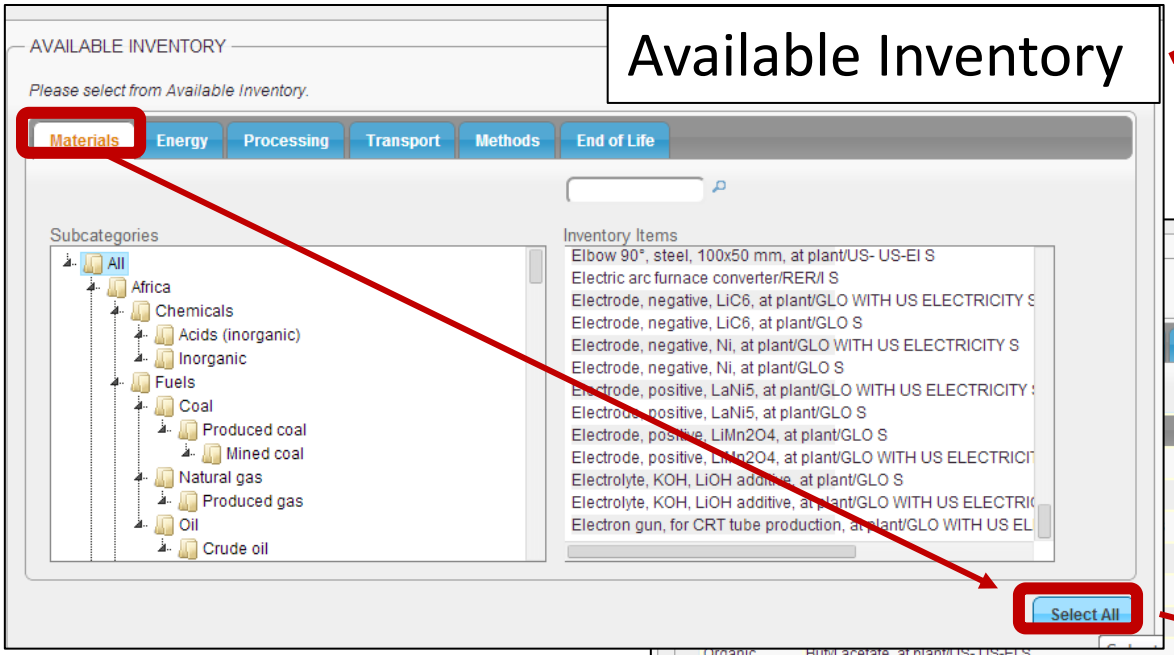
Once you have selected your project, proceed to building your Component/Activity.

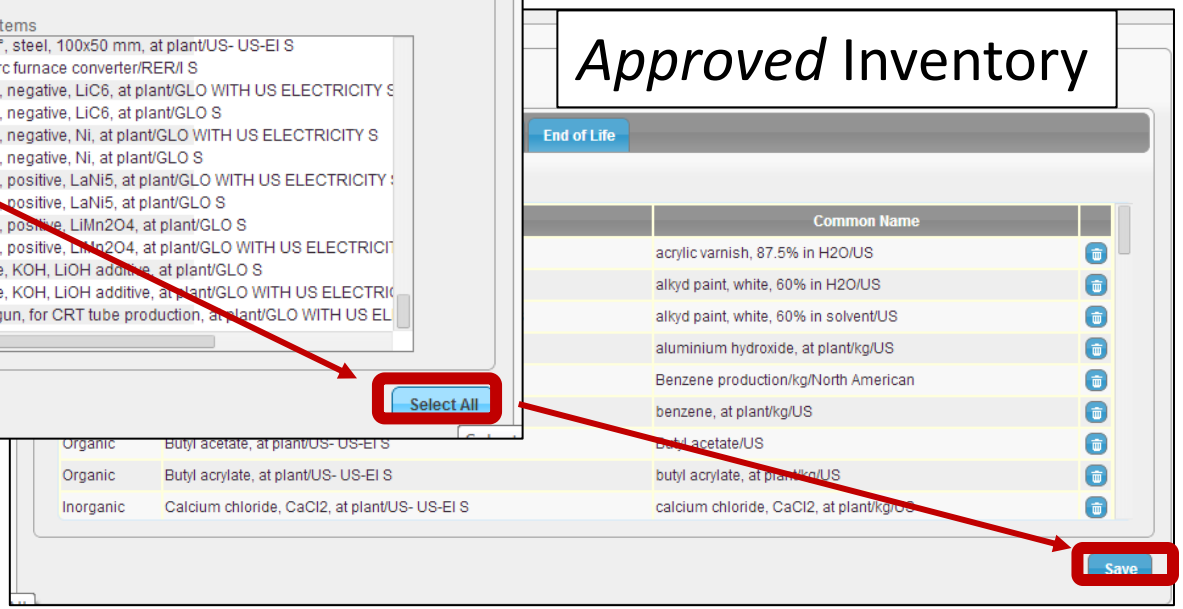
New & Save

3. Import Inventory

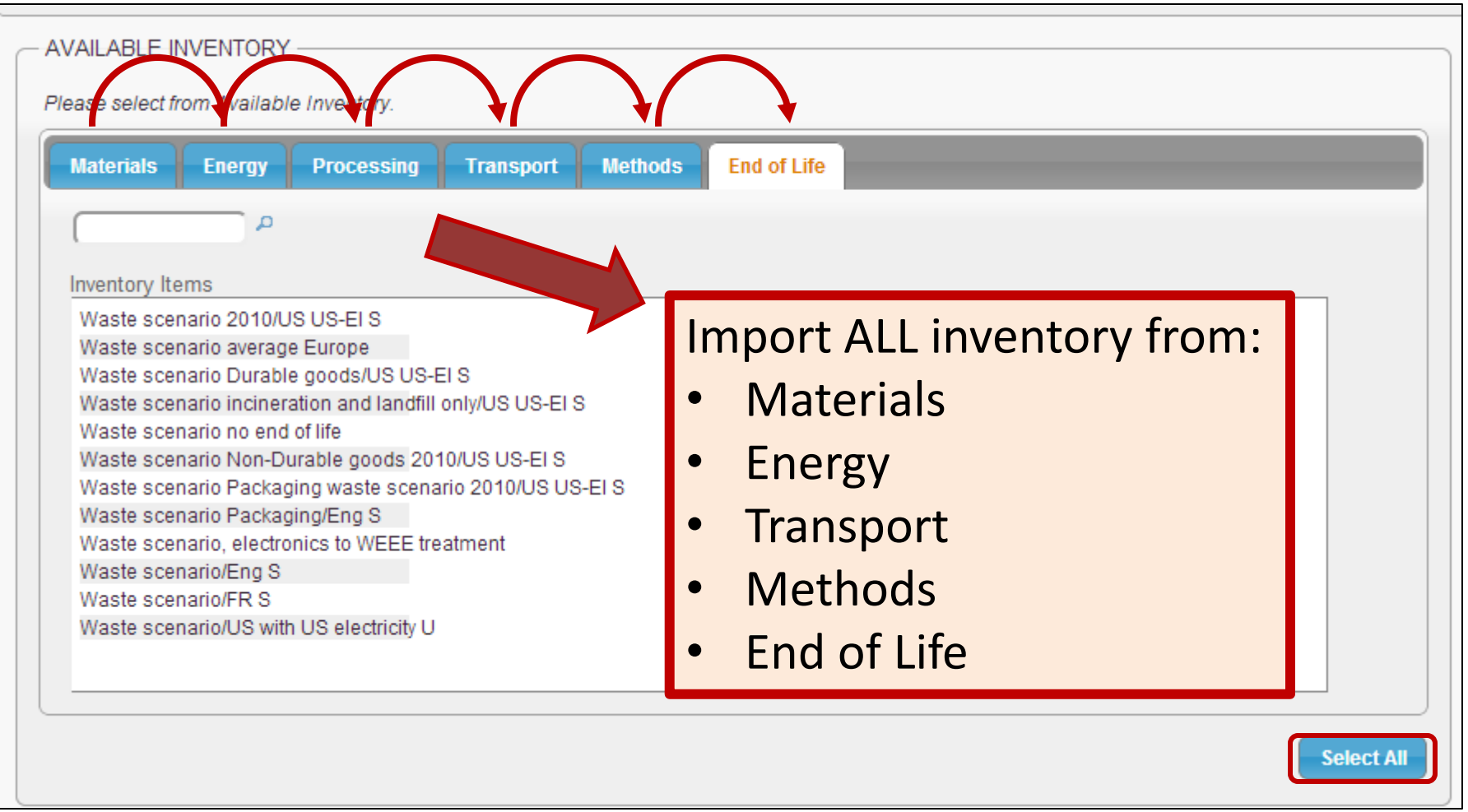


a. Go to Manage Tab
b. Transfer ALL Inventory from available → approved





3. Import Inventory



3. Goal and Scope

Purpose:
Compare 3 design choices for fan blades

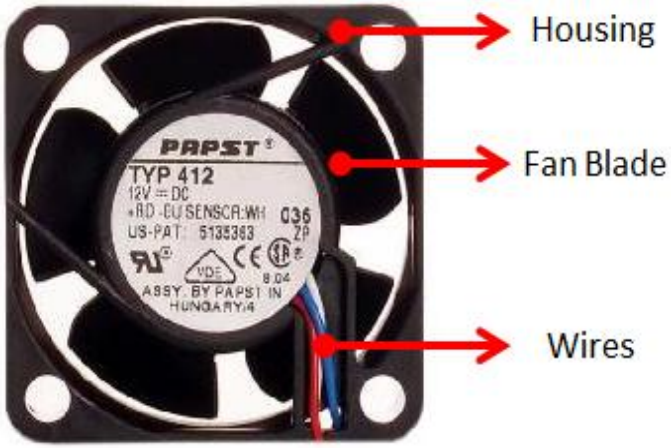

Plastic


Steel


Aluminum

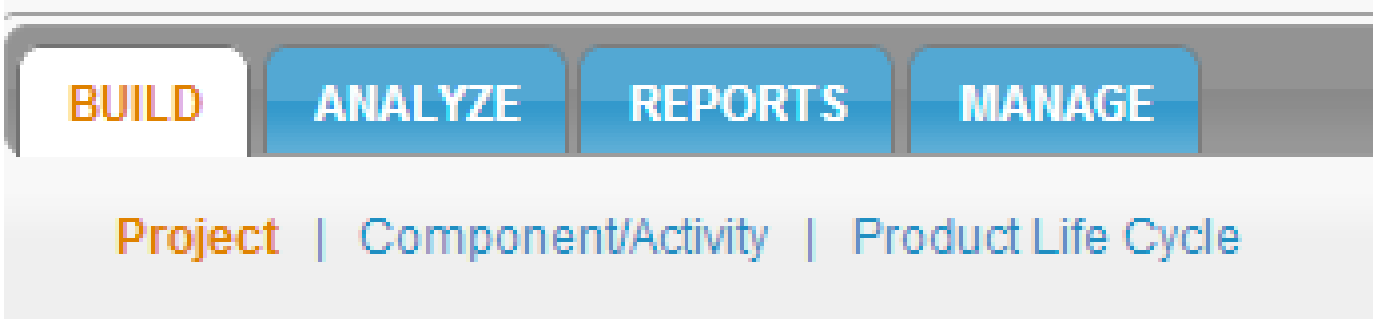
System Boundaries:
Cradle to grave

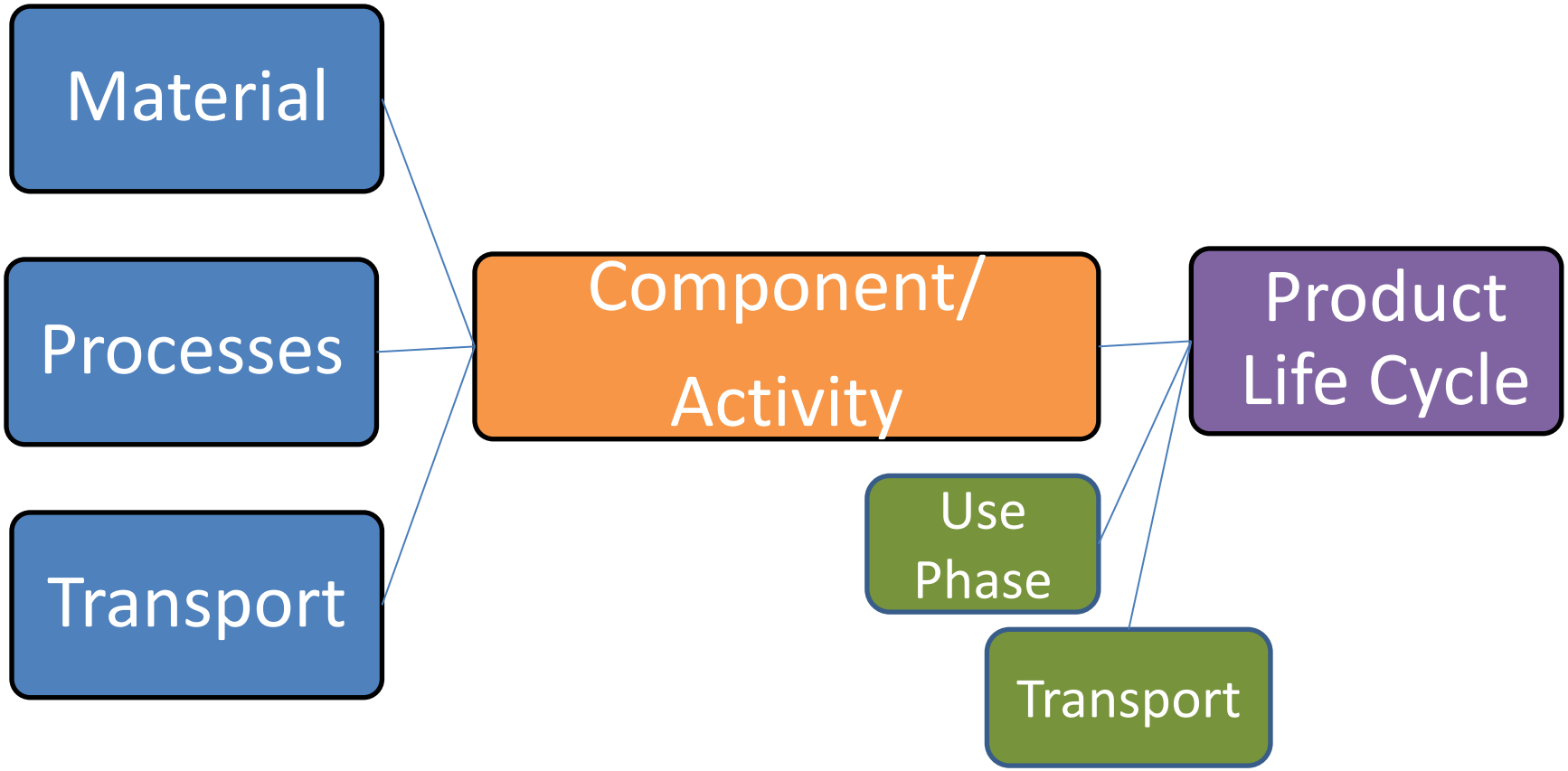
Functional Unit:
Use of a fan for 1 year



