Life Cycle Assessment of Biodiesel compared to other biomass use

Olivier Jolliet, Jinglan Hong, Josef Kaenzig, Gregory Houillon and Shanna Shaked

iMod - Impact and Risk Modeling
School of Public Health, EHS
University of Michigan
ojolliet@umich.edu

1. Objectives

- **1. Compare the substitution potential of different uses of biomass → method**
- **2. Determine the Life Cycle Impacts of biodiesel and compare it with those of conventional diesel**
- **3. Test the robustness of the comparison using both Monte Carlo uncertainty techniques and Taylor series expansion with lognormal distribution**

1. A consistent approach to compare different uses of biomass:

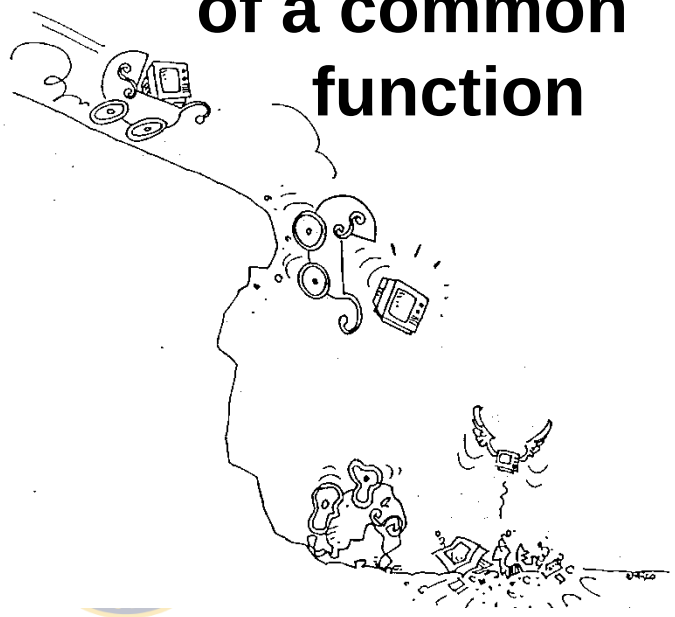
- **Compare the environmental impact of bio-based products per:**
  - **Kg of product**
  - **Functional Unit (FU)**
  - **Area basis**
- **Review of LCA studies on bio-based products**
- **Investigate and identify main features of each field of application**

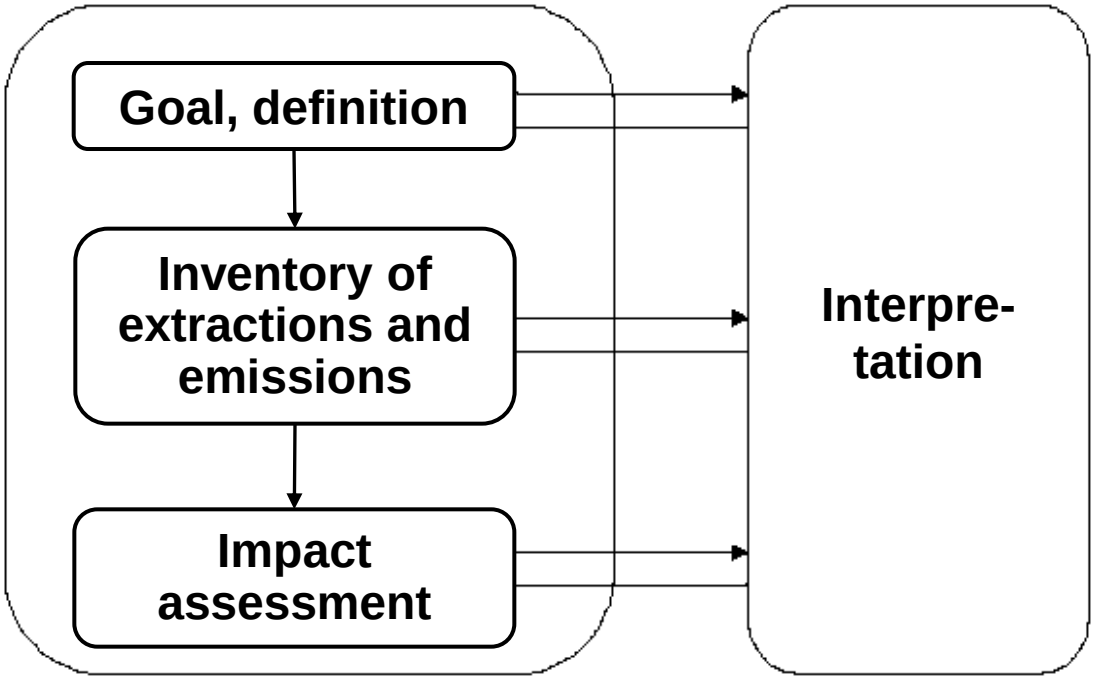
Life Cycle Assessment (LCA)

- **Quantitative method for comparing product or service systems in terms of their total system-wide environmental consequence**

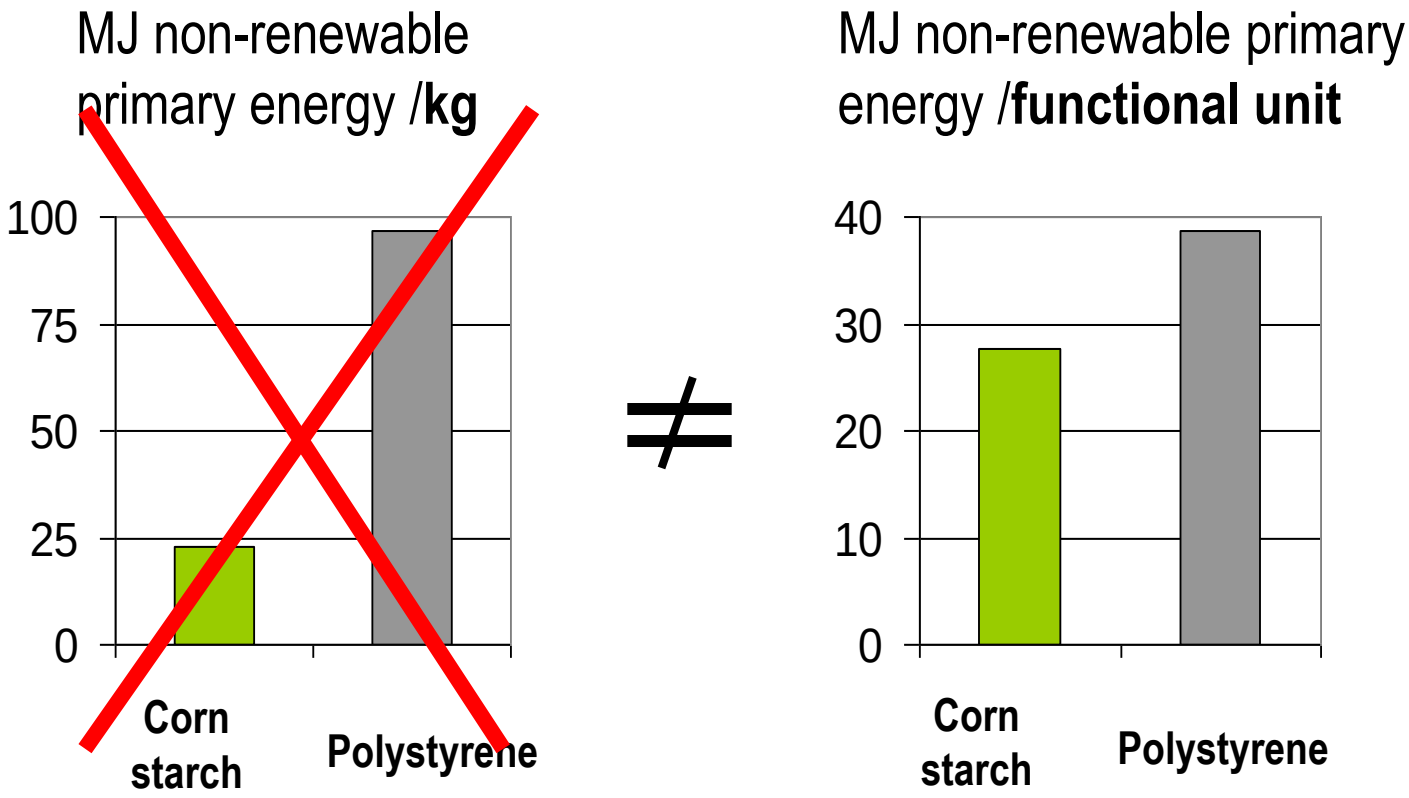
- from cradle to grave …

- on the basis of a common function





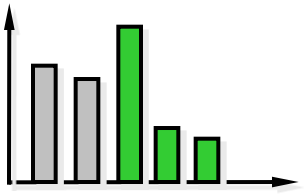
Comparison of the environmental impact per kg and per functional unit (ex. Loose-fills)



