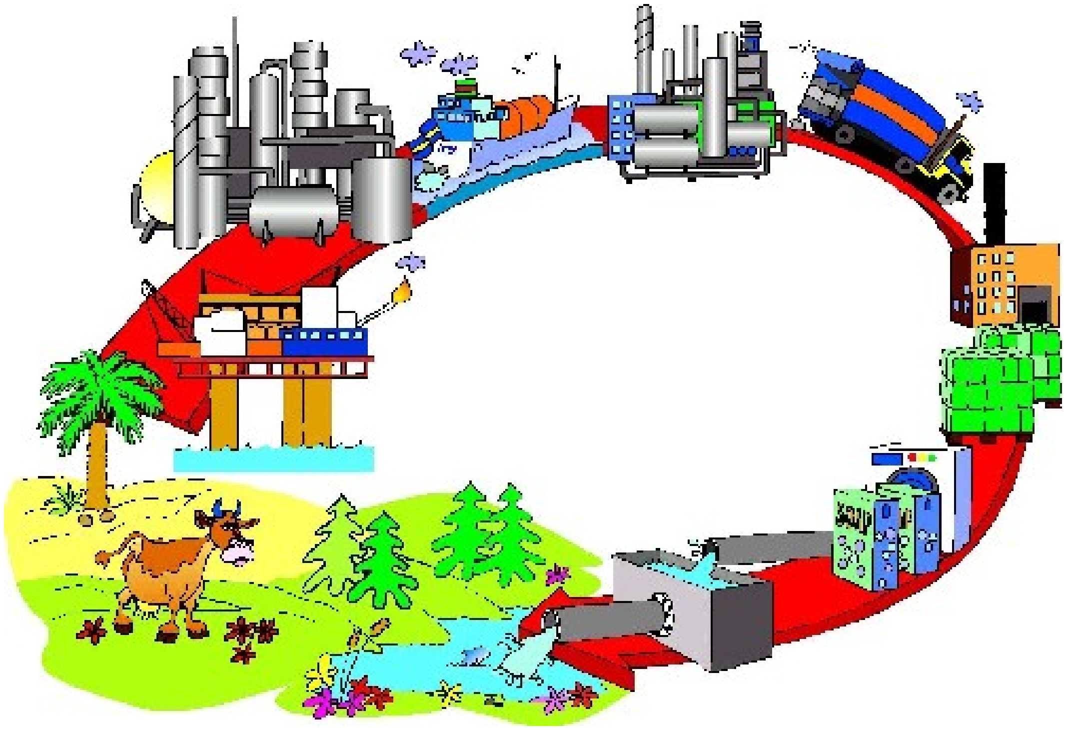
Environmental Life Cycle Assessment
PSE 476/FB 576

