RENEWABLE ENERGY TRAINING PROGRAM
MODULE 8 | BIOENERGY
Life-cycle Analysis of Woody Biomass Energy

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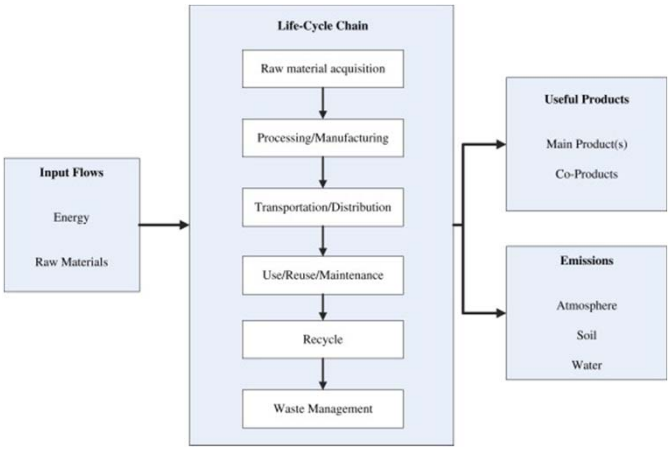
Overview

- What is LCA?
- How is it done?
- Key concepts
- Examples
  - LCAs for bioenergy
  - Charcoal in Brazil

What is LCA?



1. Goal and scope definition
2. Life cycle inventory
3. Impact assessment
4. Interpretation

LCA methodologies

1. Goal and scope definition:
   defines the system boundary and functional unit and level of detail required for input data.

An example from my research:

- **Goal:** compare environmental impacts of producing charcoal using hot-tail kilns, as is current practice, and using container kilns with pyrolysis gases utilized for cogeneration

What happens when you add cogeneration to a traditional charcoal production system?

- **Boundary:** nursery to plantation-gate (prior land use not included)
- **Functional Unit:** 1 ton of carbon in charcoal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Energy for Sustainable Development

Innovation in charcoal production: A comparative life-cycle assessment of two kiln technologies in Brazil

LCA methodologies

2. Life cycle inventory

Cataloging material flows along all stages of production:

- All input/output (I/O) data to define the system
- Sources of data include:
  - direct observation
  - life cycle inventory (LCI) databases
  - previous/similar analyses


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Energy for Sustainable Development

Innovation in charcoal production: A comparative life-cycle assessment of two kiln technologies in Brazil

Rob Bailis, Charissa Rajanayeeh, Puneet Dwivedi, Adriana de Oliveira Vilela, Howard Chang, Rogério Carneiro de Miranda