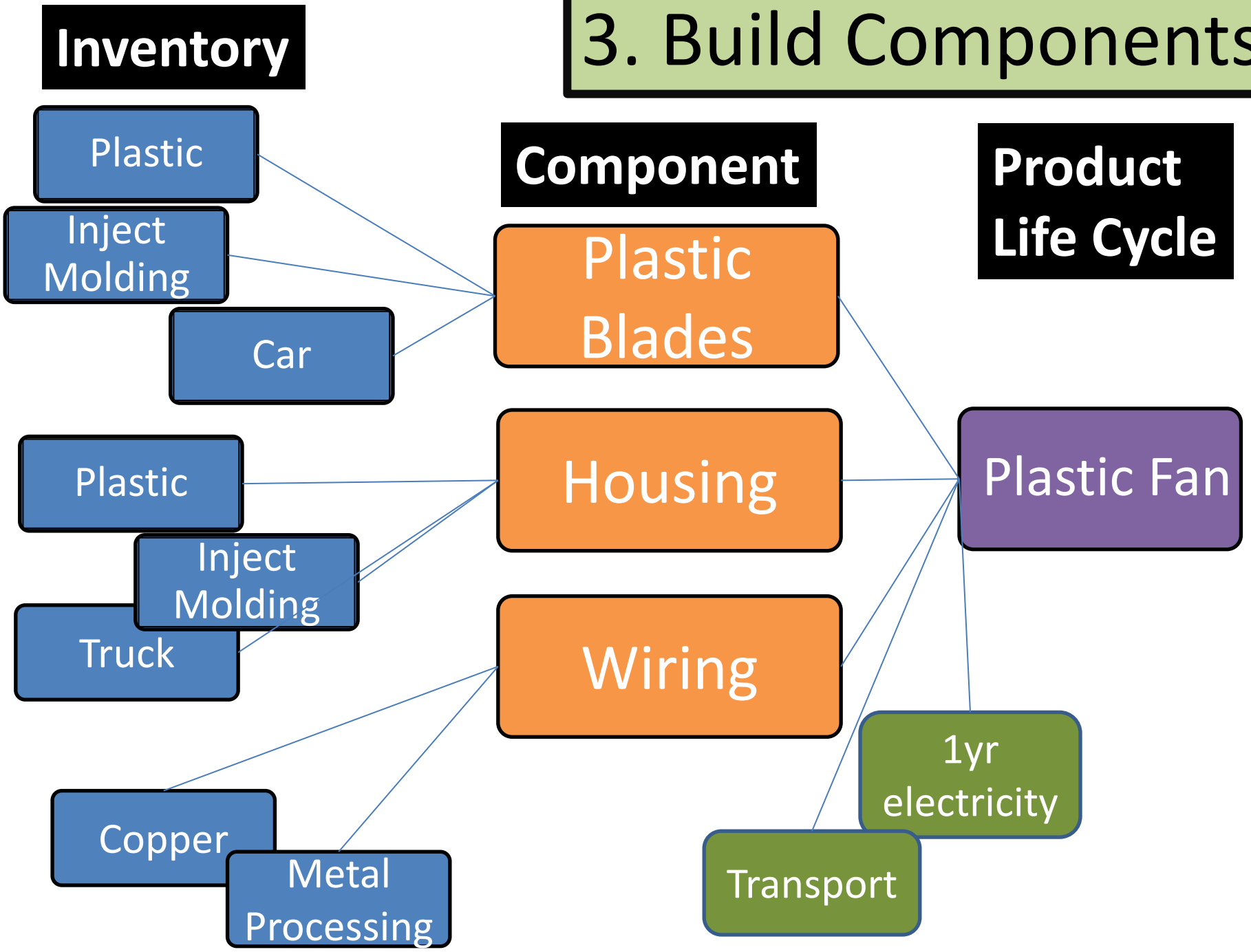
EarthShift
Changing the way we look at natural resources

3. Build Components



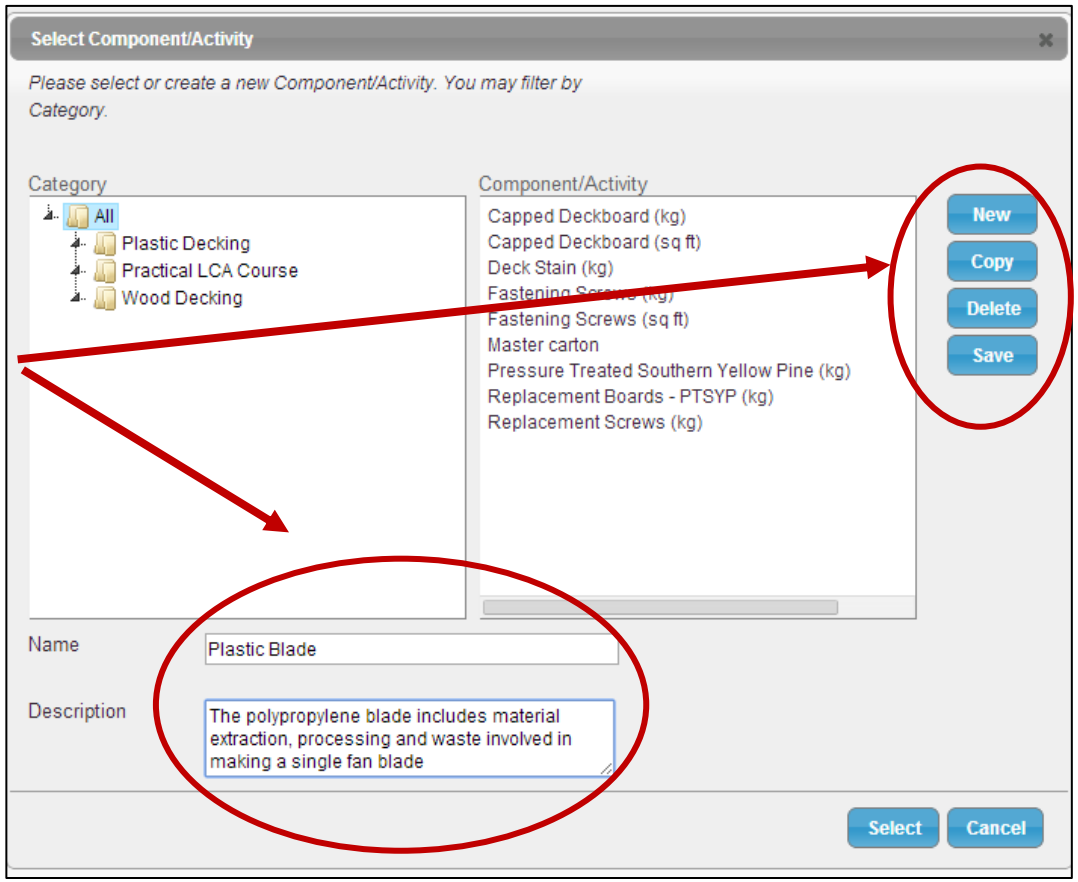


3. Build Components



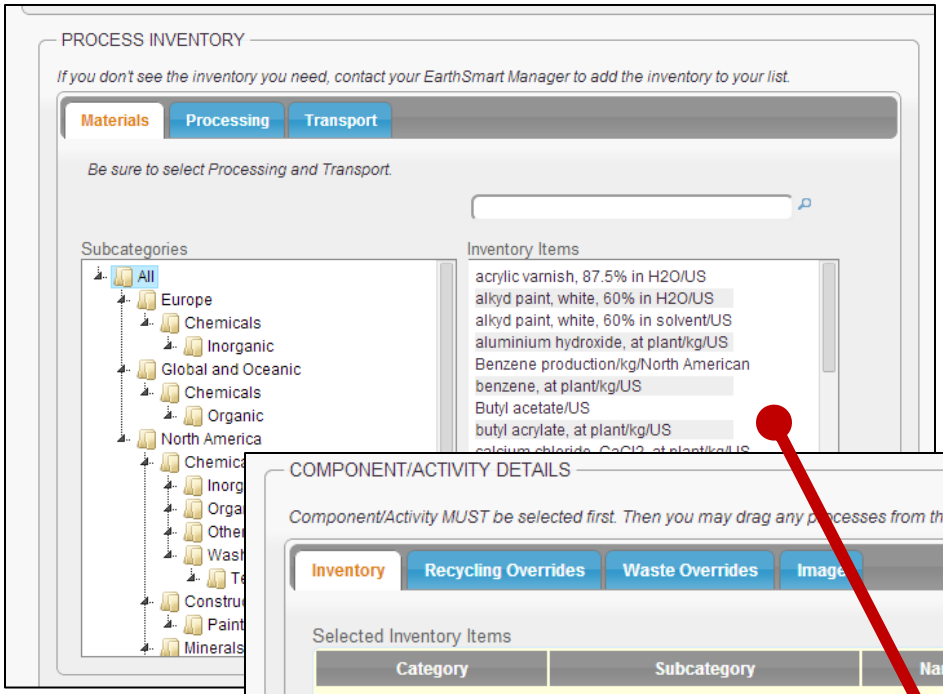
3. Create Component

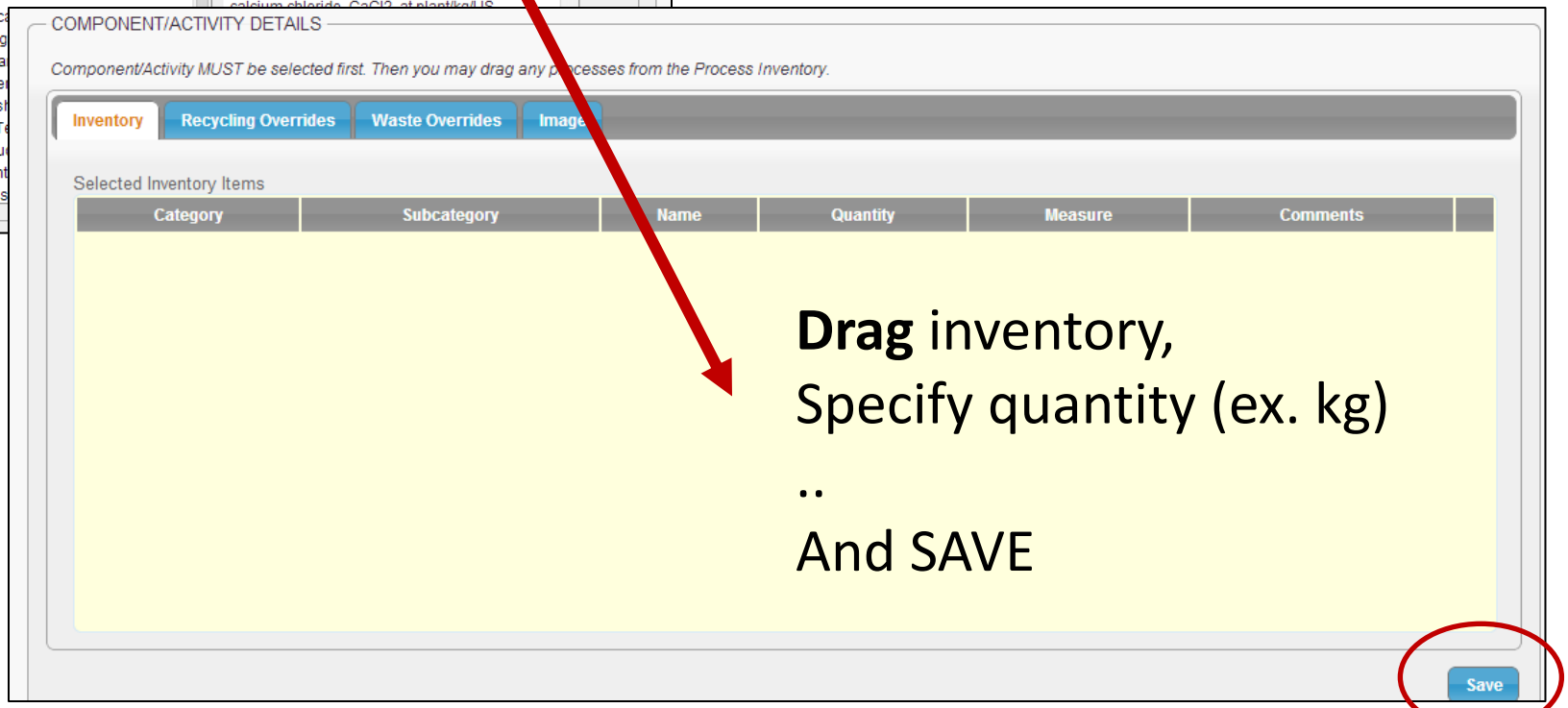
a. Go to Build Tab
b. Select “Component/Activity



c. New
d. Fill in Name & Description
e. Save!
f. select

3. Create Component





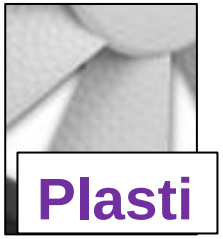
Drag inventory from:

- Materials
- Processing
- Transport

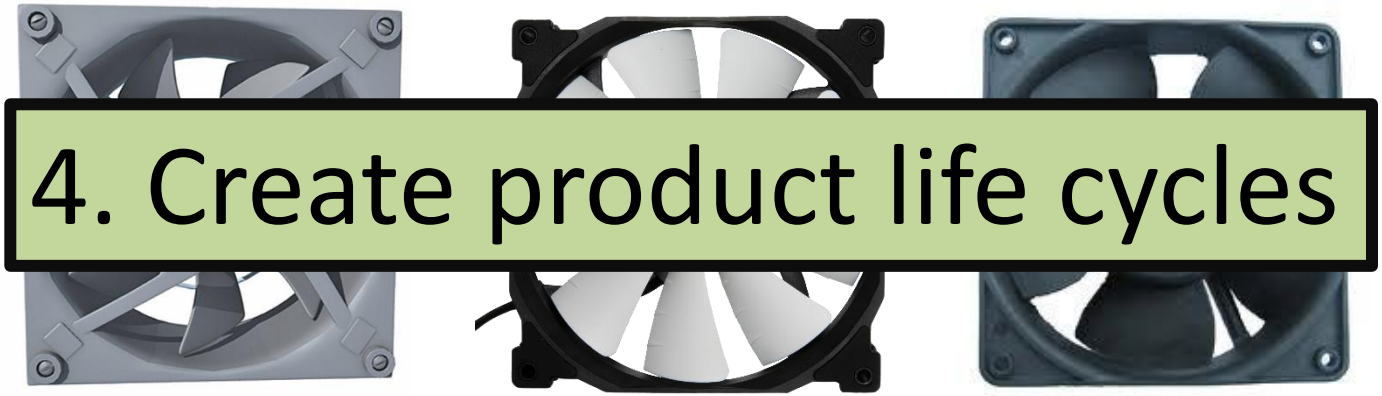
Drag inventory,
Specify quantity (ex. kg)
..
And SAVE

Component/ Activity

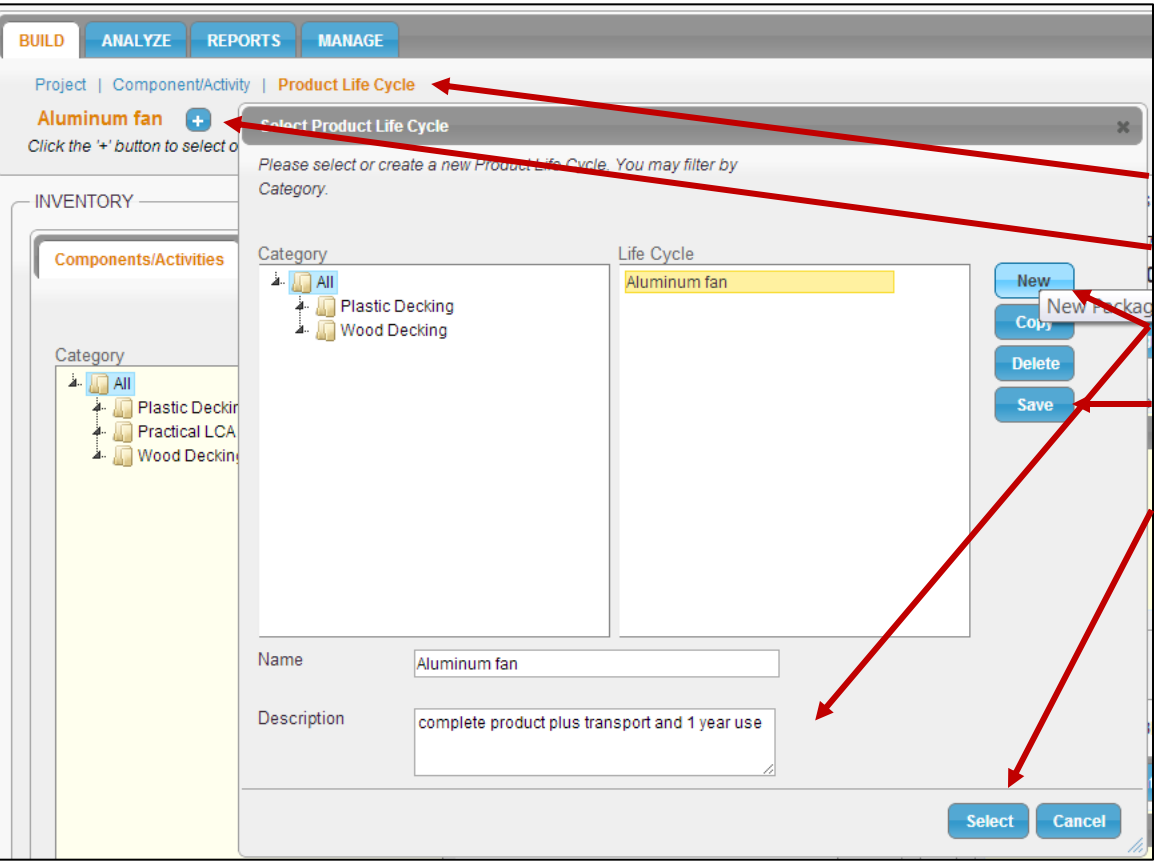
1. Aluminum Blades
2. Plastic Blades
3. Steel Blades
4. Housing
5. Wiring
6. Electricity



Aluminum Fan Plastic Fan Steel Fan



4. Create product life cycles



a. Go to “Product life cycle”
b. “+”
c. New (Fill form)
d. Save
e. Select

INVENTORY

Components/Activities | Transport

Category | Component

Aluminum Fan

Place "*components*" into the "*product life cycle*"

Wood Decking

Copper wiring
Deck Stain (kg)
Fastening Screws (kg)
Fastening Screws (sq ft)
hern Yellow Pine (kg)

- Alum. Blades
- Wiring
- Housing

LIFE CYCLE DETAILS

Product Life Cycle MUST be selected first. Then add n

System Weight **0.78 kg**

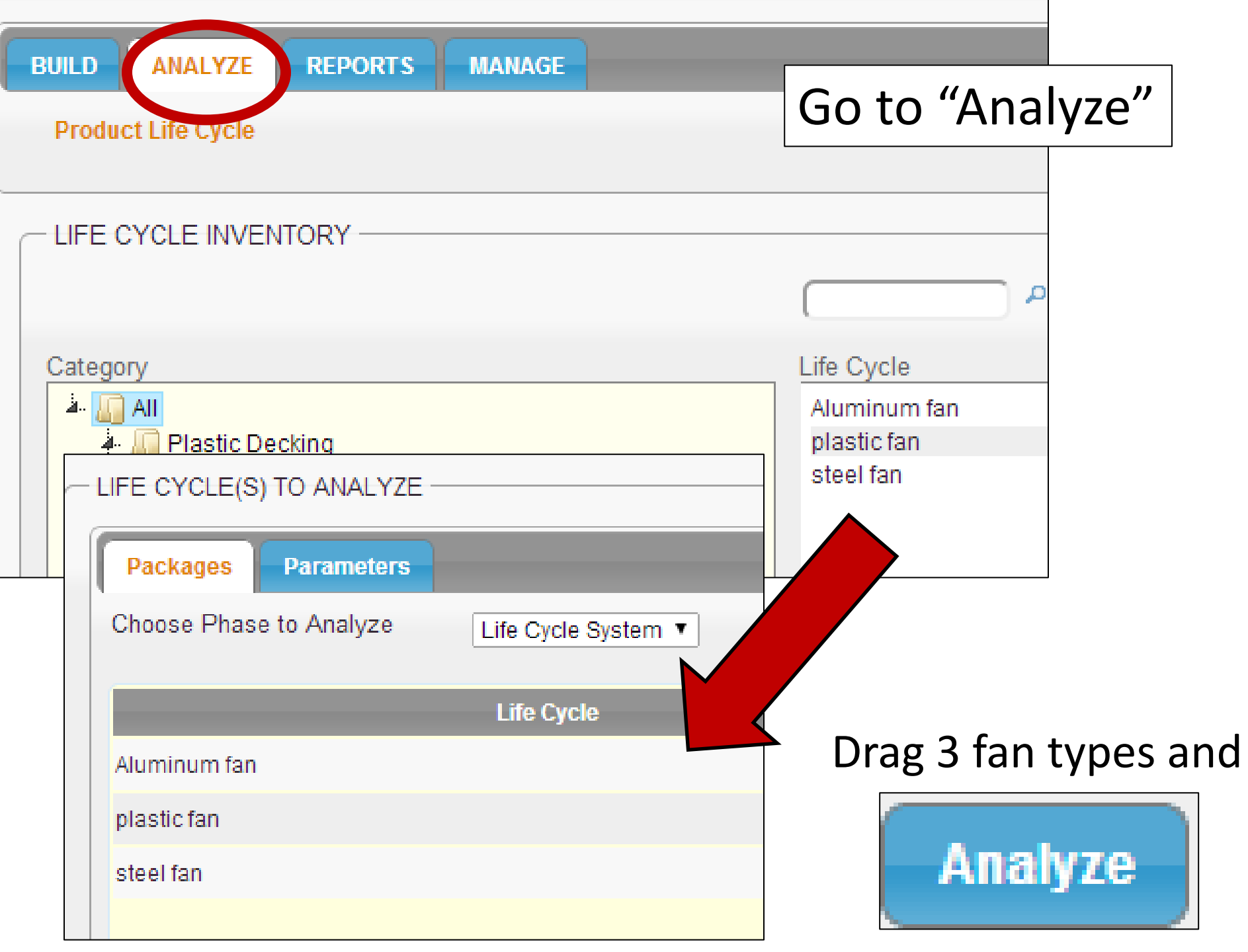
Product | Packaging | Use Phase | Transport

Selected Assemblies and Components/Activities

Uses	Assembly or Component/Activity	Quantity	
1	Aluminum blade	1	
1	Copper wiring	1	
1	Plastic Housing	1	

Recalculate & Save

Recalculate | View BOM | Save


BUILD
ANALYZE
REPORTS
MANAGE
Product Life Cycle
Go to “Analyze”
LIFE CYCLE INVENTORY
Category
All
Plastic Decking
Life Cycle
Aluminum fan
plastic fan
steel fan
LIFE CYCLE(S) TO ANALYZE
Packages
Parameters
Choose Phase to Analyze
Life Cycle System
Life Cycle
Aluminum fan
plastic fan
steel fan
Drag 3 fan types and
Analyze

LIFE CYCLE(S) TO ANALYZE

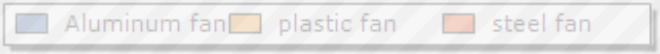
Packages | Parameters

Choose Phase to Analyze: Life Cycle System

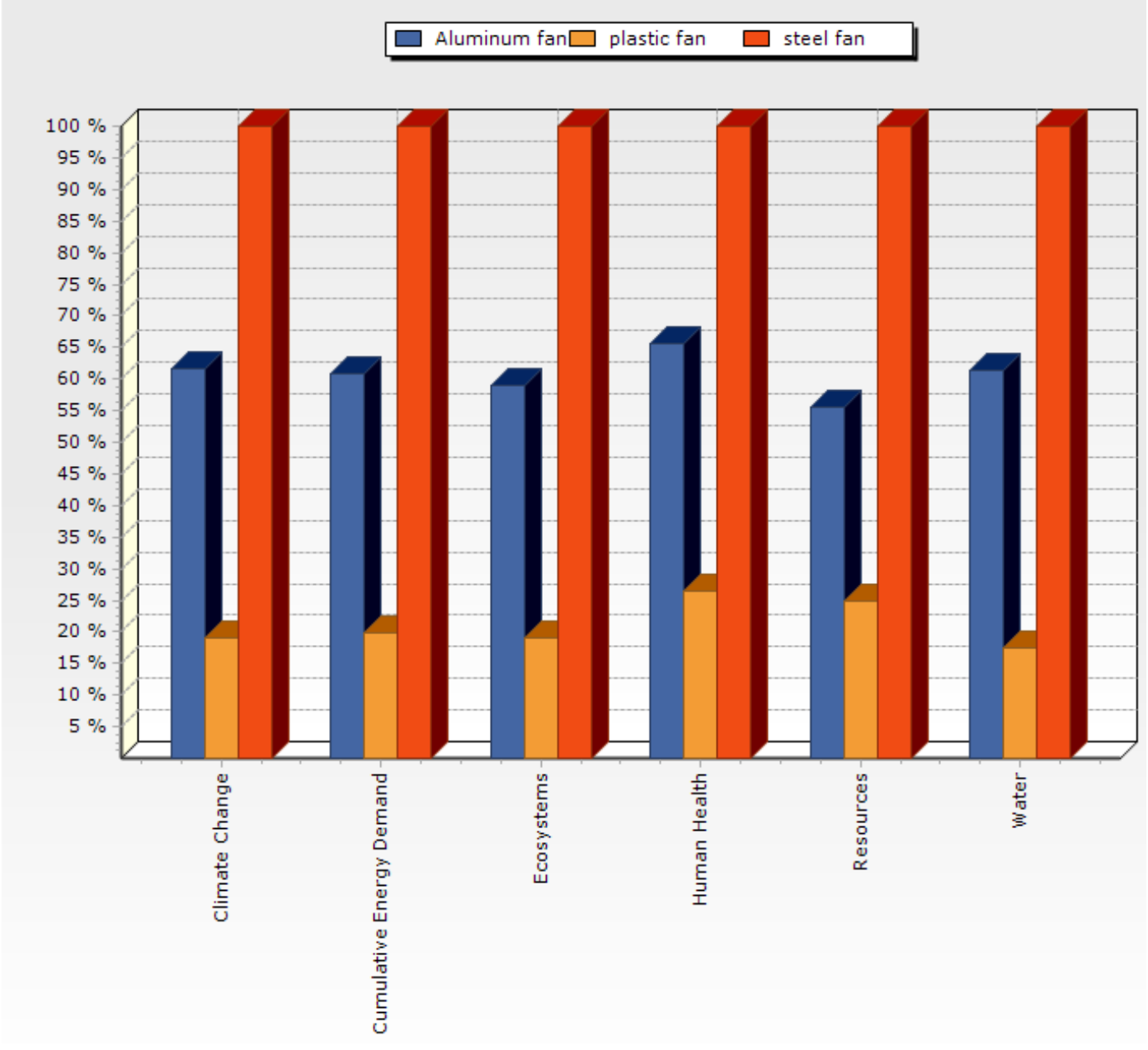
Life Cycle	
Aluminum fan	1
plastic fan	1
steel fan	1