Lecture 14: Normalization, Weighting and Aggregation to Single Score



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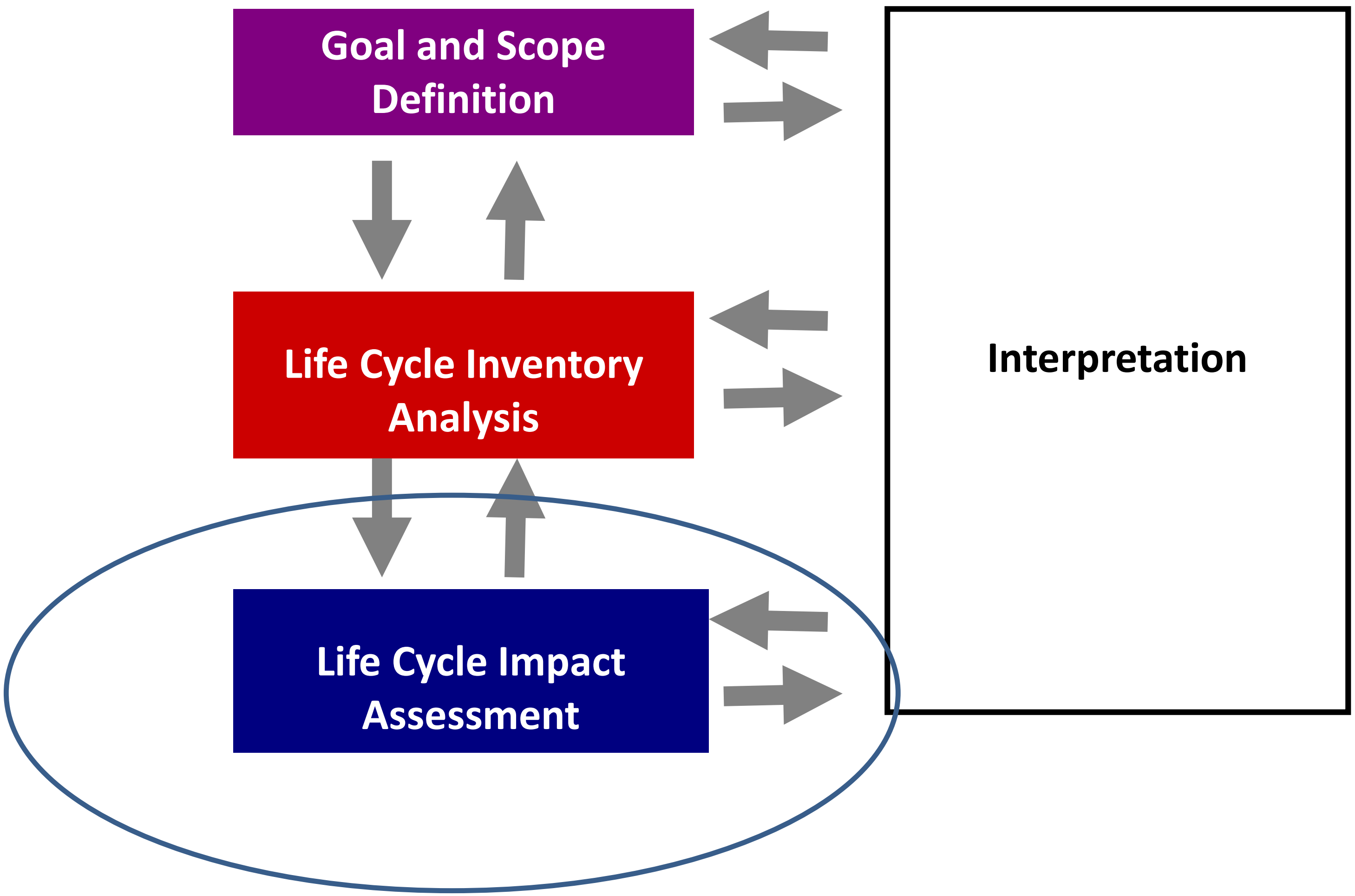
Major Parts of a Life Cycle Assessment



ISO 14040 LCIA:

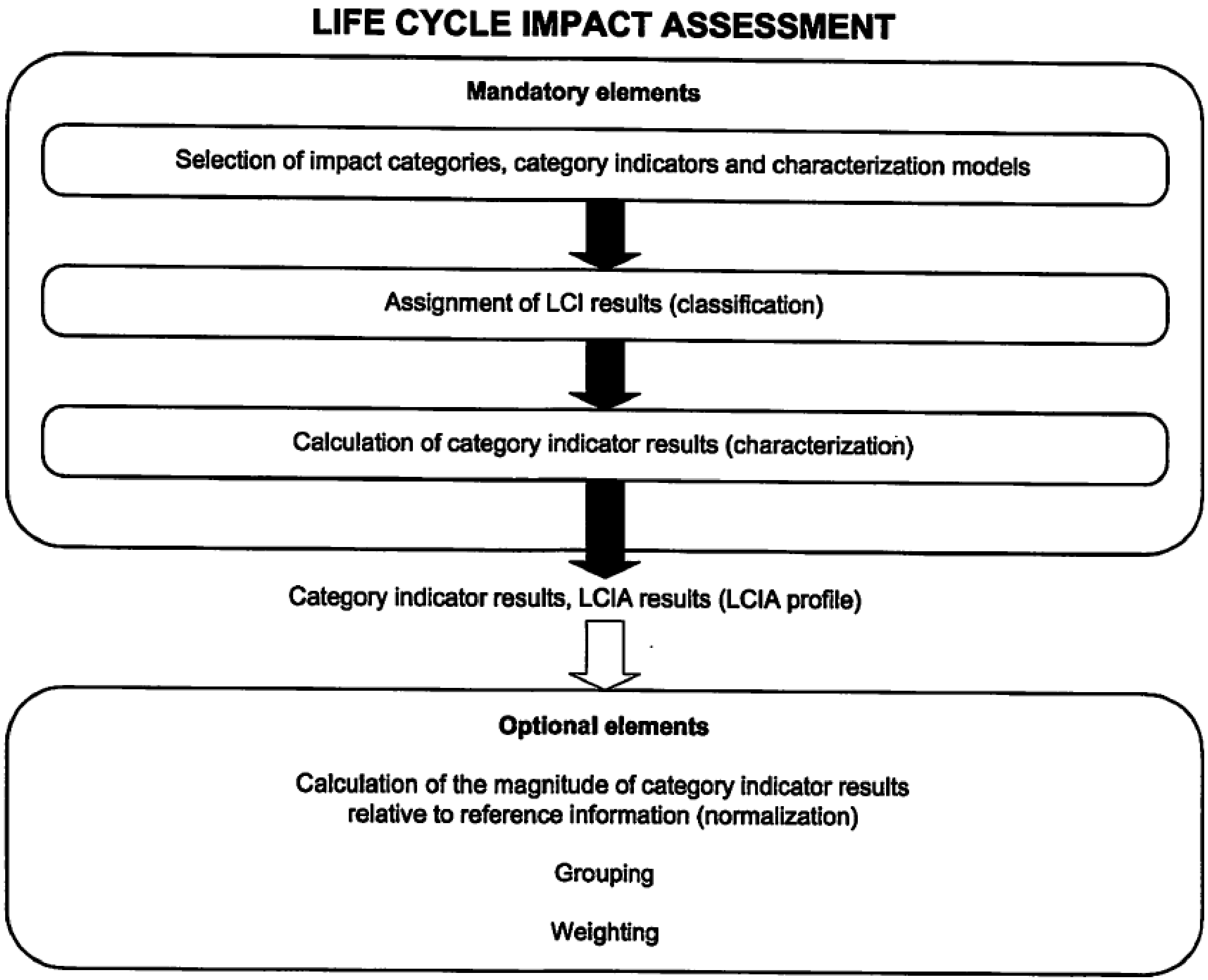


Figure 4 — Elements of the LCIA phase

Life Cycle Impact Assessment Optional elements

- **Grouping**: sorting the impact categories into sets defined in the goal and scope,
  - such as by characteristics of the inputs or outputs or if the impacts are local or global in nature
  - or by a ranking, such as high, medium and low priority
- **Normalization**: calculation of the magnitude of category indicator results to reference information
- **Weighting**: converting indicator results of different impact categories by using numerical factors based on value choices that are not scientifically based

Grouping

- Nominal grouping of impact results according to some quality

Grouping	Impact category
Geographic scale grouping:	
Global impacts	climate change, fossil fuel depletion
Regional impacts	acidification, photochemical smog
Impact typology grouping:	
Ecological health	climate change, acidification
Human health	photochemical smog
Resource use	fossil fuel depletion

Table 12.1 Examples of Nominal Grouping of Impact Categories

Grouping

- Ordinal grouping of impact results according to some preference (ranking)

Importance Ranking	Category rank by commissioner A	Category rank by commissioner B
highest	human toxicity	climate change
high	ozone layer depletion	marine ecotoxicity
low	climate change	human toxicity
lowest	marine ecotoxicity	ozone layer depletion