ABSTRACT

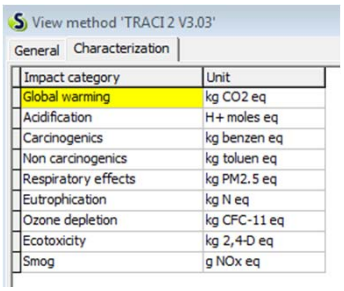
Life cycle materials and processes	Units [a]	Per hectare		Per Functional Unit (FU)	
Nursery stage					
Water	liters	10667	10667	75.6	57.4
Electricity	kWh	5.24	5.24	0.037	0.028
KCl	kg-K_2O	2.6	2.6	0.019	0.014
Mono-ammonium phosphate (as N)	kg-N	0.004	0.004	3.0E-05	2.3E-05
Mono-ammonium phosphate (as P_2O_5)	kg-P_2O_5	0.021	0.021	1.5E-04	1.1E-04
$CaNO_3$	kg-N	0.61	0.61	4.3E-03	3.3E-03
Blend of NPK fertilizers (as N) [b]	kg-N	0.062	0.062	4.4E-04	3.4E-04
" (as P_2O_5)	kg-P_2O_5	0.31	0.31	2.2E-03	1.7E-03
" (as K_2O)	kg-K_2O	0.062	0.062	4.4E-04	3.4E-04
$(NH_4)_2SO_4$	kg-N	0.13	0.13	9.2E-04	7.0E-04
$MgSO_4$	kg	4.2	4.2	0.030	0.022
Sowing and management stage					
Water for irrigation	liters	15,000	15,000	106	81
Water transpired by trees	liters	262,800,000	262,800,000	1.9E6	1.4E6
Fuel (diesel)	liters	348	348	2.5	1.9
Glyphosate (applied for new seedlings)	liters	10	10	0.07	0.05
Blend of NPK fertilizers (as N) [c]	kg-N	0.19	0.19	0.001	0.001
" (as P_2O_5)	kg-P_2O_5	0.39	0.39	0.003	0.002
" (as K_2O)	kg-K_2O	0.17	0.17	0.001	0.001
50% KCl (plus micronutrients)	kg-K_2O	310	310	2.2	1.7
Tractor	p	0.00057	0.00057	0.0000041	0.0000031
Harvesting and transport of feedstock					
Fuel (diesel)	liters	1695	1695	12.0	9.1
Feller/buncher	p	3.3E-04	3.3E-04	2.3E-06	1.8E-06
Skidder	p	3.3E-04	3.3E-04	2.3E-06	1.8E-06
Cutter/delimber	p	3.3E-04	3.3E-04	2.3E-06	1.8E-06
Loader	p	3.3E-04	3.3E-04	2.3E-06	1.8E-06
Kiln infrastructure					
Bricks	tons	0.67	--	0.0047	--
Mortar	tons	2.14	--	0.015	--
Steel	tons	--	0.17	--	0.001
Pyrolysis and cogeneration inputs					
Fuel (diesel)	liters	1846	1420	13.1	7.6
Lorry - 16t	p	0.0060	0.0060	0.000042	0.000032
Water (for cooling in cogen units)[d]	m^3	NA	NA	0	0/1.6/3.7/6.7
Electricity demand [c]	kWh	NA	NA	0	52/52/64/97
Pyrolysis and cogeneration outputs					
Charcoal output	tons	192	240	1.4	1.3
Charcoal-carbon output	tons	142	187	1.0	1.0
Electricity to grid [c]	kWh	NA	NA	0	0/274/613/1122
Tar [c]	kg			0	0/220/0/0

LCA methodologies

3. Impact assessment:

   Converts raw input/output data into meaningful measurements

   - May be assessed as raw data, intermediate, or final impact
   - Example: climate impacts
     - Raw data: tons of CO_2, CH_4, and N_2O
     - Intermediate impact: aggregate global warming pot'l (GWP)
     - Final impact: temperature increase or physical/economic damages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General | Characterization

Impact category	Unit
Global warming	kg CO2 eq
Acidification	H+ moles eq
Carcinogenics	kg benzen eq
Non carcinogenics	kg toluen eq
Respiratory effects	kg PM2.5 eq
Eutrophication	kg N eq
Ozone depletion	kg CFC-11 eq
Ecotoxicity	kg 2,4-D eq
Smog	g NOx eq

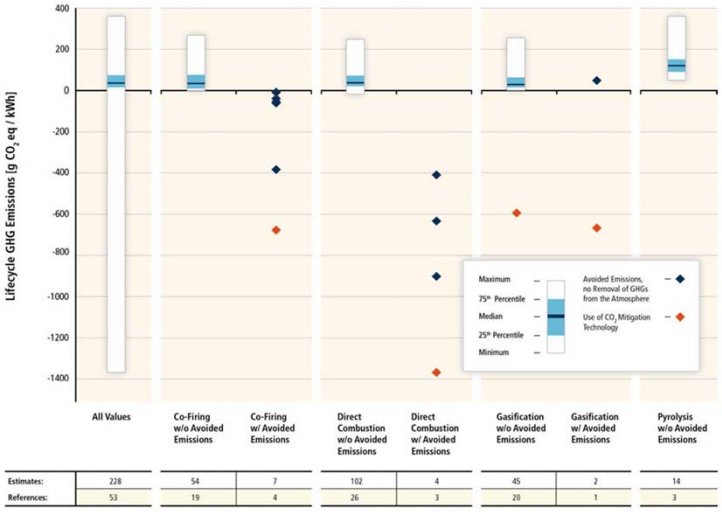
LCA methodologies

4. Interpretation: an assessment of the outcomes of the inventory analysis and impact assessment, including sensitivities.