Density of loose-fills based on starch : 12 **kg/m³**

Density of loose-fills based on polystyrene: 4 **kg/m³**

Methods for the comparison of the environmental impacts of bio-based products

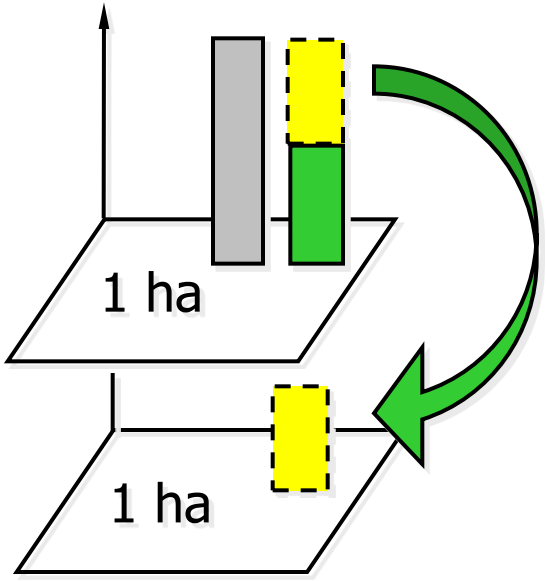


- **Kg of product** **Similar materials**
- **Functional unit** **Similar applications**

- Area (hectare) All applications

$$\frac{\text{Convention al} - \text{Biobased}}{\text{Convention al(substi tuted)}^{1)}} \quad in\ [\%]$$

$$\frac{\text{Convention al} - \text{Biobased}}{\text{area}} \quad in\ [\frac{physical\ \ units}{hectare - year}]$$

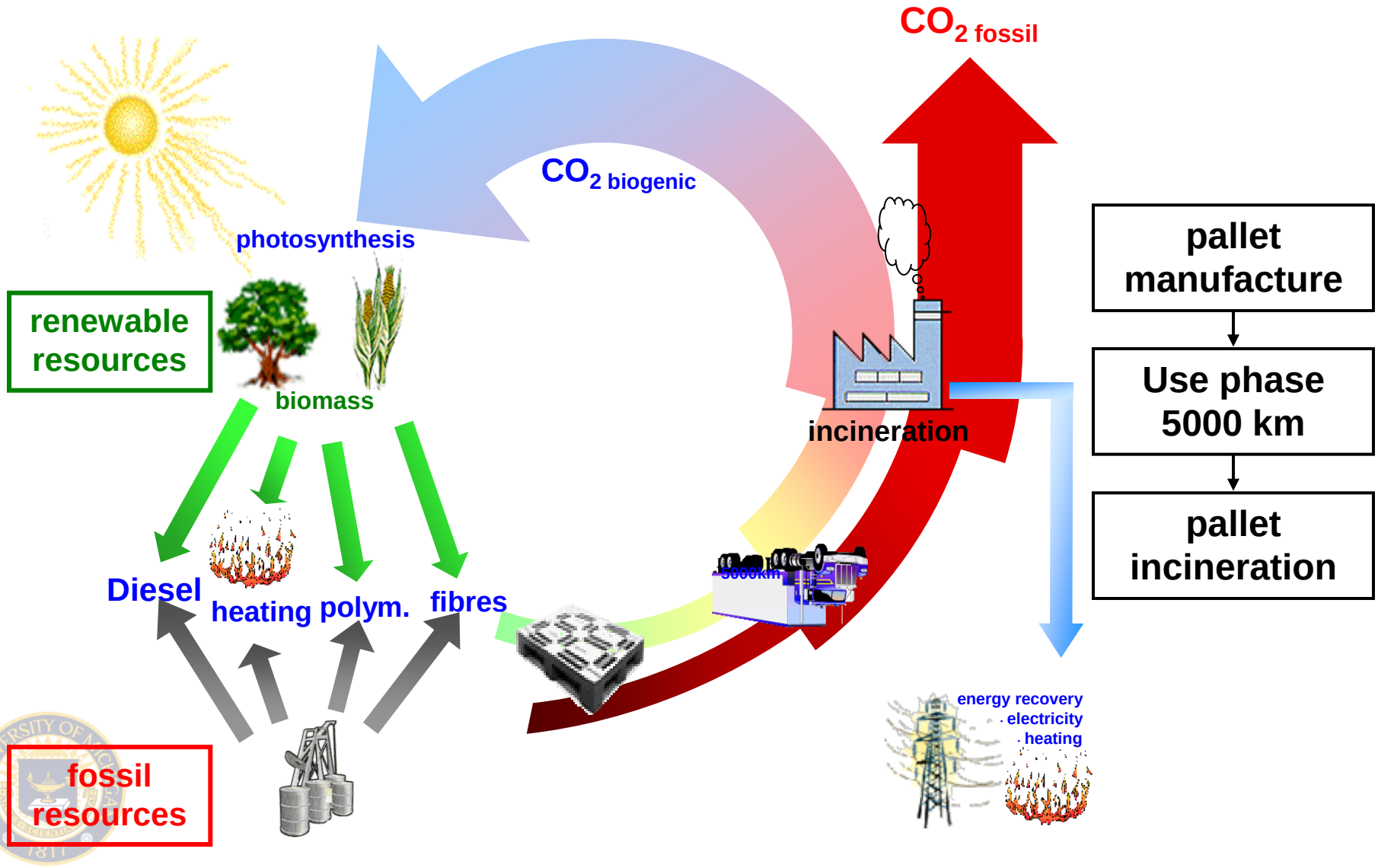


Approach for the comparison

Loose-fill packaging	Based on corn starch	Based on polystyrene
Functional unit	100 m^3	
Non-renewable primary energy consumption (GJ/FU)	28	39
Agricultural area needed (ha-yr/FU)	0.18	-
Non-renewable primary energy consumption (GJ/ha-yr)	155	216

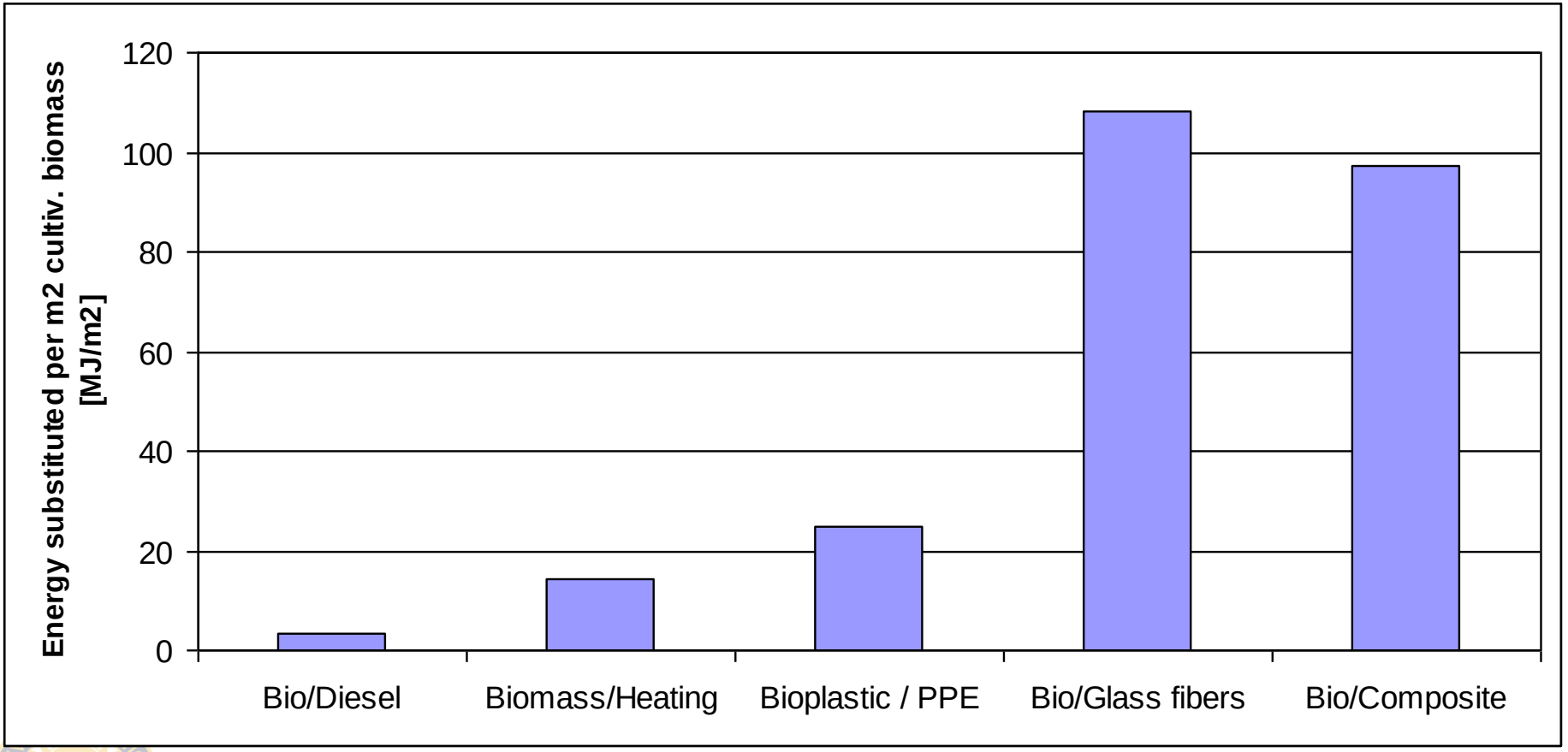
Benefit of 216 - 155 = 51 GJ /hectare-year