Table 12.2. Examples of Ordinal Grouping

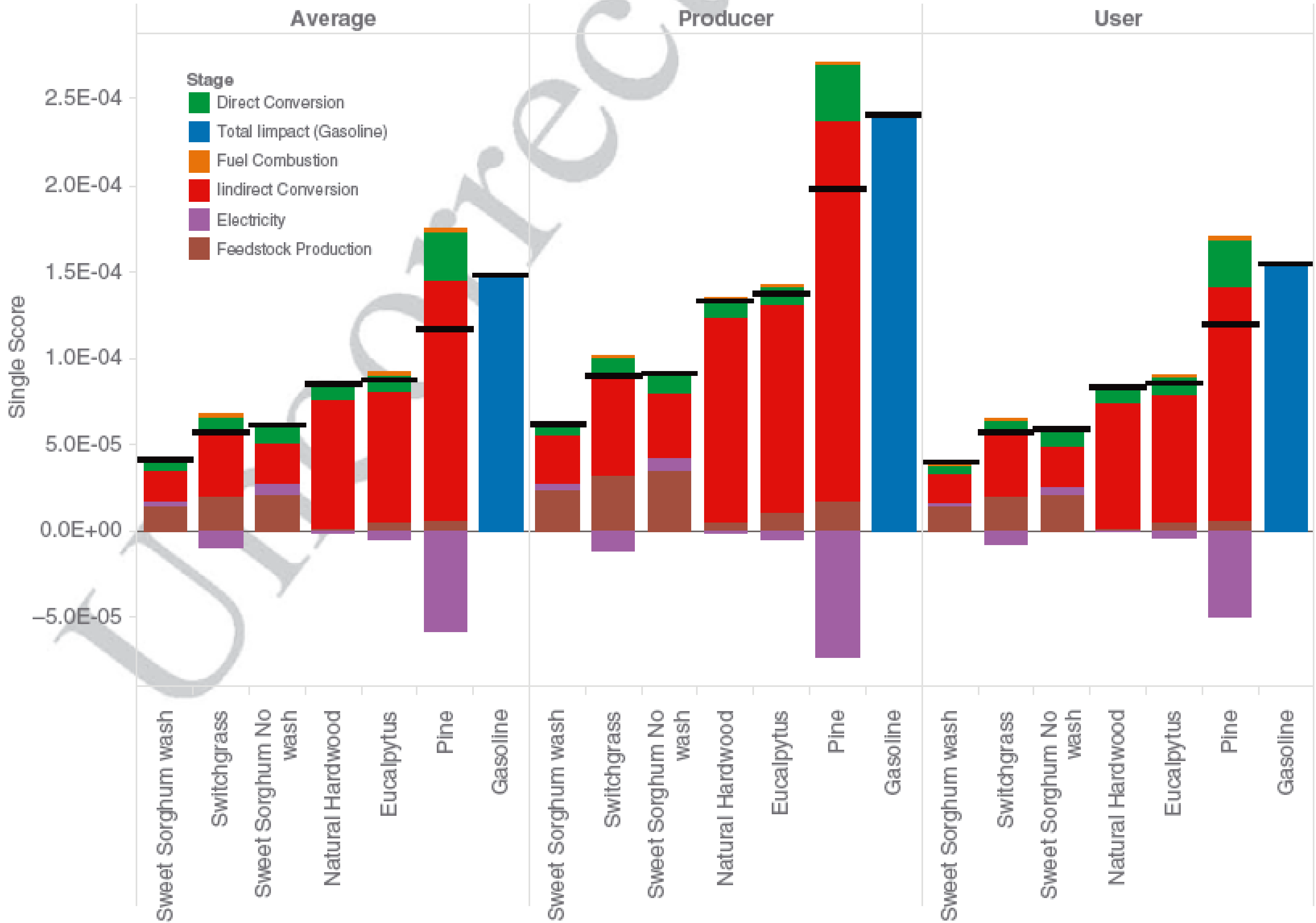


Figure 9. Cellulosic ethanol-weighted single score using average weighting, using average of all time perspectives.

Analyzing 1 p 'Assembly model Sima'; Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/A / single score

Normalization

- Definition: calculation of the magnitude of category indicator results to reference information
- Most often calculating the impact of the product system in question relative to a reference system's impact
- Renders the impact results as unitless
  - Allows for the aggregation of diffentere impact categories
- Two main methods
  - Internal normalization -- **how do two products within the study compare?**
  - External normalization – is the impact important relative to the world-wide problem (**does this product contribute significantly to the overall problem?)**

Internal Normalization: references data internal to the system studied

Impact category	Impact Unit	shoe A	shoe B	shoe C
Abiotic depletion	kg Sb eq	0.053	0.044	0.065
Acidification	kg SO_2 eq	0.054	0.062	0.041
Eutrophication	kg PO_4 eq	0.010	0.011	0.019
Global warming	kg CO_2 eq	6.701	5.820	5.459
Human toxicity	kg 1,4-DB eq	1.898	2.372	1.168

Table 12.3. Characterized Impacts of Three Types of Running Shoes

Impact category	normalized impact unit	shoe a	shoe b	shoe c
Abiotic depletion		1.00	0.83	1.22
Acidification		1.00	1.15	0.76
Eutrophication		1.00	1.12	1.94
Global warming		1.00	0.87	0.81
Human toxicity		1.00	1.25	0.62

Table 12.4 Internally Normalized Impacts of Three Types of Running

External Normalization: references data external to the system studied

Impact category	Impact Unit	shoe A	shoe B	shoe C
Abiotic depletion	kg Sb eq	0.053	0.044	0.065
Acidification	kg SO_2 eq	0.054	0.062	0.041
Eutrophication	kg PO_4 eq	0.010	0.011	0.019
Global warming	kg CO_2 eq	6.701	5.820	5.459
Human toxicity	kg 1,4-DB eq	1.898	2.372	1.168