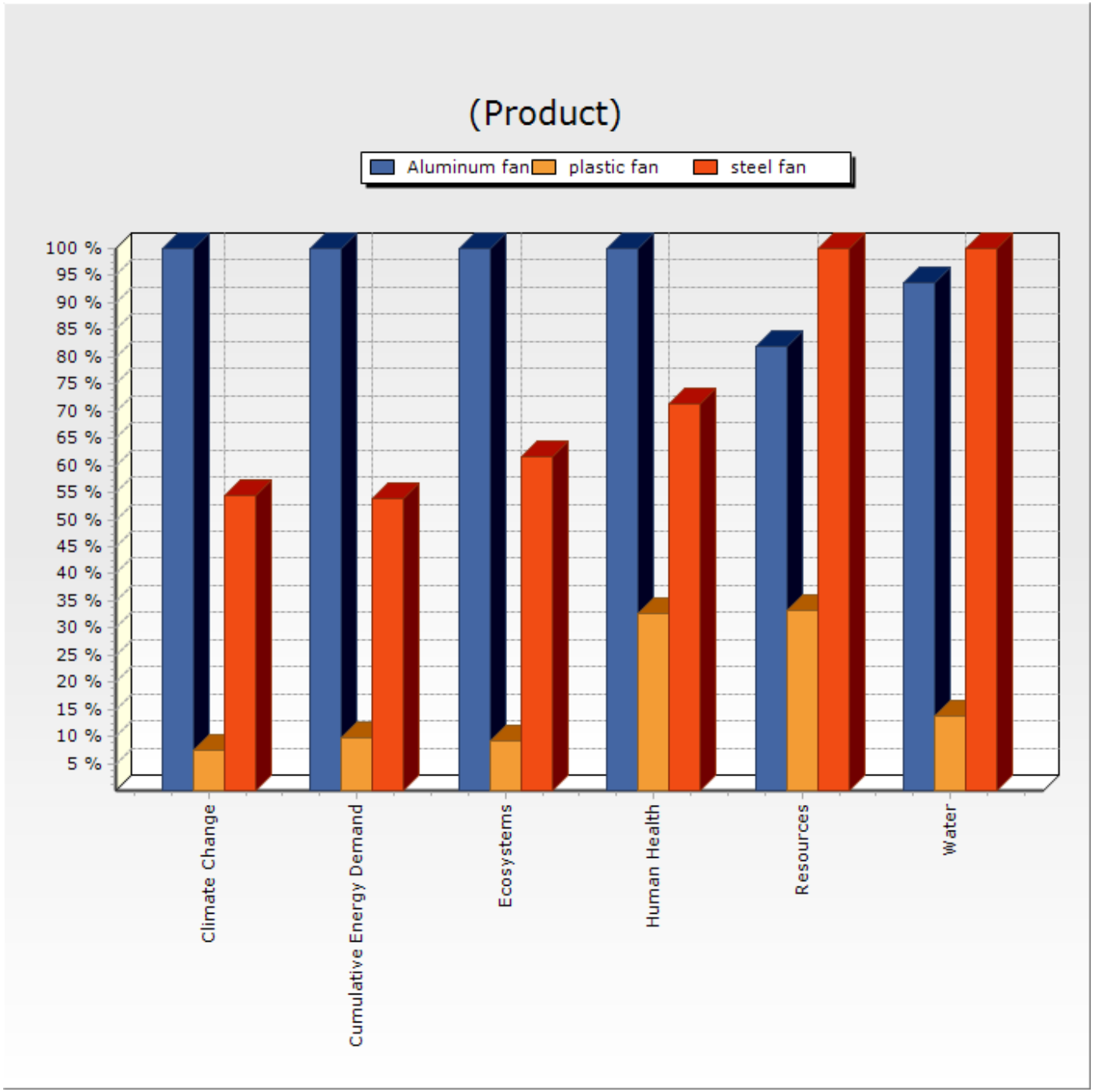
Progress

Analyzing...



Overall


Aluminum fan
plastic fan
steel fan
100 %
95 %
90 %
85 %
80 %
75 %
70 %
65 %
60 %
55 %
50 %
45 %
40 %
35 %
30 %
25 %
20 %
15 %
10 %
5 %
Climate Change
Cumulative Energy Demand
Ecosystems
Human Health
Resources
Water


(Product)
Aluminum fan
plastic fan
steel fan
100 %
95 %
90 %
85 %
80 %
75 %
70 %
65 %
60 %
55 %
50 %
45 %
40 %
35 %
30 %
25 %
20 %
15 %
10 %
5 %
Climate Change
Cumulative Energy Demand
Ecosystems
Human Health
Resources
Water

LCA studies must:

- Have a clear goal and scope
- Defined system boundaries
- Record of all data sources and calculations

EarthShift
Changing the way we look at natural resources

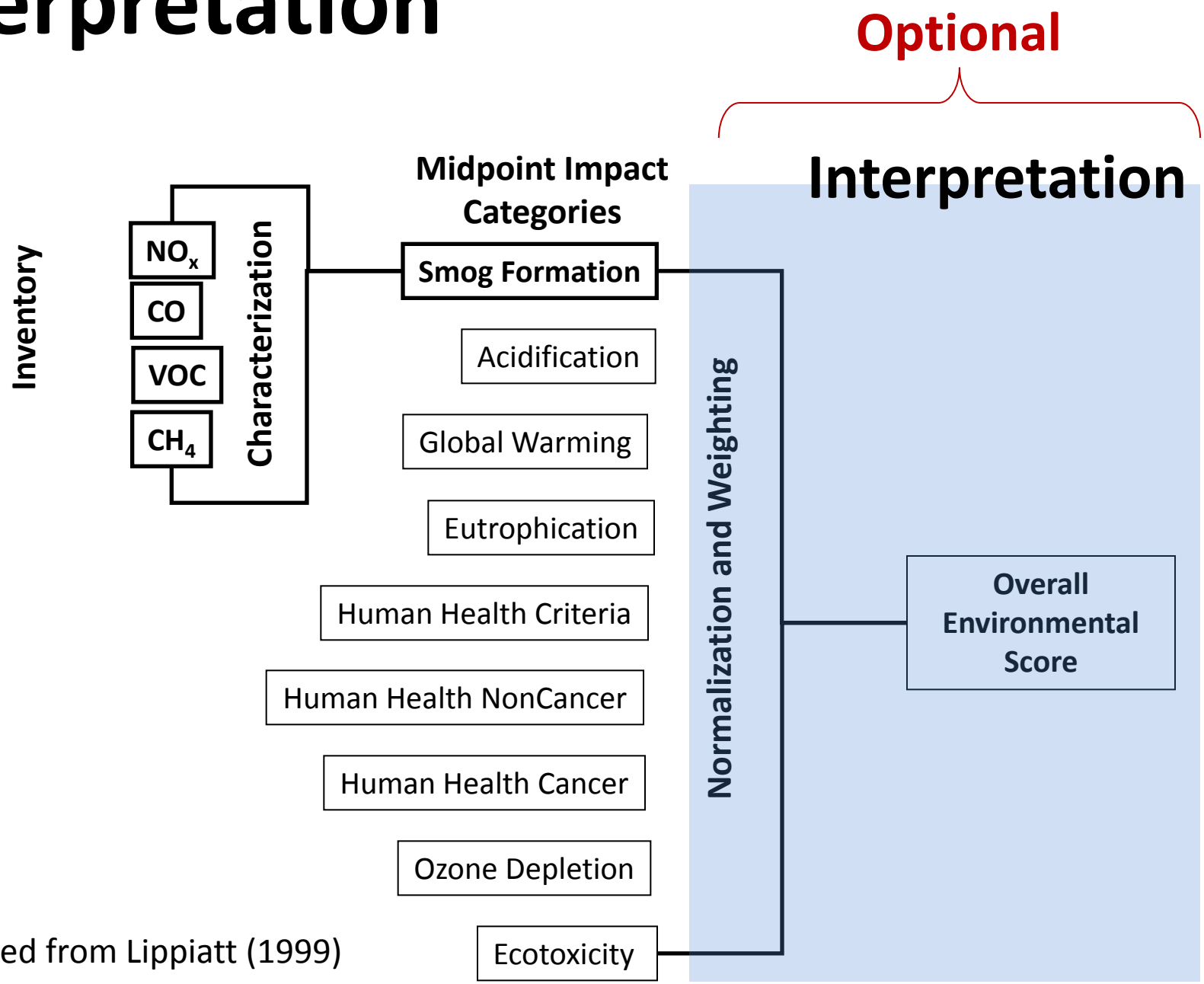
LCA applicability to PDS

LCA provides a comprehensive view by applying generalized assumptions (pros/cons)

How could you apply an LCA to your projects? (open discussion)

Part II

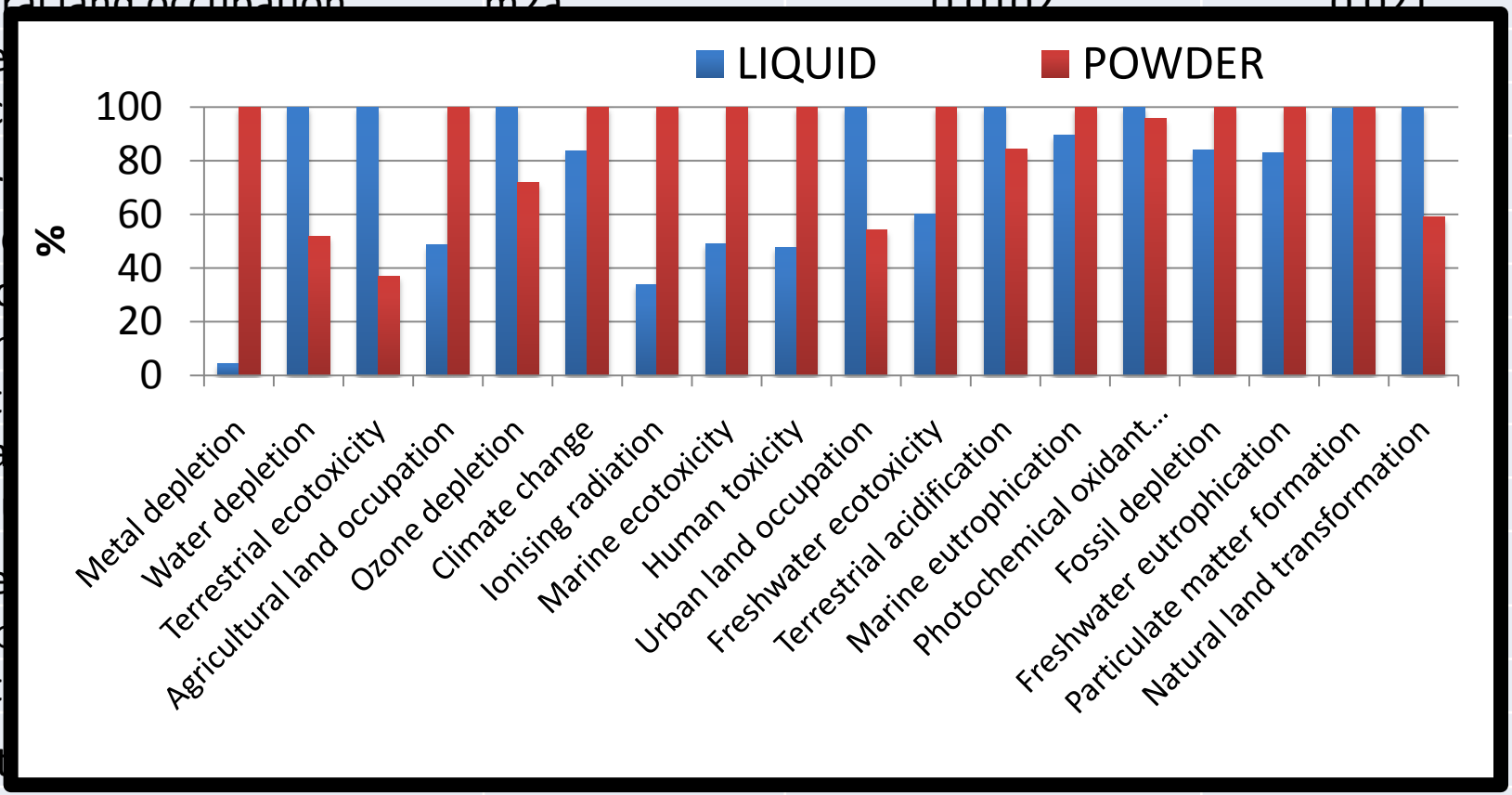
Interpretation



Adapted from Lippiatt (1999)

Characterized results (ReCiPe)

Impact category	Unit	LIQUID	POWDER
Metal depletion	kg Fe eq	0.000199	0.00443
Water depletion	m3	0.00266	0.00138
Terrestrial ecotoxicity	kg 1,4-DB eq	0.000706	0.000262
Agricultural land occupation	m2a	0.0102	0.021
Ozone de			
Climate c			
Ionising r			
Marine e			
Human to			
Urban lar			
Freshwat			
Terrestria			
Marine e			
Photoche			
Fossil dep			
Freshwat			
Particulat			
Natural land transformation	m2	0.0000195	0.0000115