Example: Comparing different use of biomass along the life cycle of a transport pallet



Limited by land use

MJ saved per m2 cultivated



Comparison of different biomass uses

Bio-based products	LCA refe-rences collected	LCA studies collected	LCA studies analysed
Surfactants	26	13	6
Lubricants and hydraulic fluids	27	11	4
Solvents	9	6	3
Intermediate Products	11	7	2
Fibers	36	17	5
Timber for construction	132	82	7
Biopolymers	40	27	9
Forestry biomass	114	75	8
Agricultural biomass	75	54	4
Oils/Esters (biofuels)	201	125	8
Alcohols/Ethers (biofuels)	213	145	9

Bibliographic Research (published LCA)

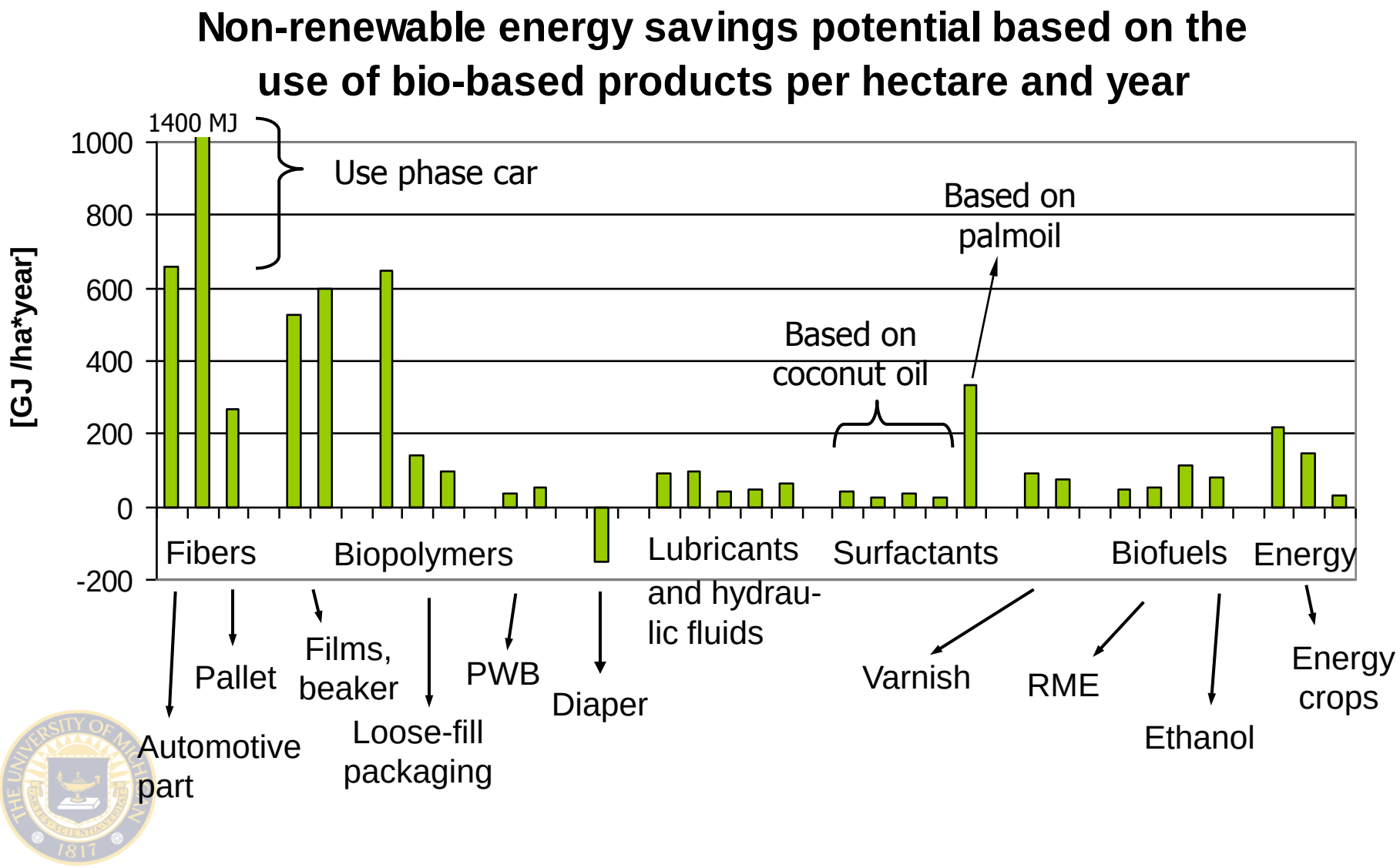
Few LCA studies exist on chemical bio-products