Table 12.3. Characterized Impacts of Three Types of Running Shoes

Example:
.053/1.6E11 = 3.4E-13

impact category	World 1995 annual per capita normalization values & units*		normalized impact unit	normalized impacts shoe A	normalized impacts shoe B	normalized impacts shoe C
Abiotic depletion	1.6E+11	kg Sb eq./person-year	1 /person-year	3.4E-13	2.8E-13	4.2E-13
Acidification	3.2E+11	kg SO2 eq./ person-year	1 /person-year	1.7E-13	1.9E-13	1.3E-13
Eutrophication	1.3E+11	kg PO4 eq./ person-year	1 /person-year	7.4E-14	8.3E-14	1.4E-13
Global warming	4.1E+13	kg CO2 eq./ person-year	1 /person-year	1.6E-13	1.4E-13	1.3E-13
Human toxicity	5.7E+13	kg 1,4-DB eq./ person-year	1 /person-year	3.3E-14	4.2E-14	2.0E-14

Table 12.5. Externally Normalized Impacts of Three Types of Running Shoes. Frischnecht, et al, 2007, CML 2001, Centre of Environmental Science of Leiden University

Better, but good enough? Indicators for absolute environmental sustainability in a life cycle perspective

Bjørn, Anders; Hauschild, Michael Zwicky; Røpke, Inge ; Richardson, Katherine

Publication date:
2015

An increasing focus on sustainability has led to proliferation of the use of environmental indicators to guide various types of decisions, from individual consumer choices to policy making at the national, regional and global scale. Most environmental indicators are relative, meaning that quantified environmental interferences of a studied anthropogenic system (a product, a company, a city, etc.) are compared to those of chosen anthropogenic systems of reference. The use of relative indicators can give the impression that societies are moving towards environmental sustainability when decisions are being made which favour solutions with lower environmental interferences than alternative solutions. This impression is very problematic considering that monitoring repeatedly shows that many environments are highly degraded and that degradation often increases over time. This shows that society-nature interactions in many cases are environmentally unsustainable and that the level of unsustainability may be increasing over time. A clear rationale therefore exists for developing and using absolute environmental sustainability indicators (AESI) that not only can identify the anthropogenic system with the lowest environmental interferences in a comparison of systems, but also can evaluate whether any of the compared systems can be considered environmentally sustainable, and if not, can quantify the decrease in environmental interferences required for environmental sustainability. The purpose of this PhD thesis is to improve AESI using life cycle assessment (LCA) and to deepen the understanding of drivers and obstacles for increasing the use of AESI in decision-support. The thesis summarizes in three core chapters the work of five peer reviewed scientific articles and one scientific viewpoint article.

Class Activity

Your Aunt Mabel has been living in the same house for the last 40 years in an older neighborhood backed up to a large undeveloped wooded land mass with several significant creeks and a river, about 20 square miles. For each of the items, respond with a 1-10 rating, 1 representing the mildest dislike of the scenario and 10 representing the strongest dislike of a scenario.

________ A company wants to establish a golf course on the property on about 1/5th of the land. Pesticides, herbicides and fertilizers applied to the golf course are expected to somewhat effect birds, squirrels and fish. Also effected will be many of the plants surrounding the course as well as the water in the creeks and rivers

________ A company wants to harvest unique, uncommon, stray rocks that lie on the ground that are valuable for interior home decoration. These rocks were formed over long periods of time and will not be replaced.

________ A very small part of the land mass is sold to a company that will put a factory very close to the neighborhood and emit low, below permissible levels of lead in a smoke stack

Time, gloss, color, opacity,

Weighting

- Applies weighting multipliers to each impact category that reflect how important each impact category is to the overall environmental result

- Incorporates some stakeholder perception about the relative importance of different impact categories

- Depends on value choices

- Two reasons for weighting
  - 1. To assist in interpreting the impact indicator results
    - Allows comparison of different impacts
    - Allows for the calculation of a single score
  - 2. Quantify consequences when defining cut-off criteria as defined in the goal and scope phase
    - For example, cut off criteria may be to consider only impacts that are greater than 1% of the total environmental impacts

- Weighting values will add up to 1.0 or 100%

- It is far more useful to weight normalized data than non-normalized data

Weighting normalized impact category results:

Impact category	Impact Unit	shoe A	shoe B	shoe C
Abiotic depletion	kg Sb eq	0.053	0.044	0.065
Acidification	kg SO_2 eq	0.054	0.062	0.041
Eutrophication	kg PO_4 eq	0.010	0.011	0.019
Global warming	kg CO_2 eq	6.701	5.820	5.459
Human toxicity	kg 1,4-DB eq	1.898	2.372	1.168