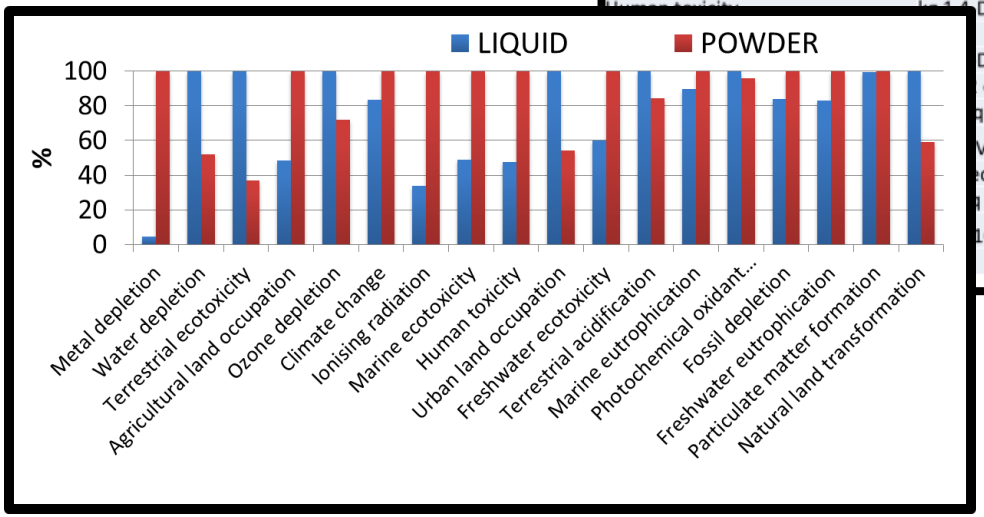


Prado-Lopez et al., 2014

Analytic aid in result interpretation

- Multiple indicators (different units)
- Multiple alternatives (Comparative Assessments)
- Uncertainty
- Decision Makers
- Environmental tradeoffs

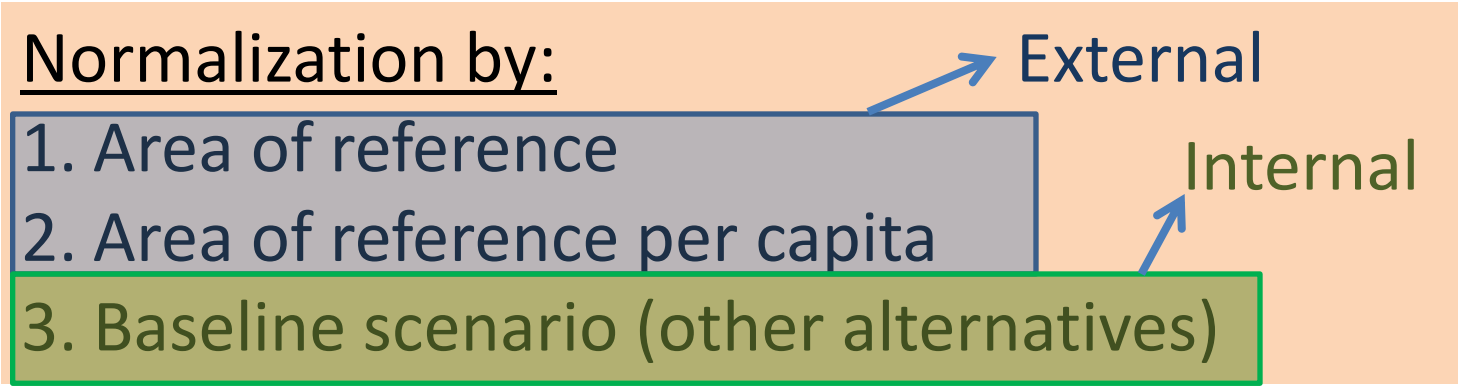
Impact category	Unit	LIQUID	POWDER
Metal depletion	kg Fe eq	0.000199	0.00443
Water depletion	m3	0.00266	0.00138
Terrestrial ecotoxicity	kg 1,4-DB eq	0.000706	0.000262
Agricultural land occupation	m2a	0.0102	0.021
Ozone depletion	kg CFC-11 eq	9.24E-09	6.65E-09
Climate change	kg CO2 eq	0.090378177	0.102304355
Ionising radiation	kg U235 eq	0.00689	0.0203
Marine ecotoxicity	kg 1,4-DB eq	0.00051	0.00104
	DB eq	0.0195	0.041
		0.00143	0.000775
	DB eq	0.000702	0.00117
	eq	0.000518689	0.000436512
		7.05104E-05	7.92817E-05
	VOC	0.000306118	0.000289197
	eq	0.0329	0.0392
		0.0000349	0.000042
	10 eq	0.000159255	0.00015987
		0.0000195	0.0000115



Normalization

"Normalization is the calculation of the magnitude of the category indicator results relative to some reference information. The aim of the normalization is to understand better the relative magnitude for each indicator results of the products system under study"

ISO 14044:2006



Norris, 2001, Lautier et al., 2010

International Organization for Standardization

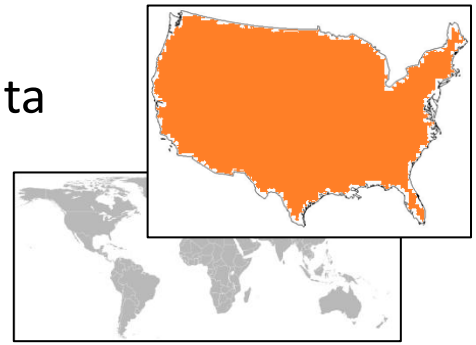
iso.org

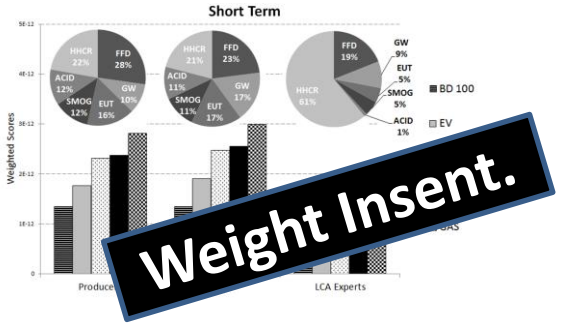
weighting

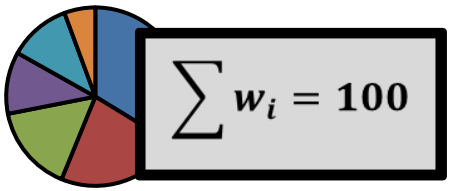
Limitations of Existing Interpretation Practices

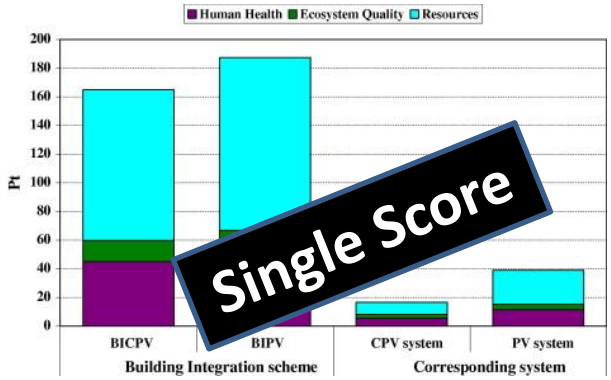
$$\sum \frac{\text{Characterized Impact}}{\text{Normalization References}} \times \text{Weight} = \text{Overall score}$$

- **External Normalization**
  - Lack of uncertainty data
  - Data set discrepancy
  - Weight Insensitivity
- **Weighting**
  - Discreet values
- **Single Score**
  - Over simplistic

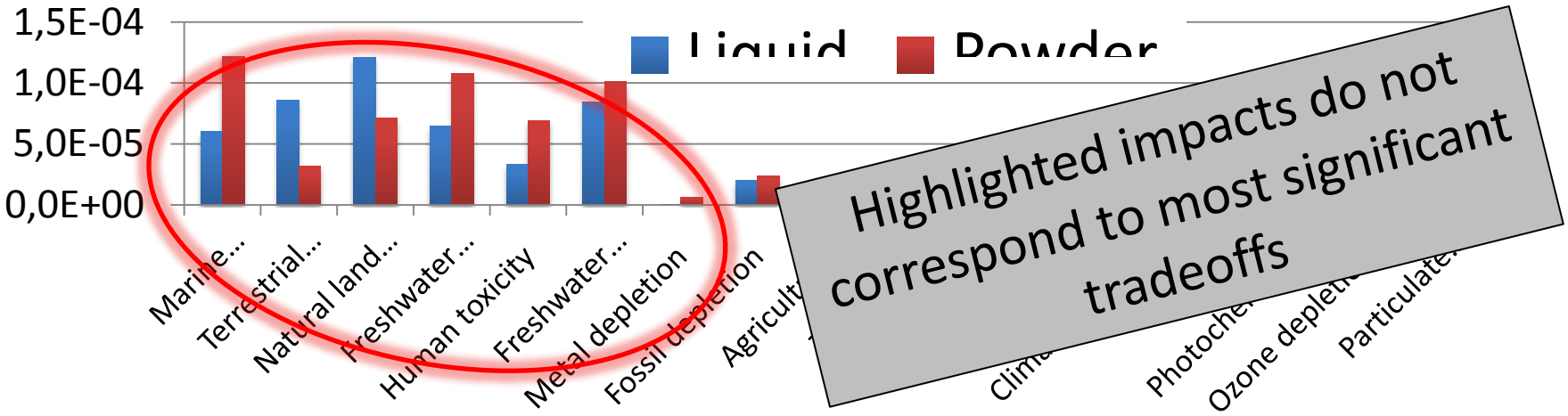


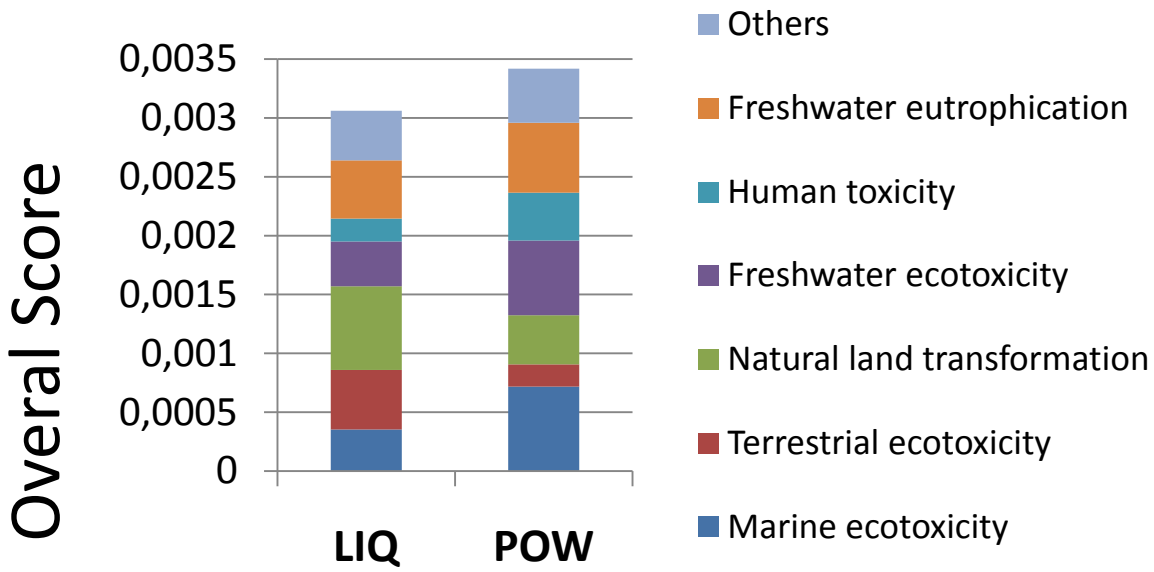






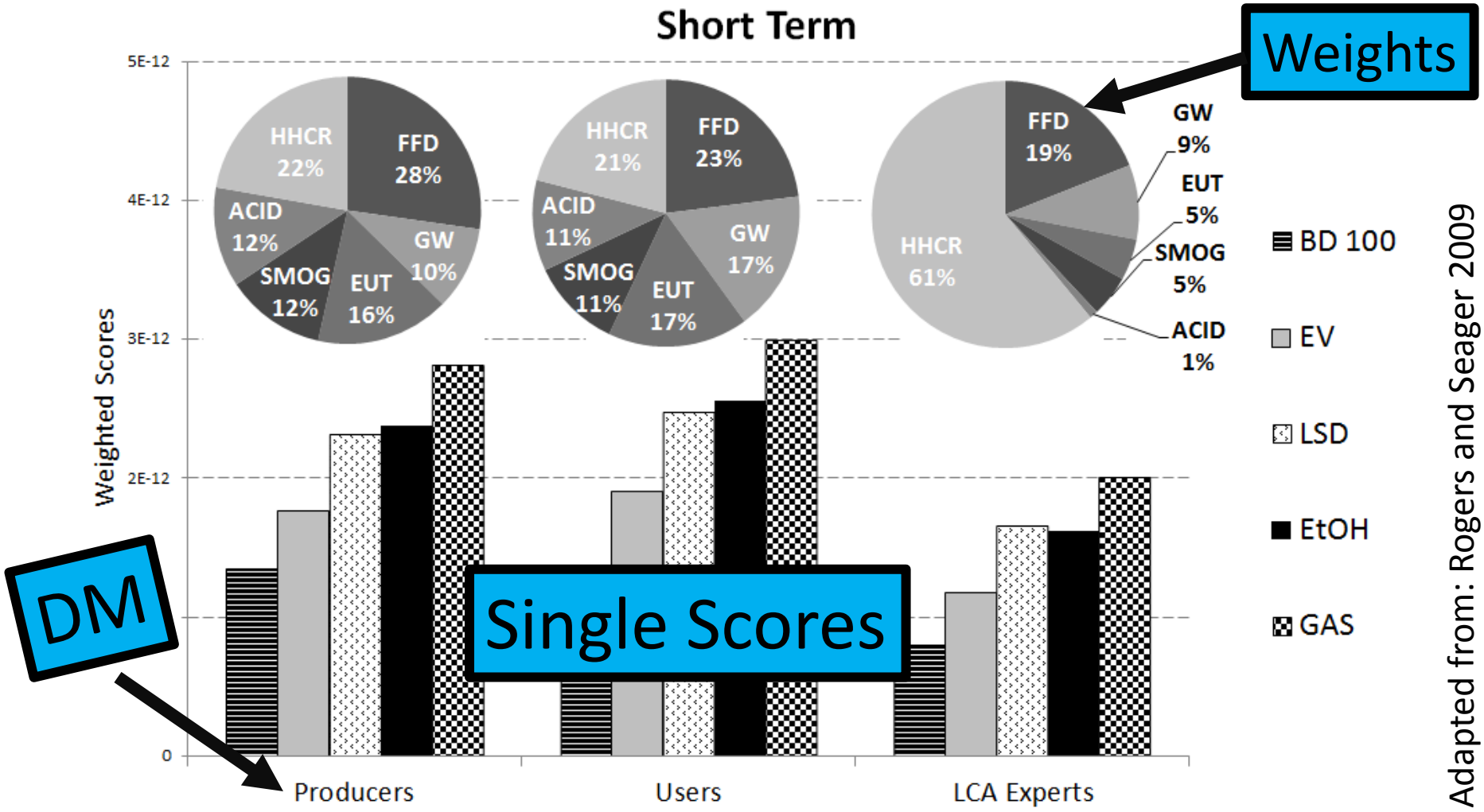
Normalized Impact (ReCiPe) Avg. EU person