Some on Biomaterials

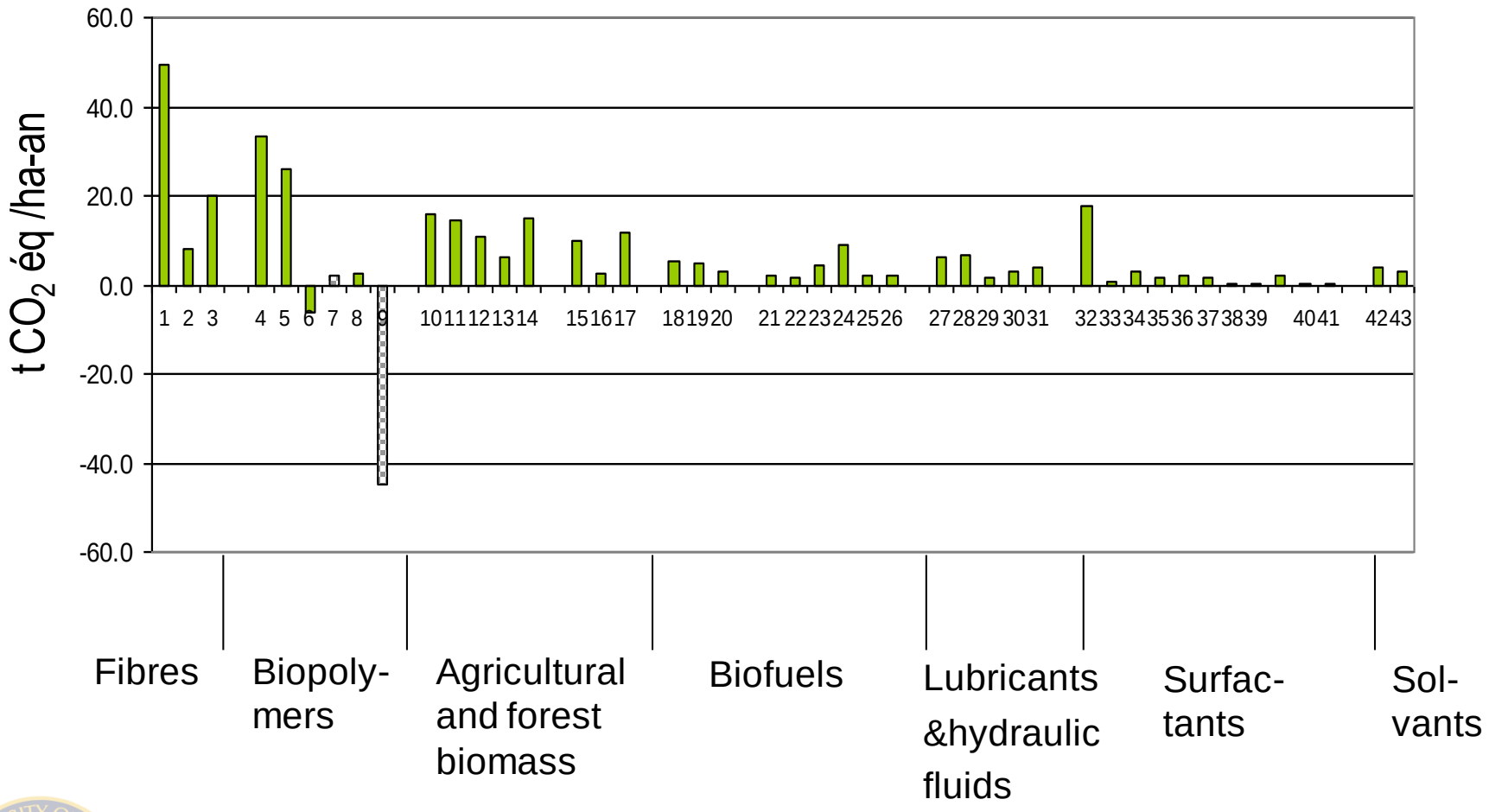
Many on biofuels and energy crops

ISO

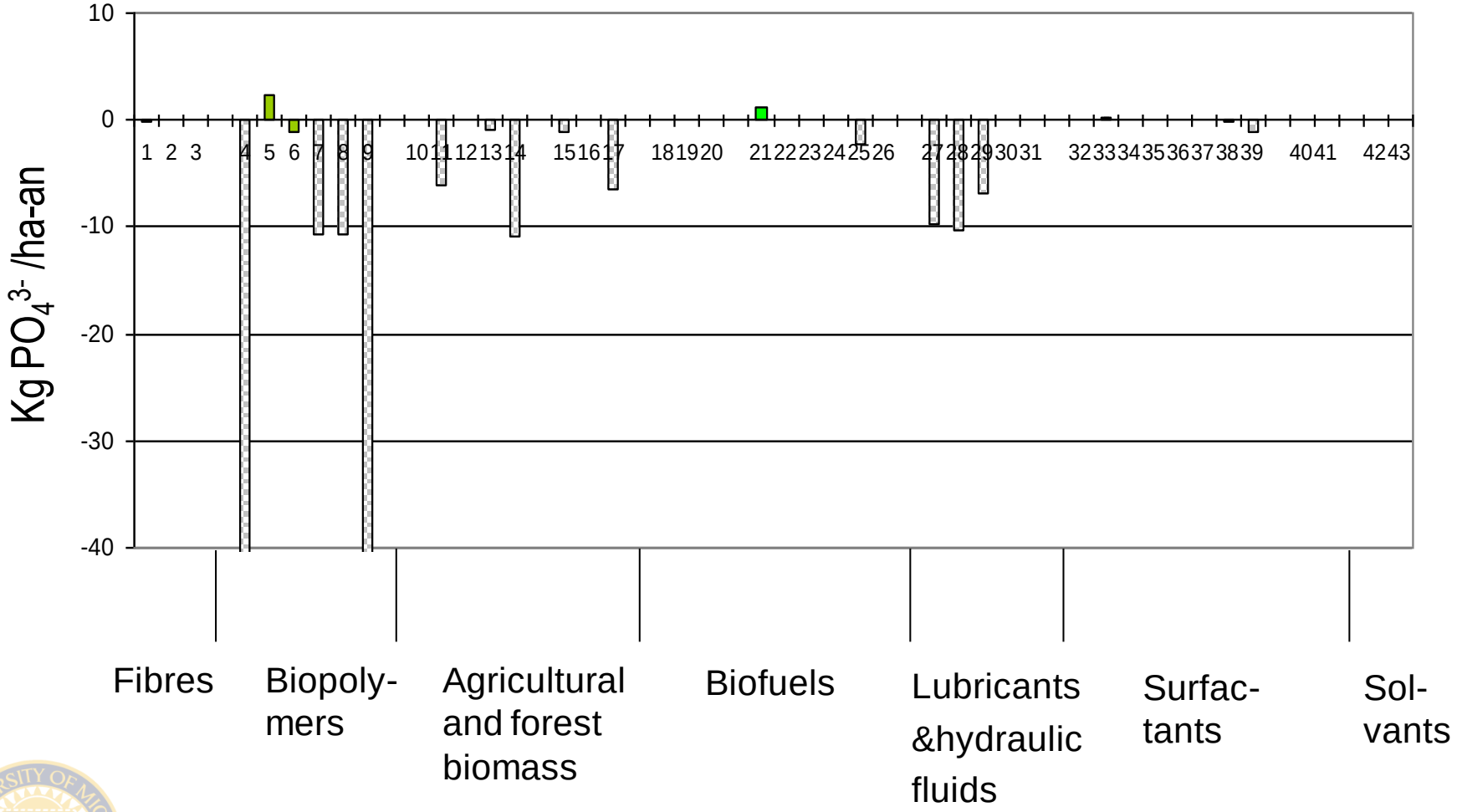
Comparison of bio-based products (/ha) Non renewable energy



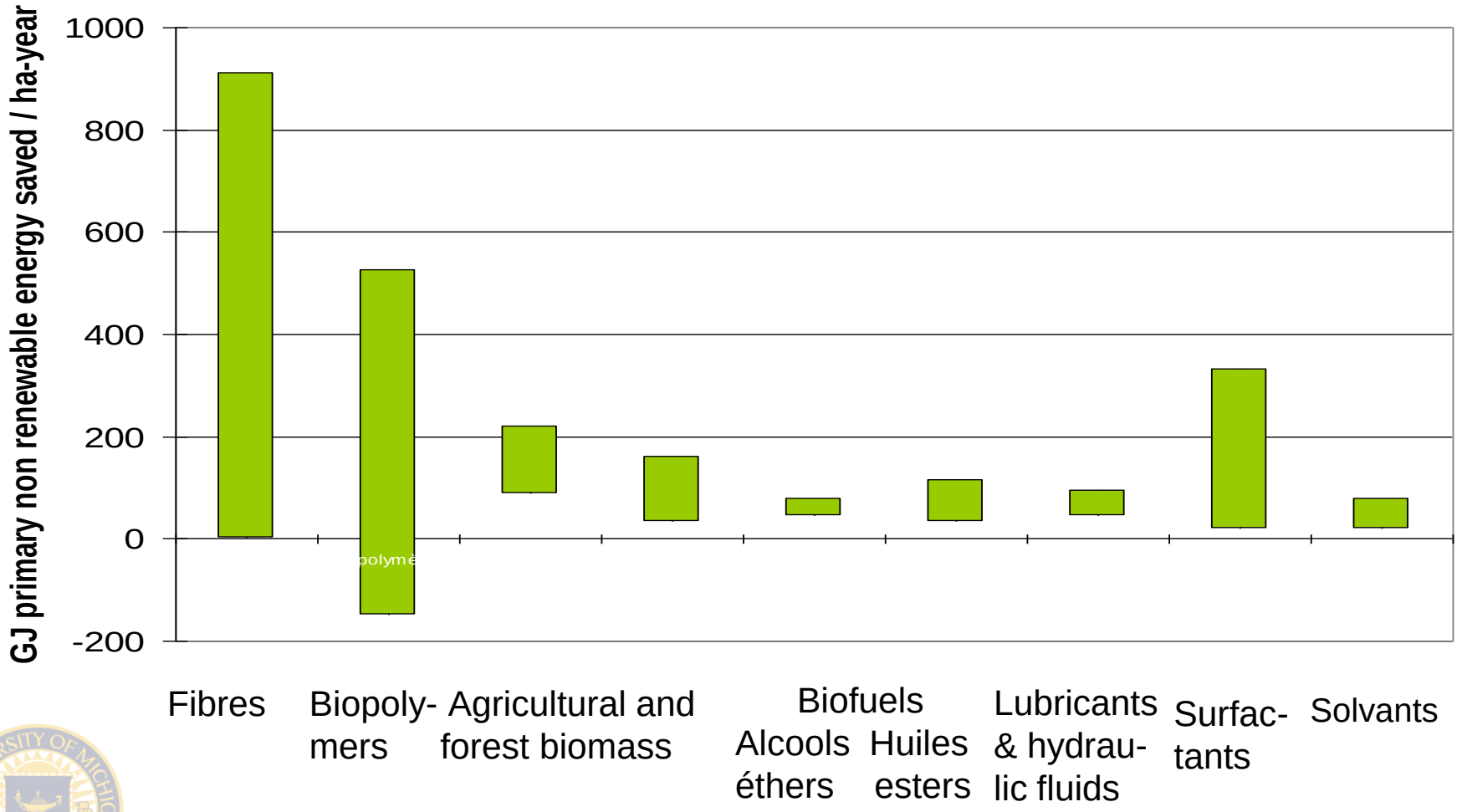
Comparison of bio-based products /ha : Global warming potential changes / hectare - year