Table 12.3. Characterized Impacts of Three Types of Running Shoes

impact category	World 1995 annual per capita normalization values & units*	
Abiotic depletion	1.6E+11	kg Sb eq./person-year
Acidification	3.2E+11	kg SO2 eq./ person-year
Eutrophication	1.3E+11	kg PO4 eq./ person-year
Global warming	4.1E+13	kg CO2 eq./ person-year
Human toxicity	5.7E+13	kg 1,4-DB eq./ person-year

Example:
0.2*.053/(1.6E11)
=6.8E-14

impact category	weighting values	normalized and weighted unit	weighted and normalized impact shoe A	weighted and normalized impact shoe B	weighted and normalized impact shoe C
Abiotic depletion	0.2	1 /person-year	6.8E-14	5.6E-14	8.4E-14
Acidification	0.2	1 /person-year	3.4E-14	3.8E-14	2.6E-14
Eutrophication	0.2	1 /person-year	1.5E-14	1.7E-14	2.8E-14
Global warming	0.2	1 /person-year	3.2E-14	2.8E-14	2.6E-14
Human toxicity	0.2	1 /person-year	6.6E-15	8.4E-15	4.0E-15
total	1.0		1.6E-13	1.5E-13	1.7E-13

Table 12.7. Externally Normalized and Equally Weighted Impacts of Three Types of Running Shoes

Which shoe is the most environmentally preferred? If you agree with the normalization and the weighting scheme then it would be shoe B.

Weighting by Different Stakeholders

- Gloria TP, Lippiatt BC, Cooper J. Life cycle impact assessment weights to support environmentally preferable purchasing in the United States. Environ Sci Technol 2007;41(21):7551-7557.

TABLE 3. Environmental Impact Importance (%) by Voting Interest and Time Horizon

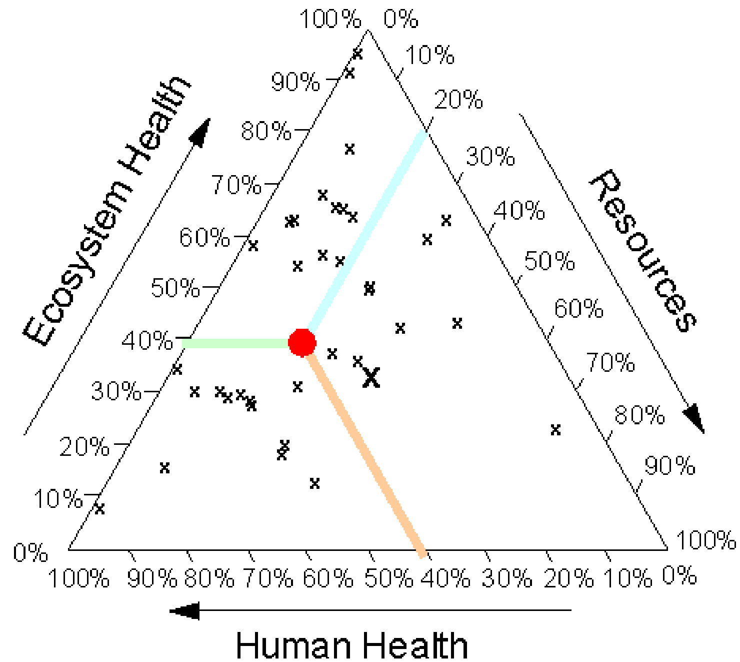
	all time horizons (100%)				short-term time horizon (24%)				medium-term time horizon (31%)				long-term time horizon (45%)			
impact category	all	producer	user	LCA expert	all	producer	user	LCA expert	all	producer	user	LCA expert	all	producer	user	LCA expert
global warming	29	16	30	50	7	5	9	7	43	26	43	60	52	30	57	68
fossil fuel depletion	10	12	7	10	15	13	12	15	7	13	3	13	4	10	1	5
criteria air pollutants	9	7	6	13	18	11	11	48	2	3	3	1	1	2	0	1
water intake	8	7	10	5	7	7	8	3	10	8	14	6	8	8	9	6
cancerous	8	8	6	6	8	11	6	5	6	4	6	4	9	9	6	7
ecological toxicity	8	8	11	3	6	5	9	2	9	12	11	3	9	9	13	5
eutrophication	6	8	6	3	8	8	9	4	6	10	5	5	3	4	2	2
land use	6	6	9	3	7	7	11	3	6	6	8	3	5	6	6	3
noncancerous	5	11	4	2	6	12	5	3	4	6	2	2	6	17	2	2
smog formation	4	4	3	2	7	6	6	4	1	3	1	1	0	1	0	1
indoor air quality	3	5	3	1	7	9	6	4	1	1	1	1	0	0	0	0
acidification	3	4	4	1	4	6	6	1	2	4	2	1	2	2	2	1
ozone depletion	2	3	2	1	2	3	3	1	2	4	2	1	2	3	1	1
inconsistency	0.03	0.05	0.03	0.05	0.04	0.06	0.06	0.05	0.02	0.04	0.02	0.06	0.06	0.11	0.08	0.13