LCA methodologies

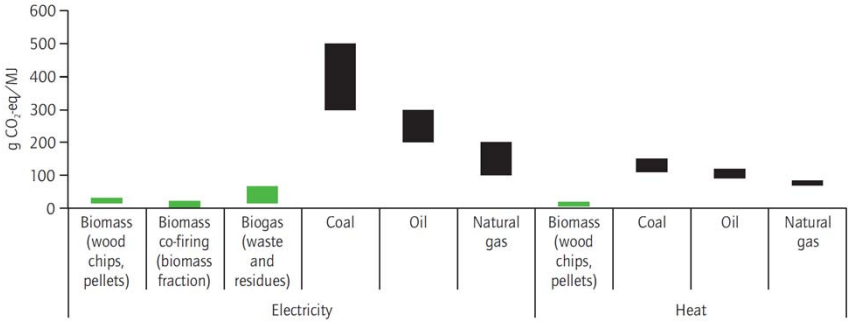
- Additional considerations:
  - Treatment of co-products
    - Most bioenergy systems multiple products
    - How do we allocate impacts?
  - Temporality (past, current and future impacts)
    - Attributional and Consequential LCA
  - Land Use Change (LUC)

Bioenergy LCAs– strong focus on GHGs



Life-cycle GHG emissions of biopower technologies per unit of electricity generation, including supply chain emissions (land use-related net changes in carbon stocks and land management impacts are excluded). Co-firing is shown for the biomass portion only (without GHG emissions and electricity output associated with coal). From IPCC SSREN.

…in comparison to fossil options



Note: Based on current state of technologies. Ranges reflect variations in performance as reported in literature. Possible emissions from land-use change are not included here.

Source: Based on Cherubini *et al.*, 2009; IPCC, 2011.

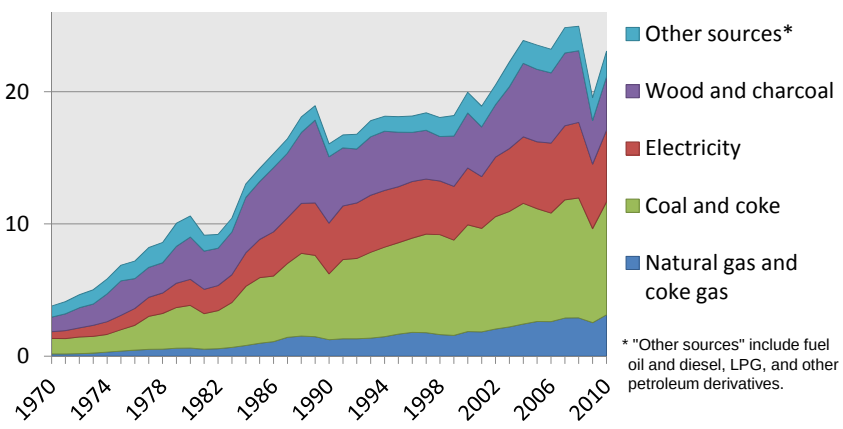
Example – Innovation in Brazilian Charcoal Production

- Brazil is the world's largest charcoal user
- > 80% used by the metallurgical industries
  - source of carbon and energy

"Rabo Quente" kilns - 70% of production

Brazilian Charcoal Production

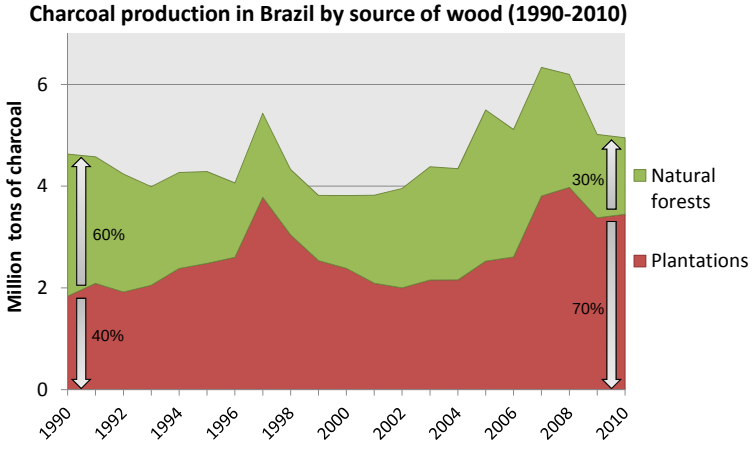
Energy sources utilized in Brazil's metallurgical industries from 1970 to 2010



* "Other sources" include fuel oil and diesel, LPG, and other petroleum derivatives.