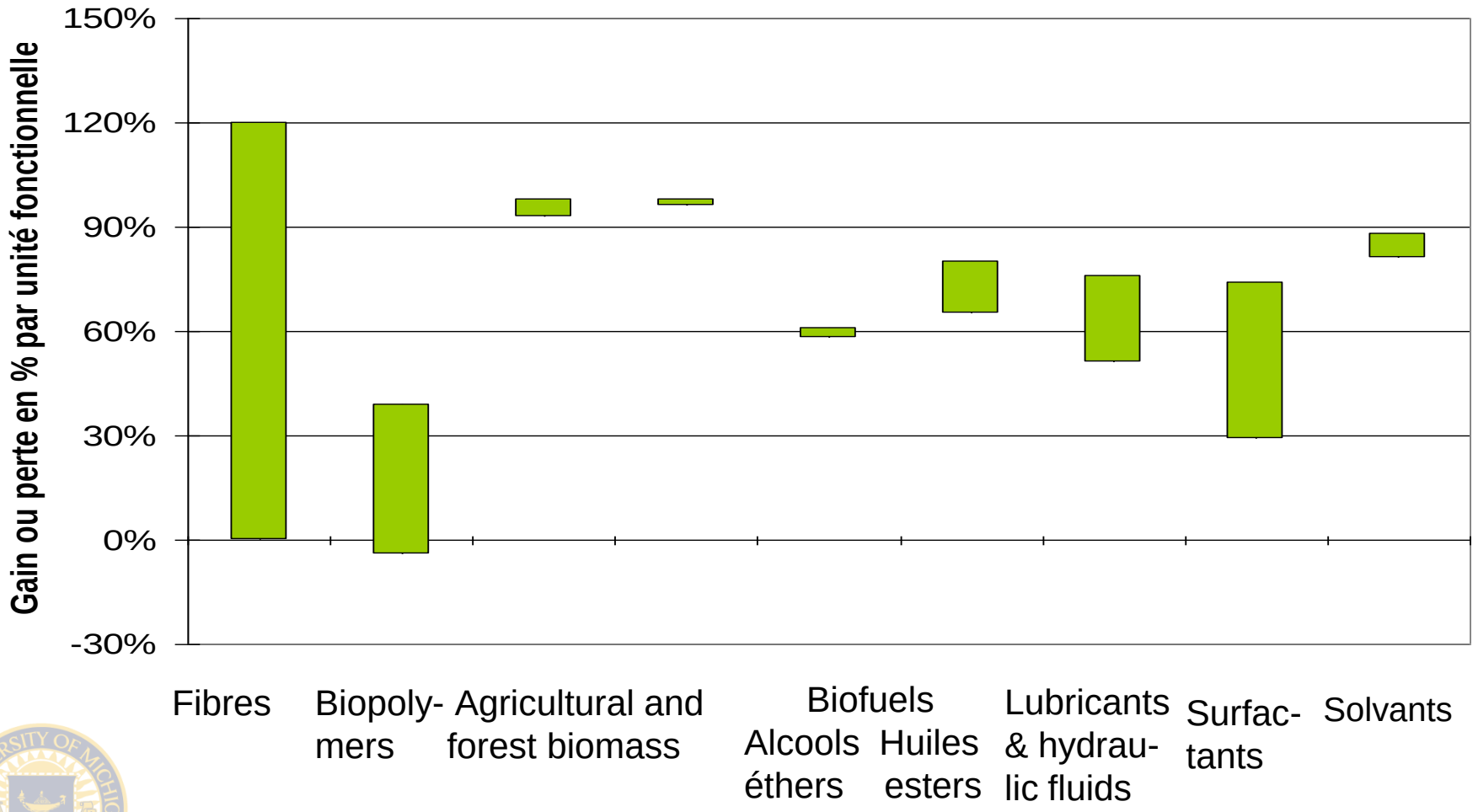
Comparison of bio-based products /ha : Eutrophication changes / hectare - year



Comparison of different products :non-renewable primary energy savings potential / ha - yr



Comparison of different products :non-renewable primary energy savings potential / ha – yr [%]



2. Case study comparison diesel vs biodiesel

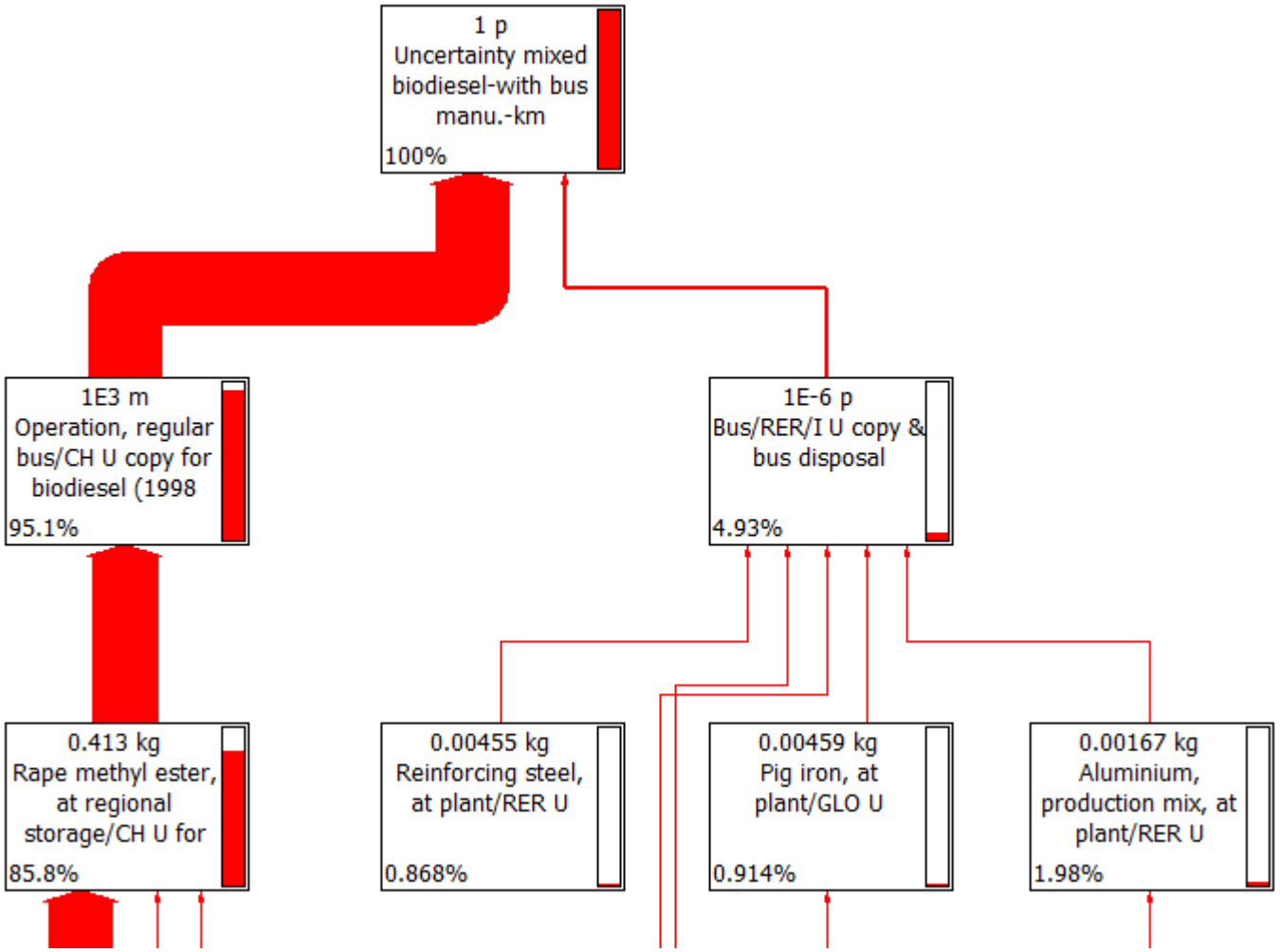
- **Functional unit: 1 km driven by a regular bus=1 bus-km**
- **Scenarios:**
  - **Scenario 1: Diesel ;**
  - **Scenario 2: Biodiesel ;**

Data sources: Ecoinvent 2.0 (Spielmann M. et al ecoinvent report V2.0 No.14; p. 28-30); NREL report (1998, p. 171-186)