Single Score (=weighting)

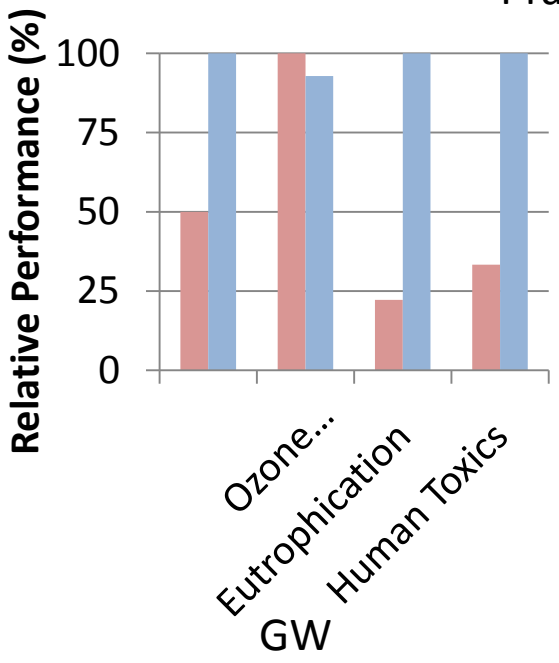
Weighting Insensitivity

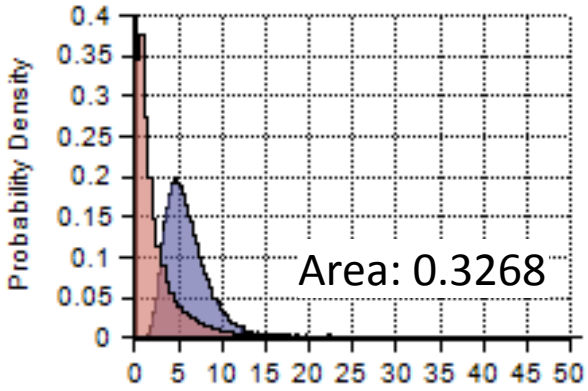


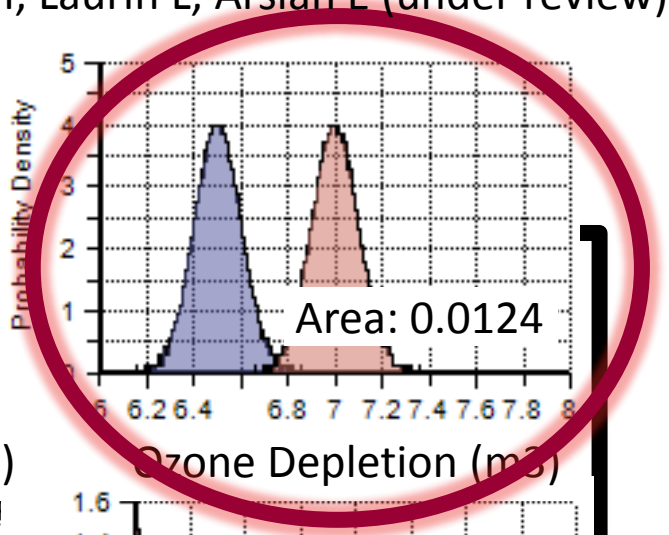
Adapted from: Rogers and Seager 2009

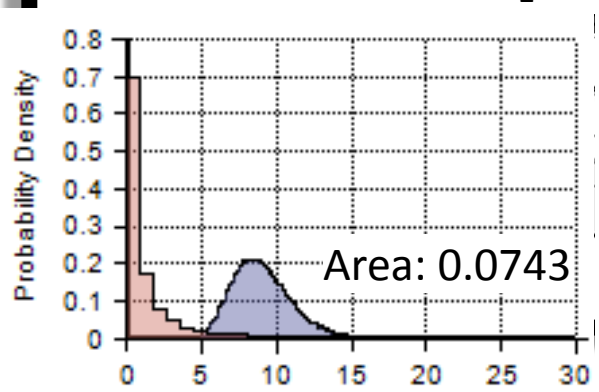
Trade-off Evaluation

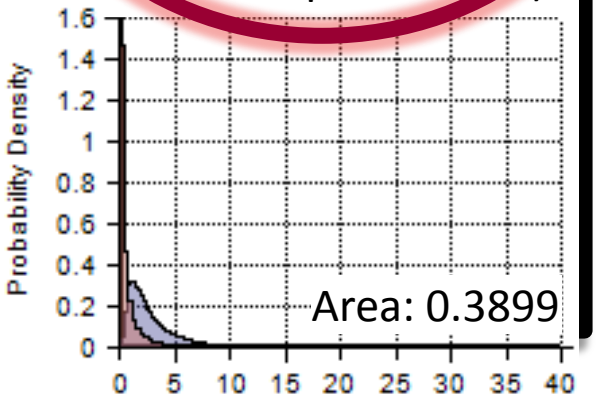
Prado-Lopez V, Seager TP, Chester M, Laurin L, Arslan E (under review)









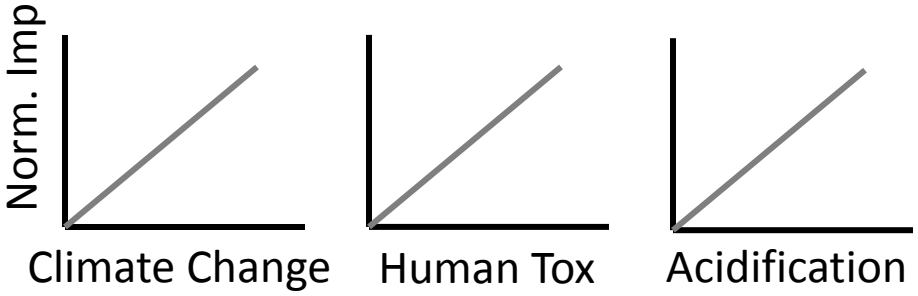


Alternative A Alternative B

Normalization Algorithms

External Normalization

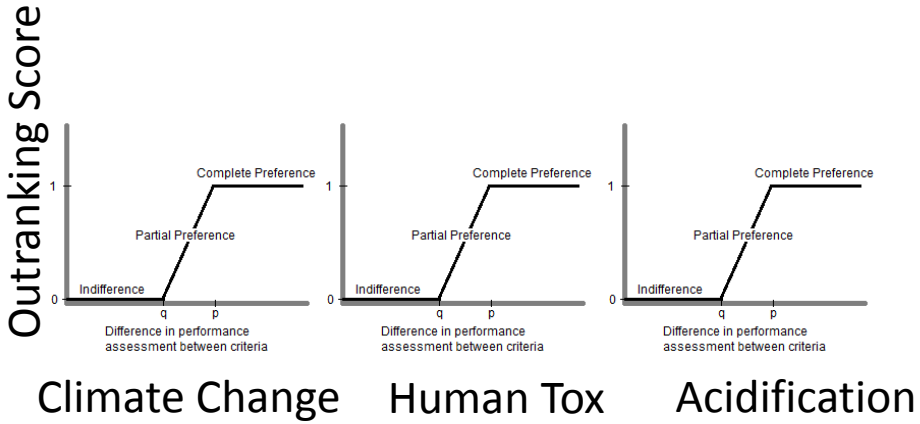
$$\frac{\textit{Characterized Imp}}{\textit{Norm. Ref}} = \textbf{Norm. Imp}$$



- Linear
- Absolute

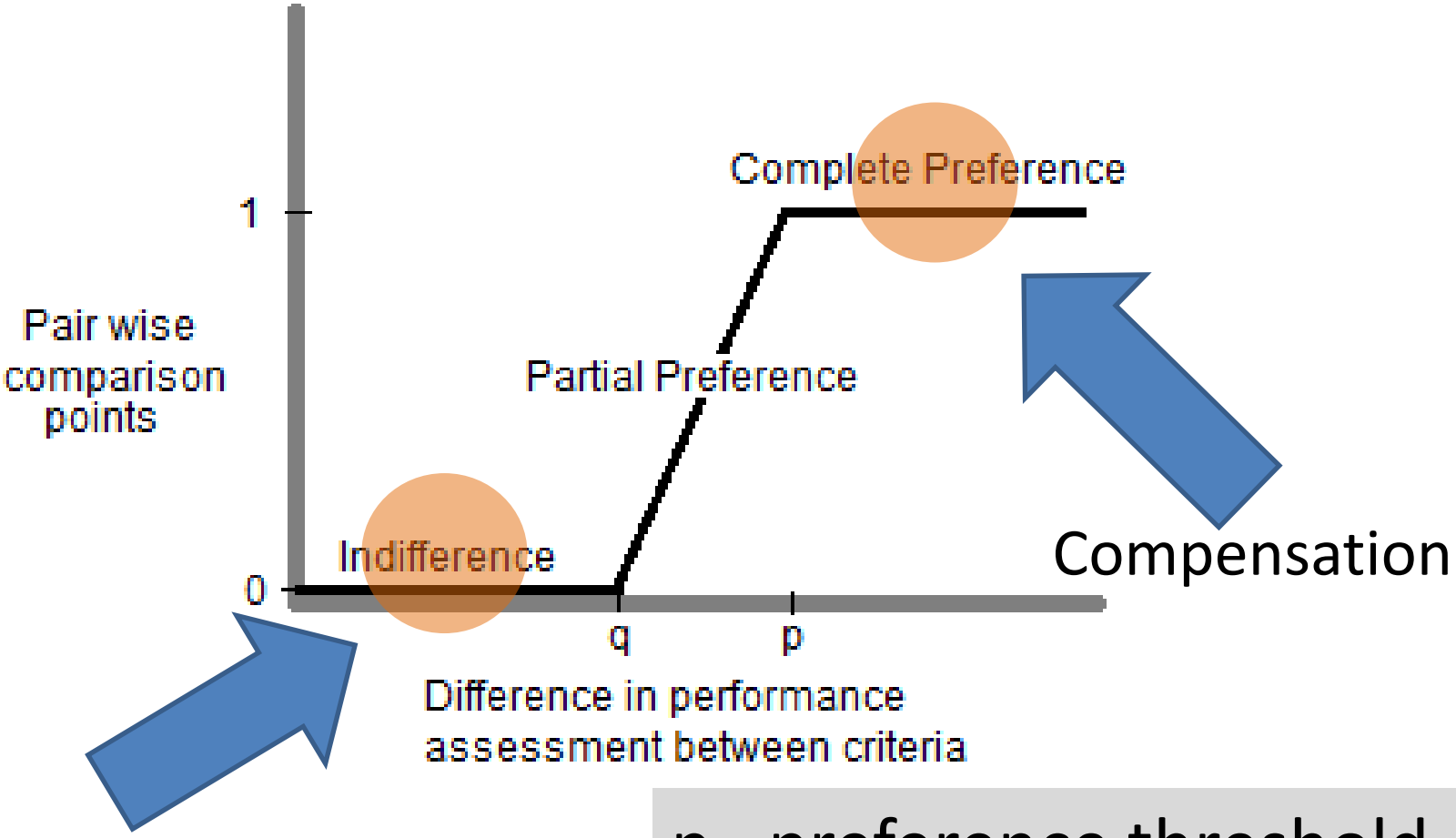
Outranking Normalization

Preference, p = avg (SD)
Indifference, q = p/2



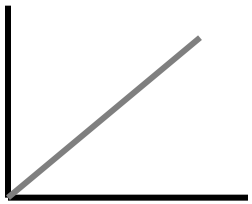
- Non linear
- Relative

Outranking

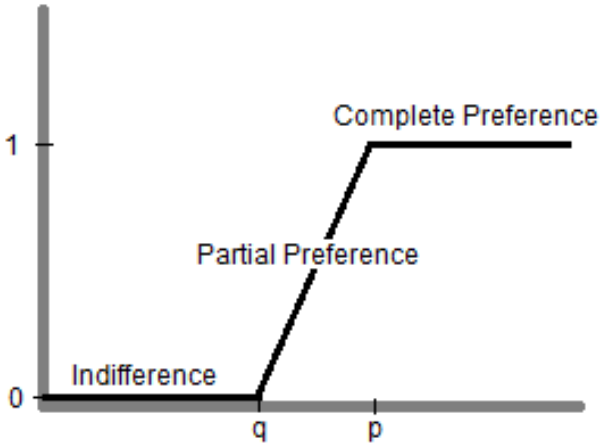


p= preference threshold
q= indifference threshold

Compensation (linearity)