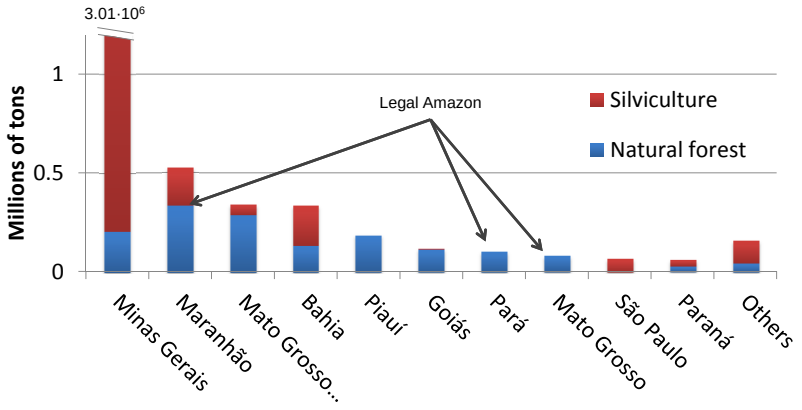
The majority of feedstock originates from plantations, but…

Charcoal production in Brazil by source of wood (1990-2010)



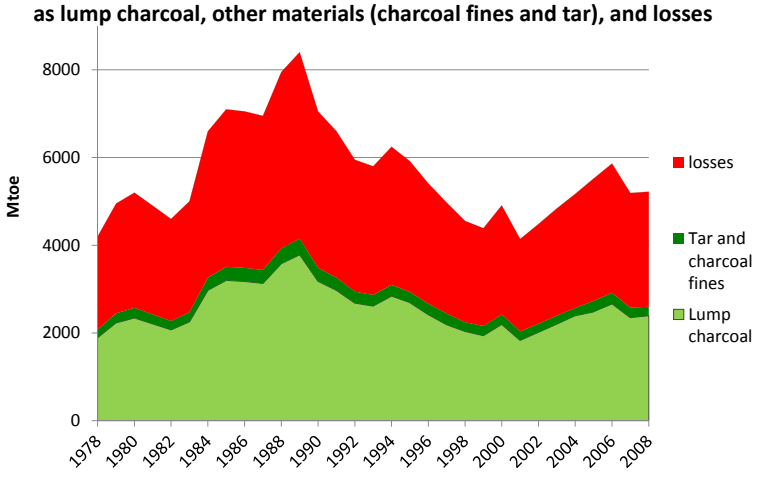
Source: IBGE, 2012

Charcoal production by state in 2010 (IBGE, 2012)



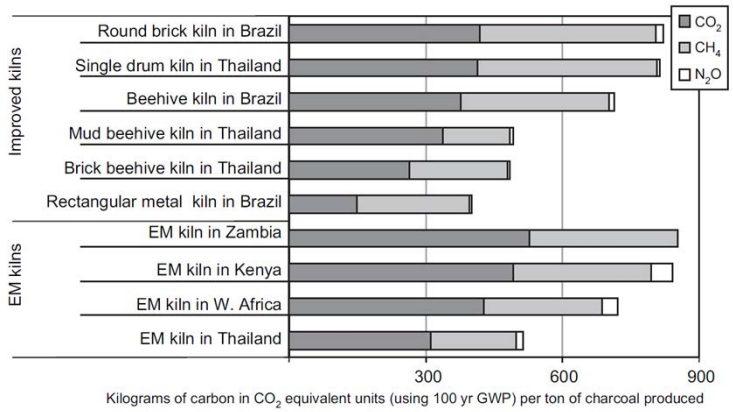
There are also large energy losses…

Energy flows in charcoal production in Minas Gerais, Brazil (1978 to 2008) as lump charcoal, other materials (charcoal fines and tar), and losses



Miranda et al. 2012

…and emissions



Emissions measured in traditional earthmound (EM) kilns and a variety of improved kilns reported in the literature showing emissions of each GHG weighted by its 100-year global warming potential (Bailis 2009)