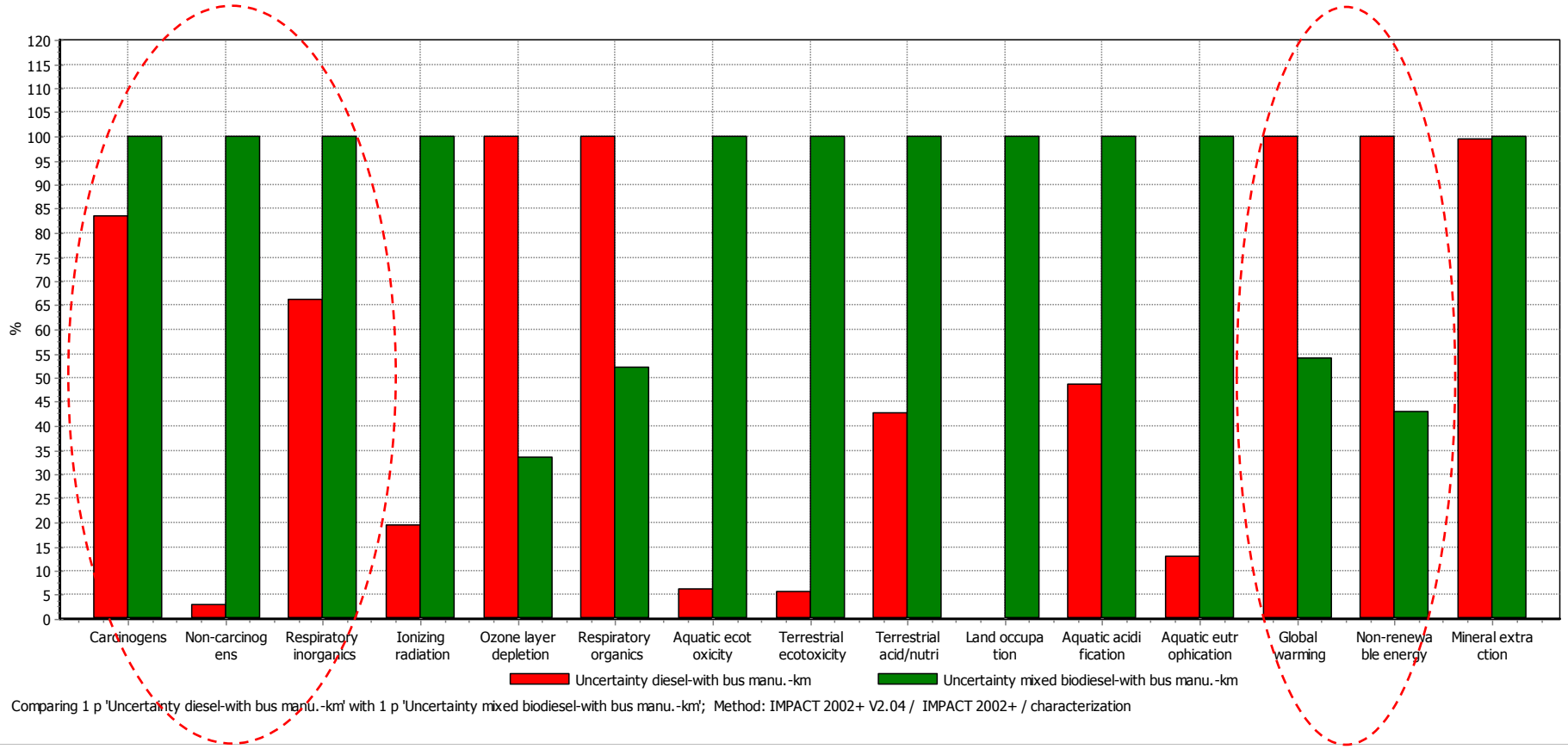
- **The results at midpoint and damage level were calculated using the IMPACT 2002+ method: Climate change & Midpoint of Respiratory inorganics are studied**

- **Software: Simapro 7.1**

Climate change : Process tree



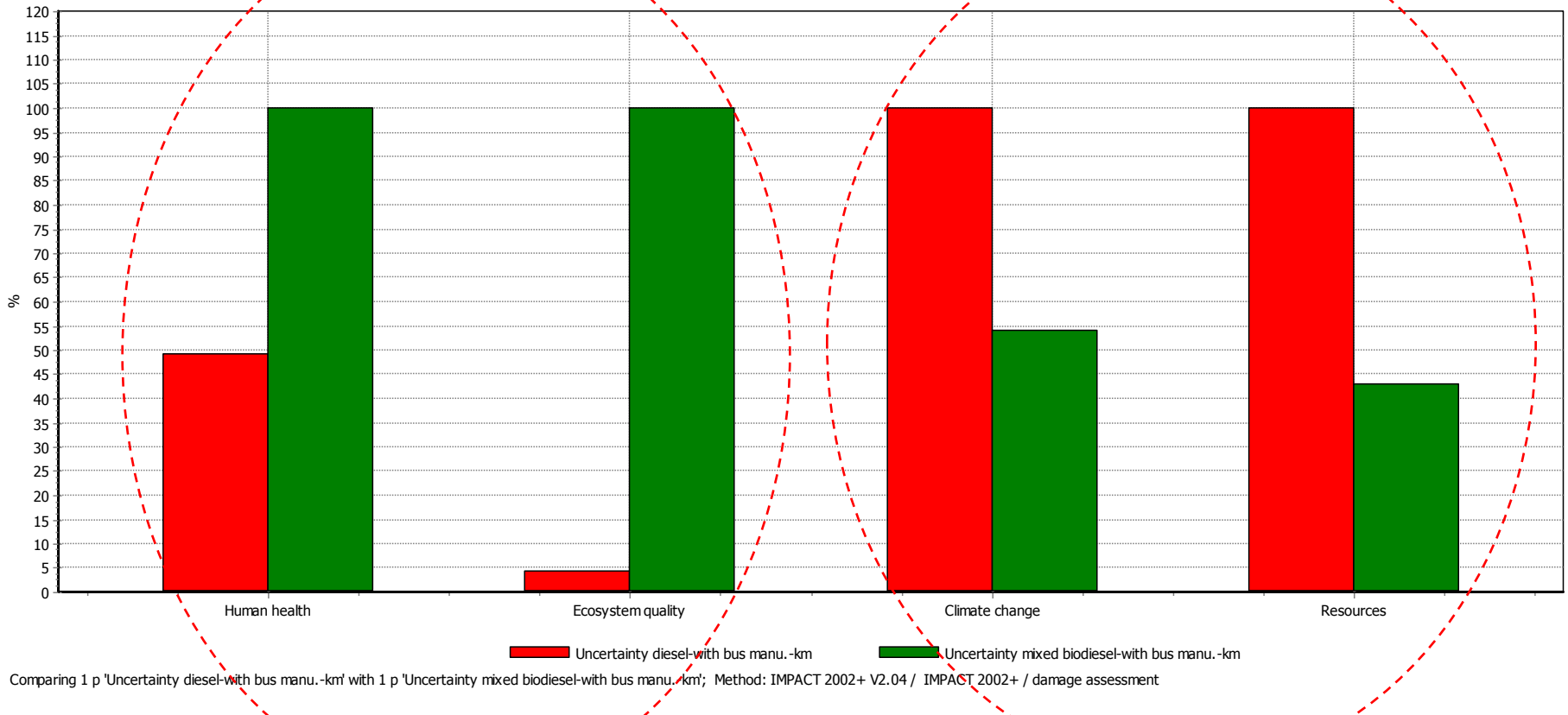
Diesel versus biodiesel (Impact 2002 midpoint)



Carcinogens **Resp.inorganics**
Non carc.