Impact Assessment: Weighting

- Weighting relates the relative importance of impact categories
- Eco-Indicator 99
  - Questionnaire sent to 365 Swiss LCA interest groups
  - Panel members ranked and weighted three damage categories
- SUBJECTIVE

Impact Category	Mean	Rounded	St. Deviation	Median
Human Health	36%	40%	19%	33%
Ecosystem Quality	43%	40%	20%	33%
Resources	21%	20%	14%	23%

[Mettier 1999] Mettier T.: Der Vergleich von Schutzguetern - Ausgewaehlte Resultate einer Panel-Befragung. In: Hofstetter P., Mettier T., Tietje O. (eds.), *Ansaetze zum Vergleich von Umweltschaeden, Nachbearbeitung des 9. Diskussionsforums Oekobilanzen vom 4. Dezember 1998*, ETH Zürich, Switzerland, 1999



Red dot represents the average weights used for Eco-Indicator 99

Aggregation: Creating a Single Score

- Aggregation of the different impact category results can be done by normalizing and then weighting the impact categories and then summing the results.

- ISO 14044.4.1 notes that a scientific basis for aggregating LC assessment results does not exist.
- Depends on value choices

- It is **not** ok to report single scores alone for public comparisons, marketing, or eco-labeling since they are not transparent

Sustainable Minds, TRACI V2.1

TRACI V2.1 impact categories, normalization factors and weighting factors used to create the Sustainable Minds impact factors. Sustainable Minds uses the 2008 US normalization factors.

Impact category	Normalization Factor [5]	Unit	Weighting Factor [7]
Ozone depletion	6.20	CFC-11 eq/year/capita	2.4
Smog	7.18E-4	O_3 eq (ozone) /year/capita	4.8
Acidification	1.10E-2	SO_2 eq (sulphur dioxide) /year/capita	3.6
Fossil fuel depletion	5.79E-5	MJ surplus/year/capita	12.1
Eutrophication	4.63E-2	N eq (nitrogen) /year/capita	7.2
Respiratory effects	4.12E-2	PM2.5 eq (fine particulates) /year/capita	10.8
Non carcinogenics	952	CTUh/year/capita	6.0
Carcinogenics	19706	CTUh/year/capita	9.6
Ecotoxicity	9.05E-5	CTUh/year/capita	8.4
Global warming	4.13E-5	CO_2 eq (carbon dioxide) /year/capita	34.9

SM: Single Score

- Sustainable Minds Software utilizes normalization followed by weighting to arrive at a value called a millipoint
- For the example below, the product system would have a single score value of 1.81 millipoints

Impact category	Normalized impacts		x Weighting value	= Weighted value	
	Amount	Unit		Amount	Unit
Global warming	0.00470	normalized points	x 0.349 x 1000 mp/p	1.639698276	millipoints
Ecotoxicity	0.00208	normalized points	x 0.084 x 1000 mp/p	0.174841629	millipoints