Alternative technologies

DK biochar reactor with Stirling Engine

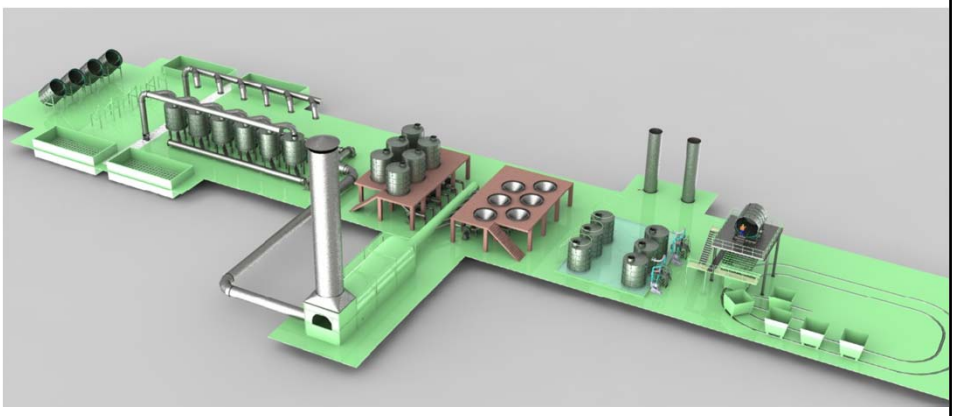
DPC charcoal reactor flaring non-condensable gases

CML charcoal plant

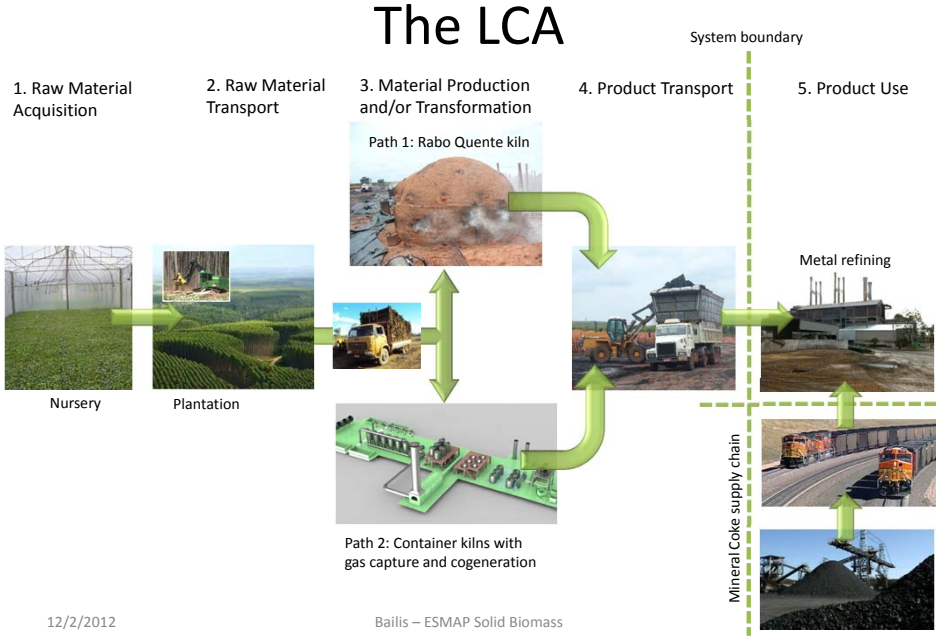
RIMA pilot plant with container kilns

Rima's concept (Vilela, 2010)

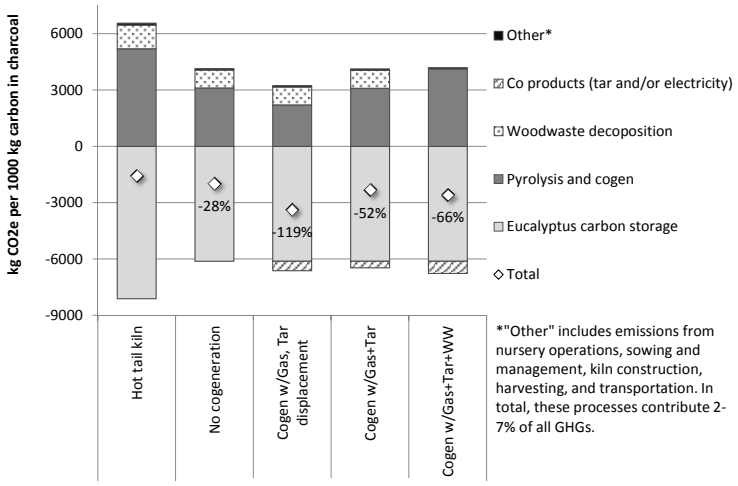
Rima's concept (Vilela, 2010)