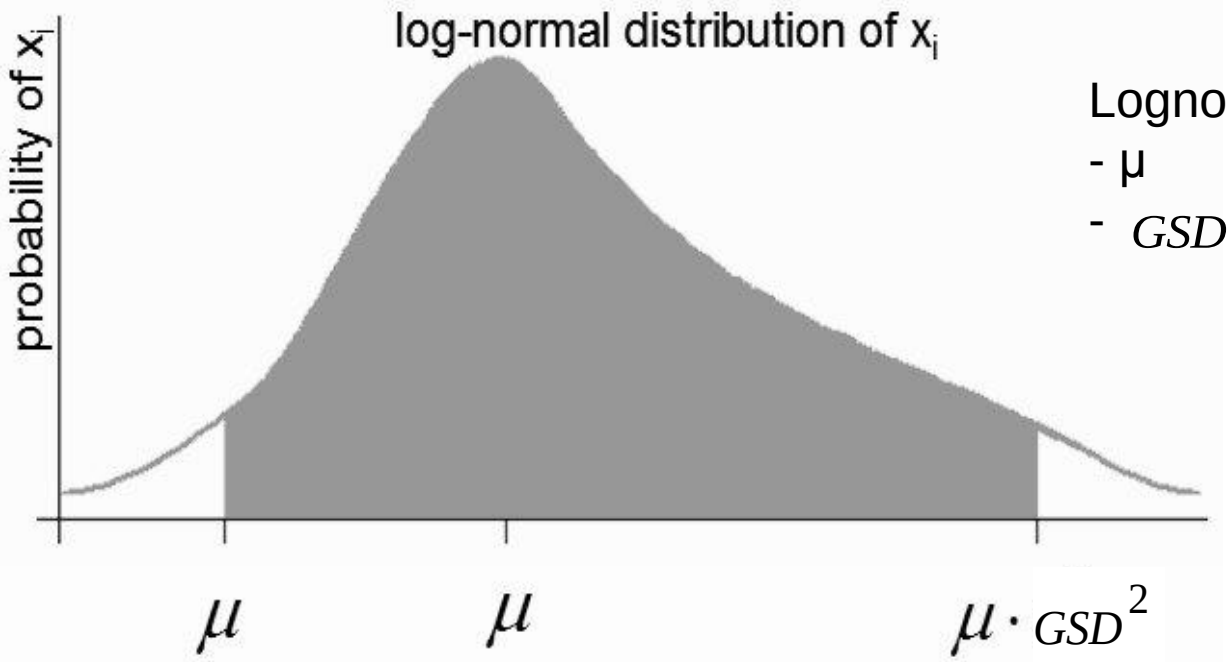
Global warming
Non ren. energy

Diesel versus biodiesel
(Impact 2002 normalized damage)



Human health **Ecosystem quality** **Climate change** **Resources**

Log-normal distributions



Lognormal:
- μ median
- GSD^2 Geometric squared standard deviation

or coefficient of variation:

$$probability\left\{\frac{\mu}{GSD^2} < X > GSD^2 \cdot \mu\right\} = 0.95$$

if $GSD^2 = 2$, *95% confidence interval*
twice lower to twice higher than the median

3. Monte carlo + Taylor series expansion method

$$GSD_O^2 = exp[\, S_{I_1}^2 (\ln GSD_{I_1}^2)^2 + S_{I_2}^2 (\ln GSD_{I_2}^2)^2 + \ldots S_{I_n}^2 (\ln GSD_{I_n}^2)^2 \,]^{1/2}$$

Geometric standard deviation on input

Sensitivity to input parameter i

Geometric standard deviation on output

$$S_i = \frac{\%\ \Delta Output_i}{\%\ \Delta Input_i} = \frac{\Delta O / O}{\Delta I / I}$$

Comparison :

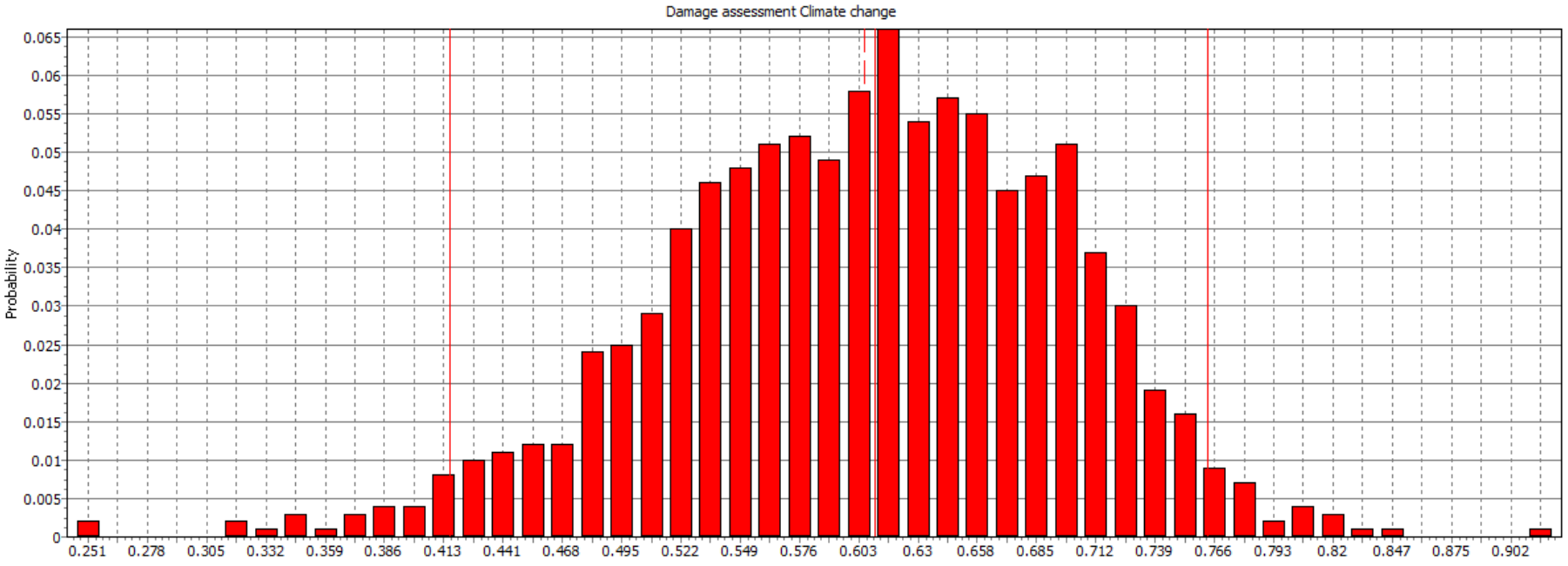
Much simpler while giving similar results to Monte-carlo

Explicit contribution of each parameter

Could depend on distribution (presently lognormal)

(MacLeod et al., 2002 , More general form by Heijungs et al., 1995)

4. 2 Uncertainty Result - Scenario Comparison
a) Climate change: biodiesel - diesel