Weak sustainability perspective



Strong sustainability perspective

Full compensation

Partial compensation

No compensation

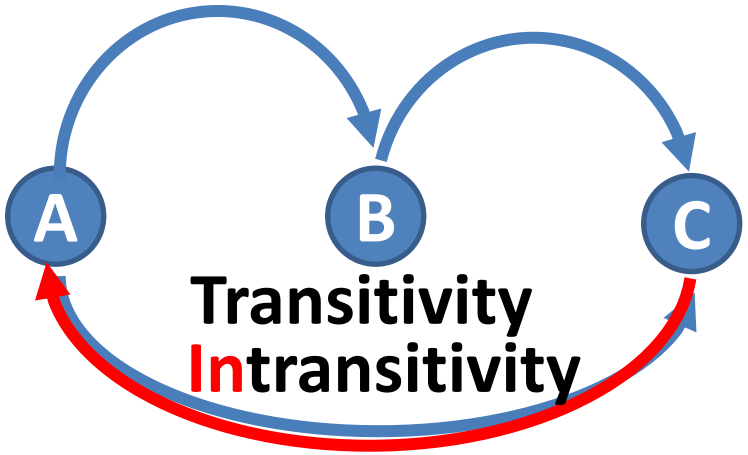
Absolute vs Relative

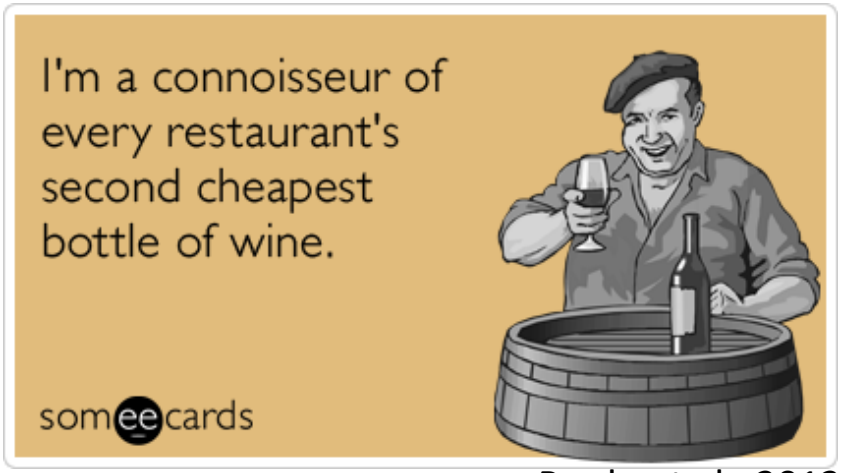
Normative (External)

- "should be"
- Absolute
- Context free
- Transitivity

Descriptive (Internal)

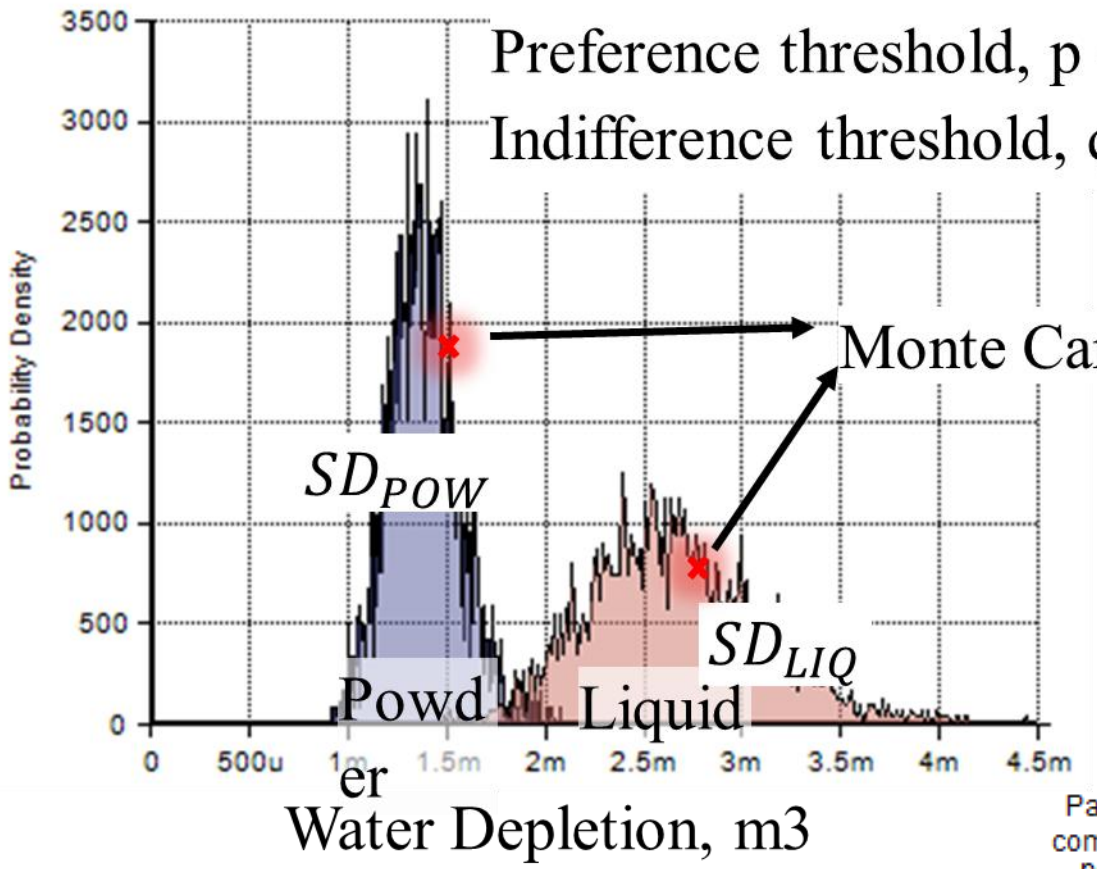
- "How they are"
- Relative
- Context effect
- Intransitivity

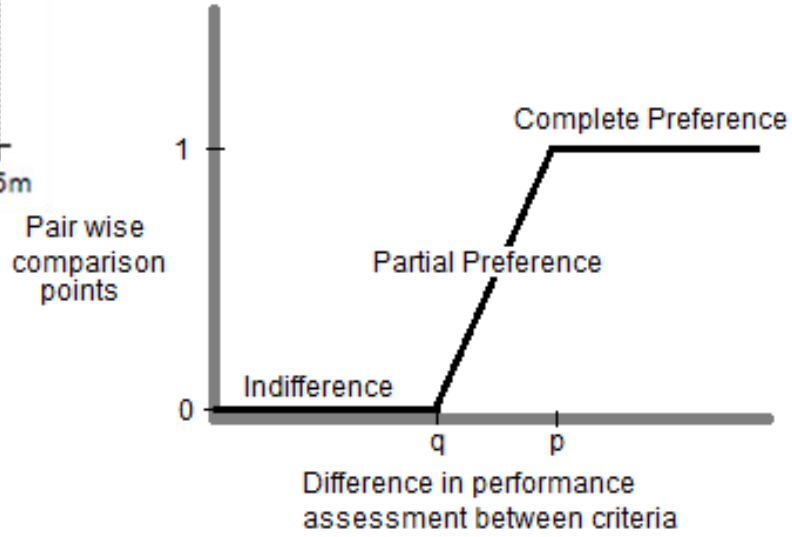




Prado et al., 2012

Stochastic Outranking





Stochastic Multi attribute Analysis (SMAA)

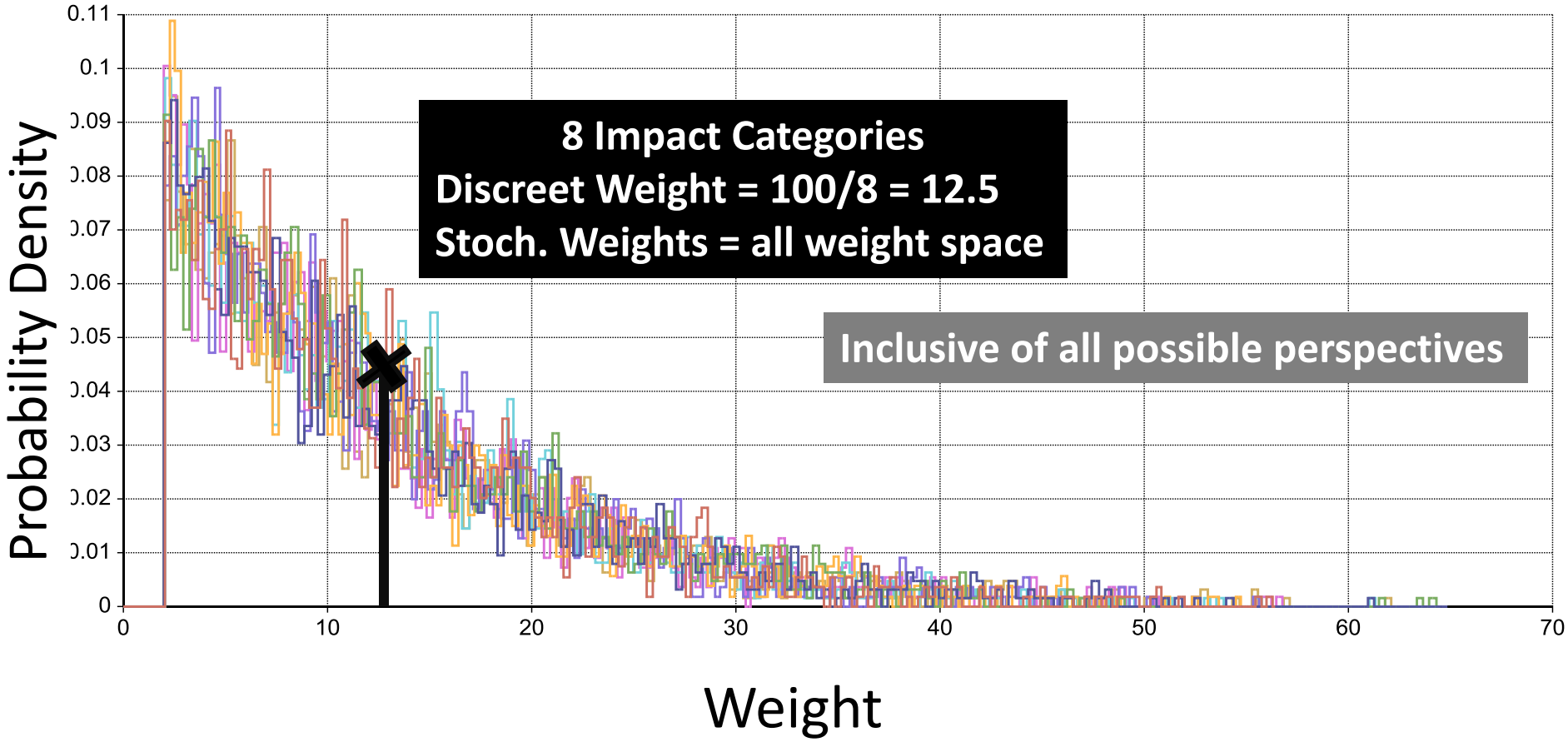
Pedigree Matrix

Table 3 – Pedigree matrix for managing cost data quality issues in eco-efficiency

Indicator score	1	2	3	4	5
Reliability of source	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions.	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate or unknown origin
Completeness	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites but for adequate periods	Representative data from an adequate number of sites but from shorter periods	Representative data but from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods	Representativeness unknown or incomplete data from a smaller number of sites and/or from shorter periods
Temporal differences	Less than 0.5 years of difference to year of study	Less than 2 years difference	Less than 4 years difference	Less than 8 years difference	Age of data unknown or more than 8 years of difference
Geographical differences	Data from area under study, same currency	Average data from larger area in which the area under study is included, same currency	Data from area with slightly similar cost conditions, same currency, or with similar cost conditions, and similar currency	Data from area with slightly similar cost conditions, different currency	Data from unknown area or area with very different cost conditions
Further technological differences	Data from enterprises, processes, and materials under study	Data from processes and materials under study from different enterprises, similar accounting systems	Data from processes and materials under study but from different technology, and/or different accounting systems	Data on related processes or materials but same technology	Data on related processes or materials but different technology

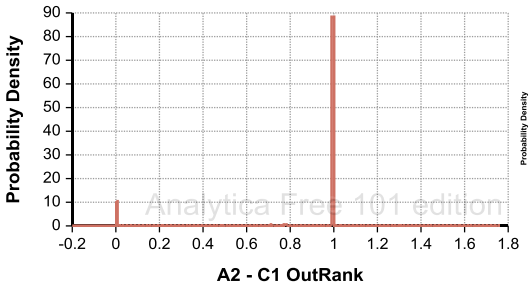
http://cxdd.broceliande.kerbabel.fr/?q=node/449/226

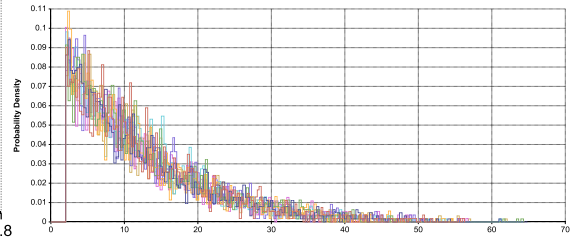
Stochastic Weights

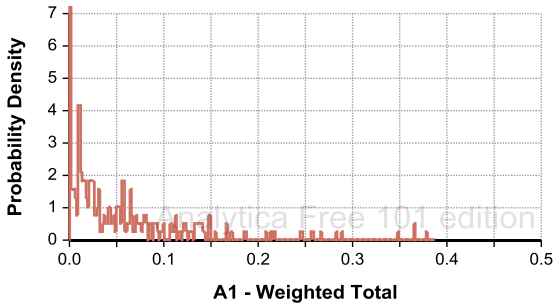


SMAA-LCA results

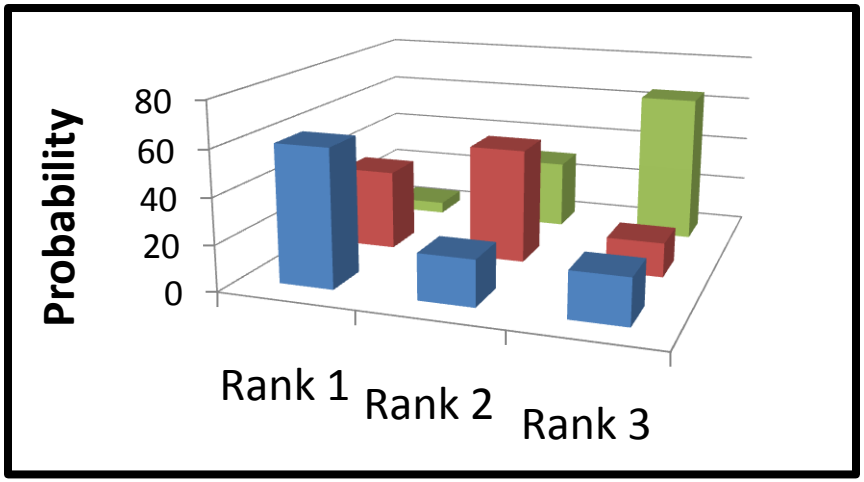
Stochastic Outranking * Stochastic Weight = Stochastic Overall Score