The LCA

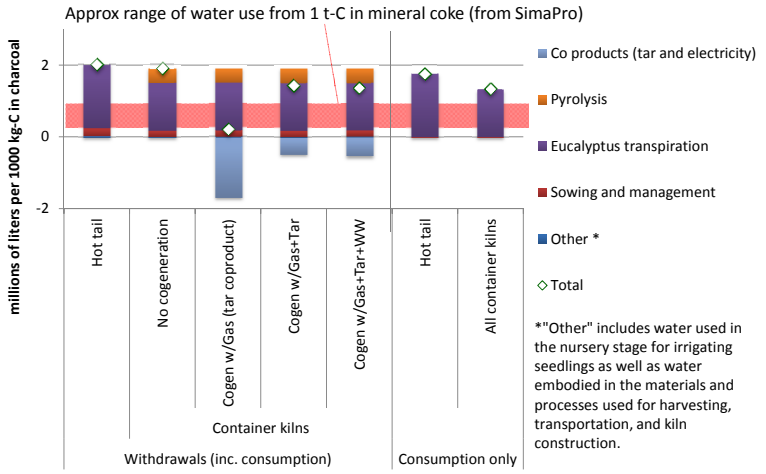


Results - GHGs

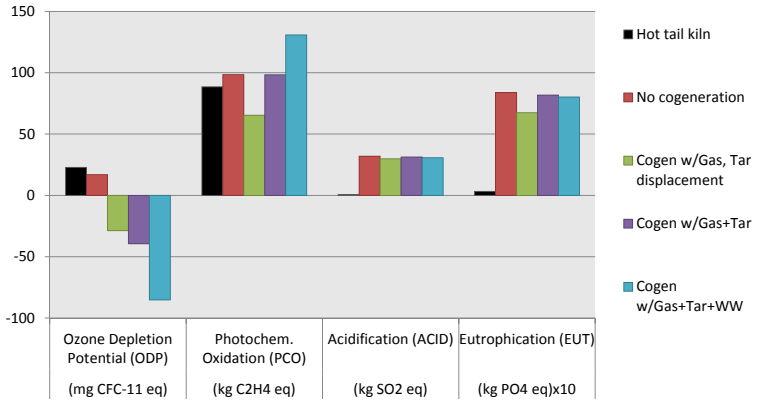


*"Other" includes emissions from nursery operations, sowing and management, kiln construction, harvesting, and transportation. In total, these processes contribute 2-7% of all GHGs.

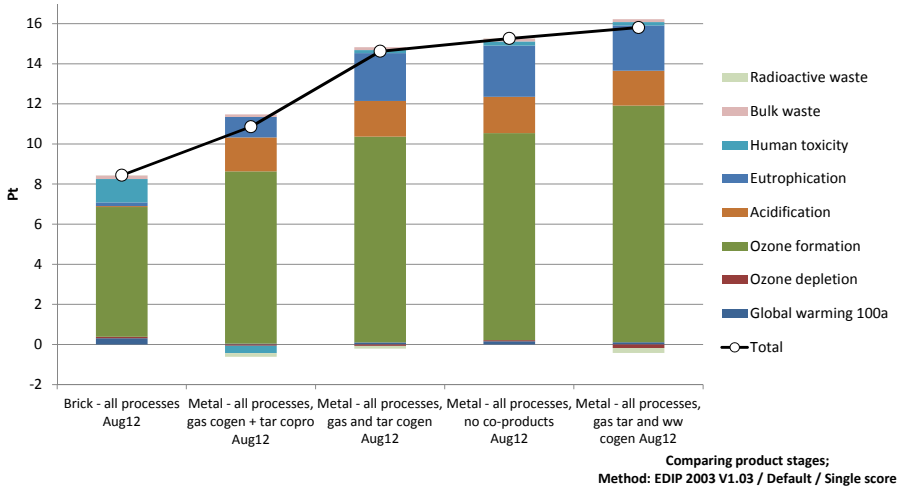
Results – water use



Results – other impacts



Aggregating results???



Concluding thoughts

- LCA is a powerful tool to compare technological options
  - But proceed with caution!
- More than just GHGs
  - When we introduce multiple impacts, comparing and/or aggregating is risky
  - Only meaningful if local context is taken into consideration