$\mu_{diesel-biodisel} = 0.60\ kg_{CO2}/km$

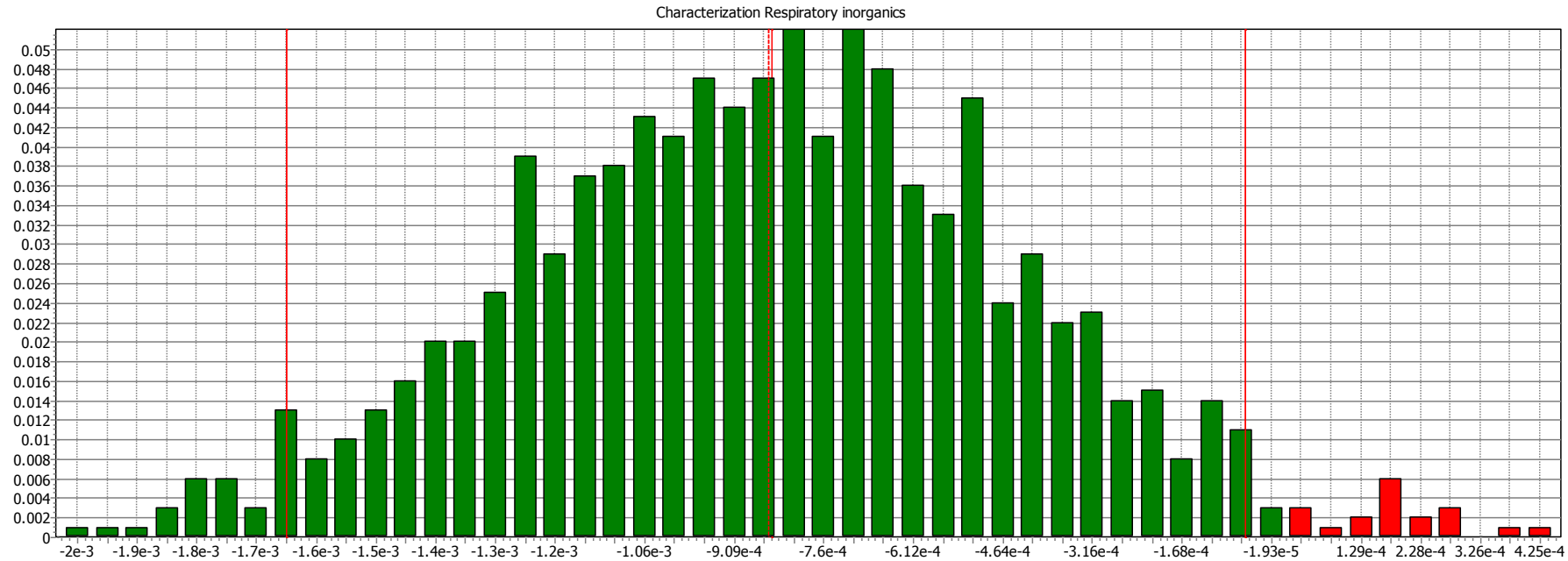
0.40 ⟷ 0.77

Monte Carlo: Probability biodiesel –diesel≥0 < 0.01%

Monte Carlo: Probability diesel-biodiesel ≥0 < 0.01%

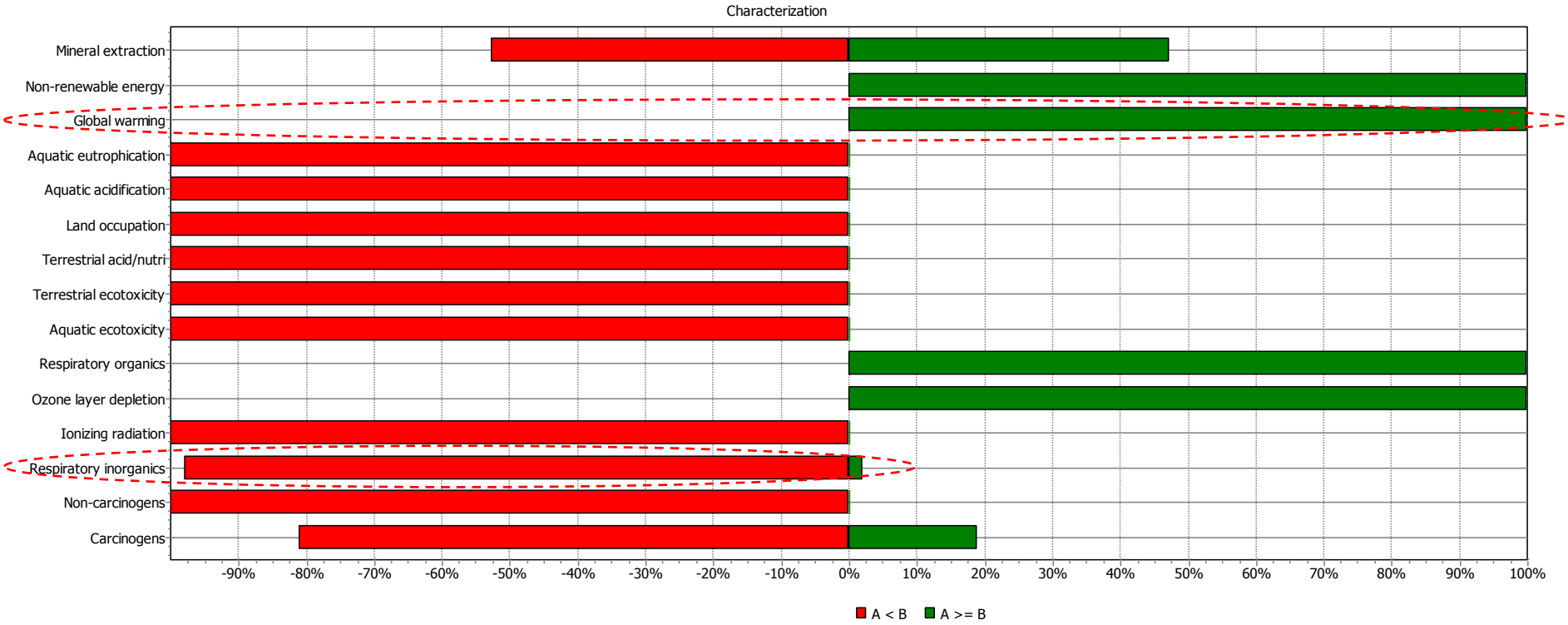
Taylor series If common dependent biodiesel/diesel ≥ 1 = 0.004%

Respiratory inorganic: diesel-biodiesel



Uncertainty analysis of 1 p 'Uncertainty diesel-with bus manu.-km' (A) minus
1 p 'Uncertainty mixed biodiesel-with bus manu.-km' (B),
method: IMPACT 2002+ V2.04 / IMPACT 2002+ , confidence interval: 95 %

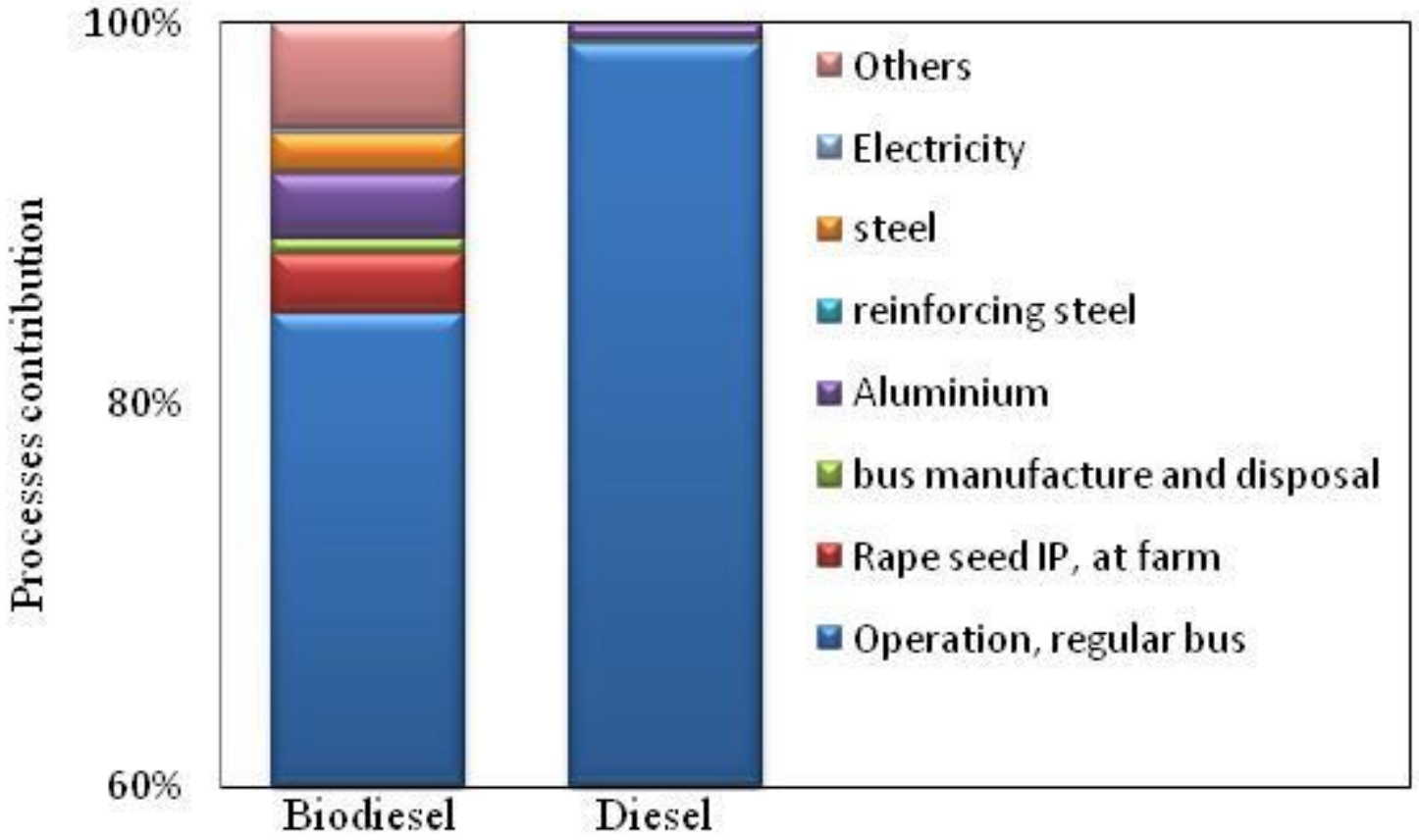
Midpoint categories: diesel-biodiesel



Uncertainty analysis of 1 p 'Uncertainty diesel-with bus manu.-km' (A) minus
1 p 'Uncertainty mixed biodiesel-with bus manu.-kmGSD^2' (B),
method: IMPACT 2002+ V2.04 / IMPACT 2002+ , confidence interval: 95 %

Probability (diesel – biodiesel) ≥ 0
Monte-Carlo = 1.9%
Taylor Expansion = 1.7%

Process contribution-climate change
GSD² in bus operation- 2.01



Process contribution to uncertainty score in scenarios

This simple and reliable approach can easily show the contribution of each process.

Conclusions

- Crucial to look across different uses of biomass. The developed method in comparable functional savings per ha and in % substituted is appropriate to compare different uses of biomass
- There are other uses of biomass that could be more efficient and would have to be considered in priority to biodiesel
- Biodiesel favorable for non renewable energy but may be unfavorable for human health impacts
- Taylor serie expansion is simpler than Monte-Carlo and provides comparable results for uncertainty analyses