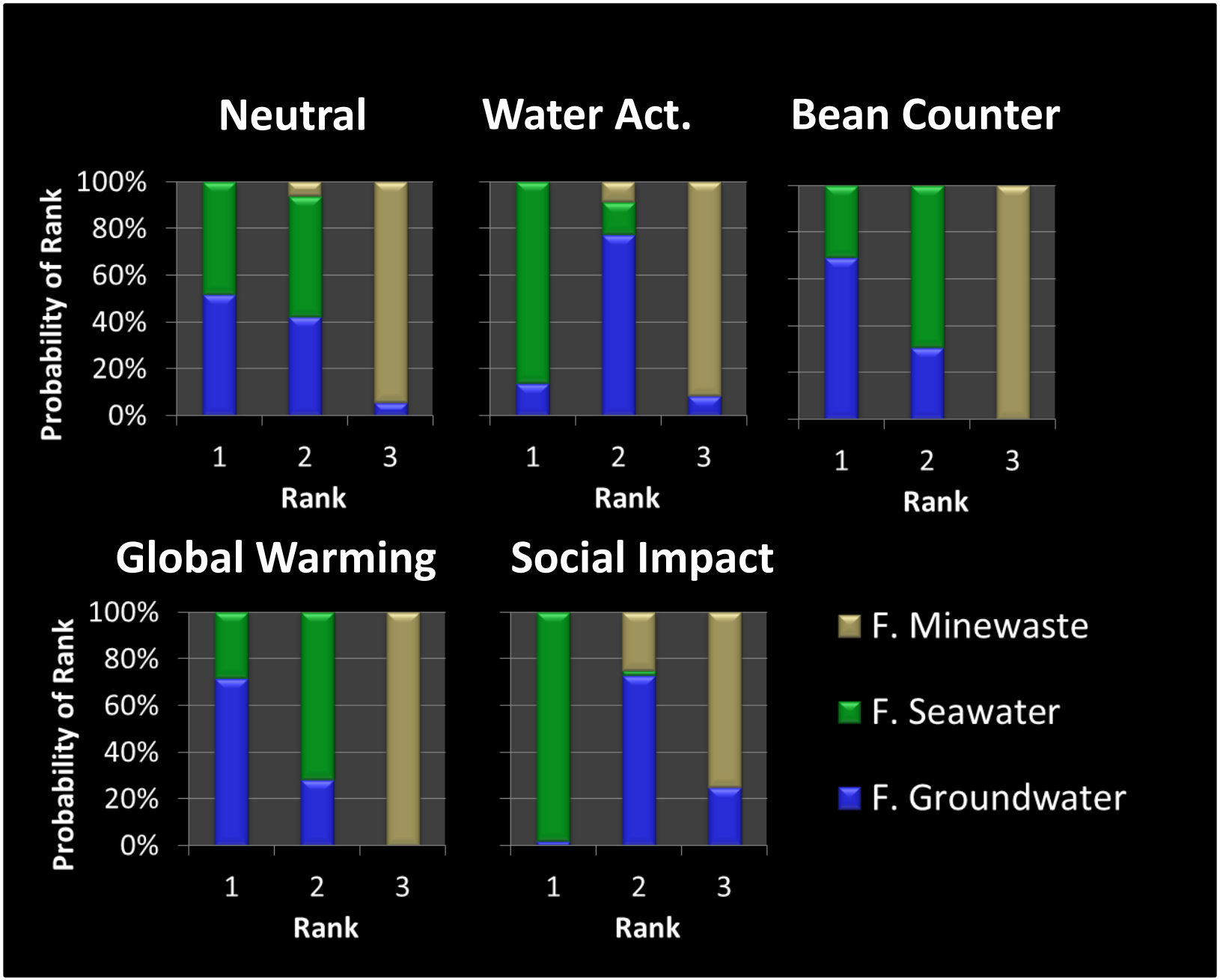






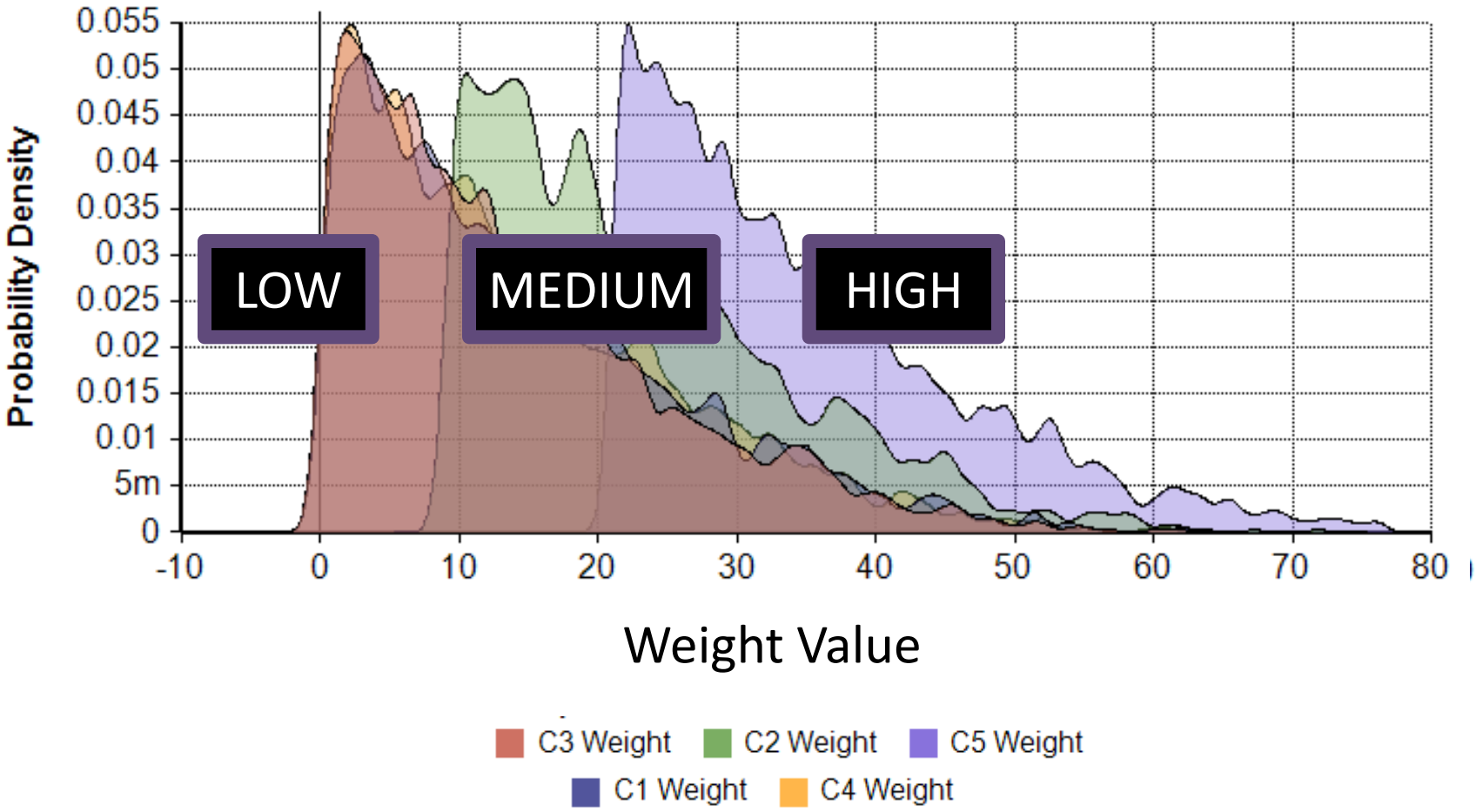
Probabilistic ranking





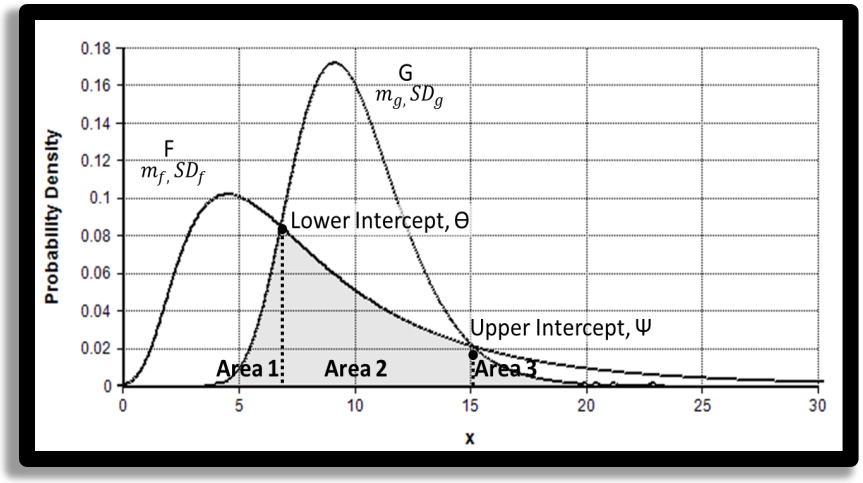
Prado-Lopez et al., 2013

Stochastic Weights (w/ preferences)

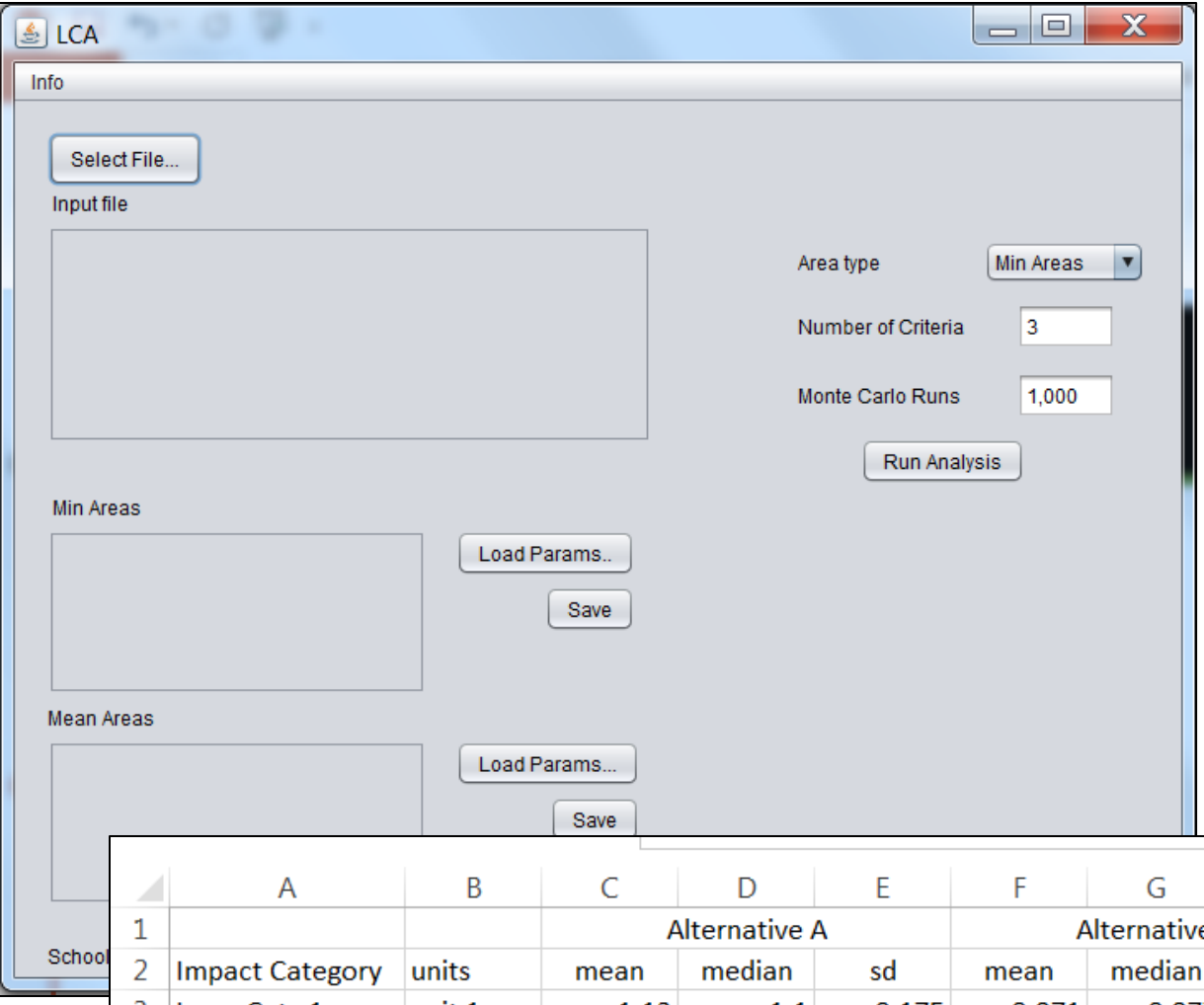


Conclusions

- Interpretation of Comparative LCAs:
  - Tradeoffs (Relative)
  - Partially Compensatory
  - Performance Uncertainty
  - Weight Uncertainty



Thank you!
valentina.prado@asu.edu



SMAA-LCA Tool (Alpha Version)

	A	B	C	D	E	F	G	H	I	J	K
1			Alternative A			Alternative B			Alternative C		
2	Impact Category	units	mean	median	sd	mean	median	sd	mean	median	sd
3	Imp . Catg 1	unit 1	1.13	1.1	0.175	0.971	0.977	0.115	0.971	0.977	0.115
4	Imp . Catg 2	unit 2	2.61	2.47	0.557	2.19	2.12	0.512	2.19	2.12	0.512
5	Imp . Catg 3	unit 3	4.21E+03	4.06E+03	877	4.65E+03	4.56E+03	944	4.65E+03	4.56E+03	944
6	Imp . Catg 4	unit 4	0.138	0.124	0.0645	0.119	0.102	0.0524	0.119	0.102	0.0524
7											
8											

Thank You!

This material is based upon work supported by the NSF under Grant No. 1140190. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.

Sustainable Energy & Environmental Decision Science