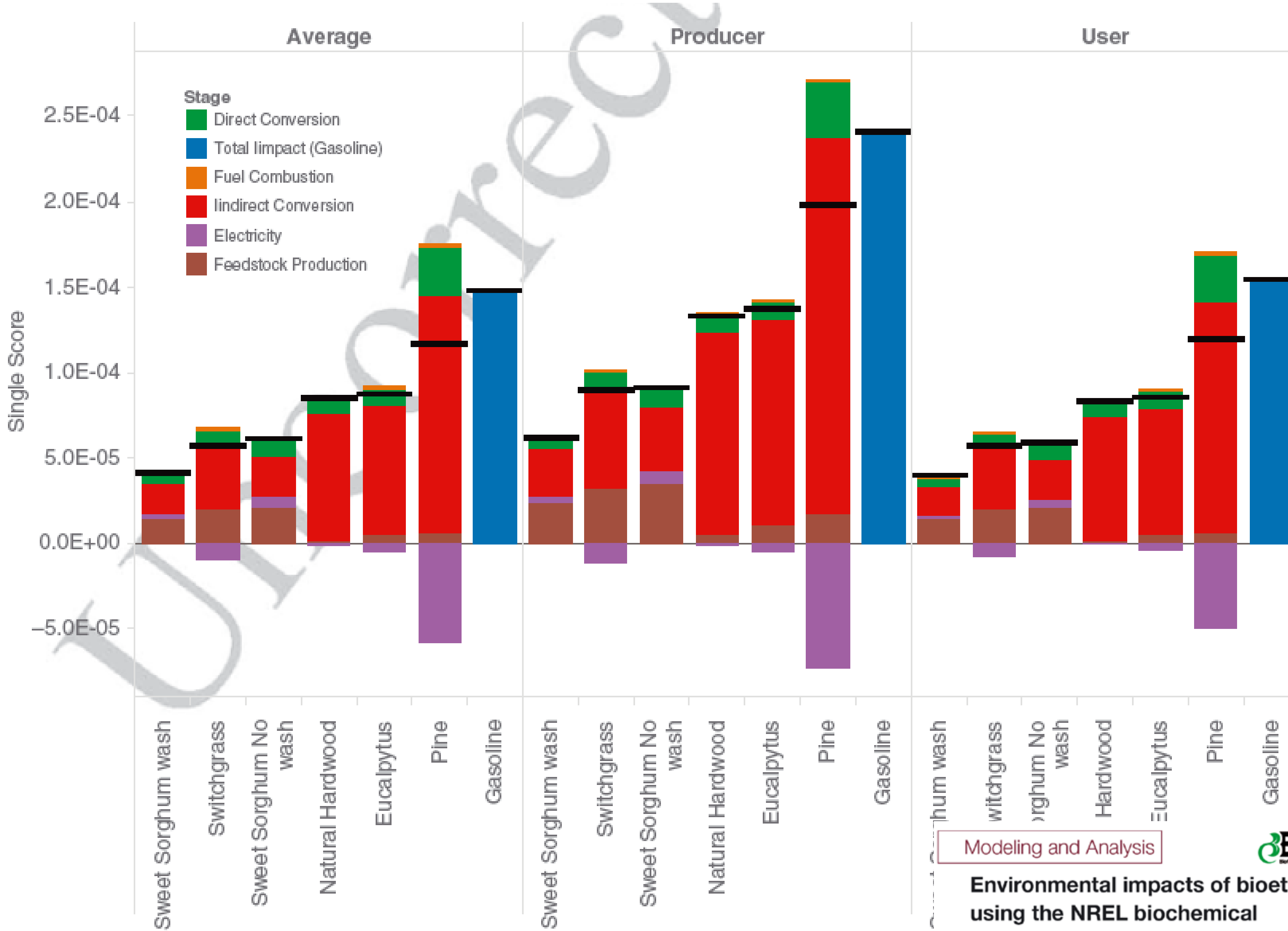


Figure 9. Cellulosic ethanol-weighted single score using average weighting,
perspectives.

Modeling and Analysis
Biofpr

Environmental impacts of bioethanol using the NREL biochemical conversion route: multivariate analysis and single score results

Jesse Daystar, Trevor Treasure, Carter Reeb, Richard Venditti, Ronalds Gonzalez, and Steve Kelley, North Carolina State University, Raleigh, NC, USA

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Biofuels, Bioprod. Bioref. 9: xxx-xxx (2015)

Example Problem: Calculating a single score

- A certain process has 0.2 CTUh of carcinogens, 0.44 CTUh non carcinogens, and 0.01 kg PM2.5 of respiratory effect impacts. Using the normalization factors below and the weighting factors of 60% for carcinogens, 30% for non carcinogens and 10% for respiratory effect, calculate a single score for the process. Use weighting scores in the form of 60 ecopoints/100 yr capita ……

TRACI 2.1 Impact category	2008 US Normalization Values*	Normalization unit
Ozone depletion	0.16	kg CFC-11 eq./ yr-capita
Global warming	24000	kg CO2 eq./yr-capita
Smog	1400	kg O3 eq./yr-capita
Acidification	91	kg SO2 eq./yr-capita
Eutrophication	22	kg N eq./yr-capita
Carcinogens	0.000051	CTUh/yr-capita
Non carcinogens	0.0011	CTUh/yr-capita
Respiratory effects	24	kg PM2.5 eq./year capita
Ecotoxicity	11000	CTUe/yr-capita
Fossil fuel depletion	17000	MJ surplus/yr-capita

Summary

- Grouping
- Global Impacts
- Regional Impacts
- Normalization
- Weighting
- Nominal Grouping
- Ordinal Grouping
- Internal Normalization
- External Normalization
- Stakeholders
- Value choices
- Aggregation to a single score
- Millipoint