CIE CENTER FOR INDUSTRIAL ECOLOGY

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Life Cycle Assessment and associated methods for sustainability evaluation in bioenergy

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Outline

- Center for Industrial Ecology (CIE)
- Introduction to LCA
- Main phases of LCA methodology
- Evolution of LCA and Future
- Examples of LCA for sustainability evaluation in biofuels

Center for Industrial Ecology

- Research in the multi-disciplinary field of Industrial Ecology (~ Circular Economy).
- Develops models and applies tools to enhance the sustainability of products and systems supported by life-cycle thinking.
- Takes a holistic and systematic approach to the analysis of sustainable systems by exploring trade-offs and synergies between economy, environment and society.
- Promotes R&D&I to support industry, public authorities, organizations, and consumers towards sustainable production and consumption.

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Research Agenda

- Environmental life-cycle assessment (Carbon, water, environmental footprints)
- Life-cycle management, LC Costing, TEA, Social LCA
- Life-cycle sustainability assessment
- LCA & multi-objective optimization, LCA & Partial Equilibrium Analysis (LCAA)
- LCA & MultiCriteria Decision Analysis
- Extended LC approaches: uncertainty, variability, local aspects & spatial different
- Eco-design, fleet-based LCA, Dynamics
- Urban metabolism & Material Flow Analysis, MFA & LCA
- Circular Economy

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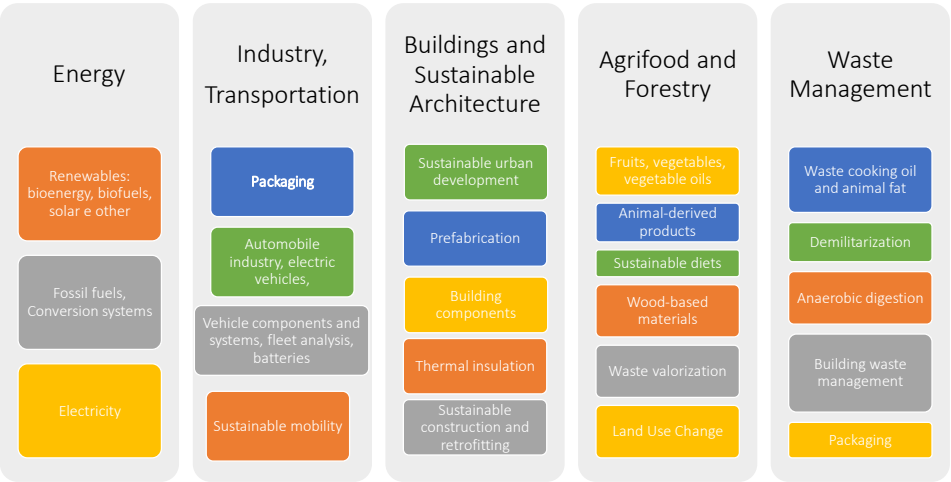
Application areas



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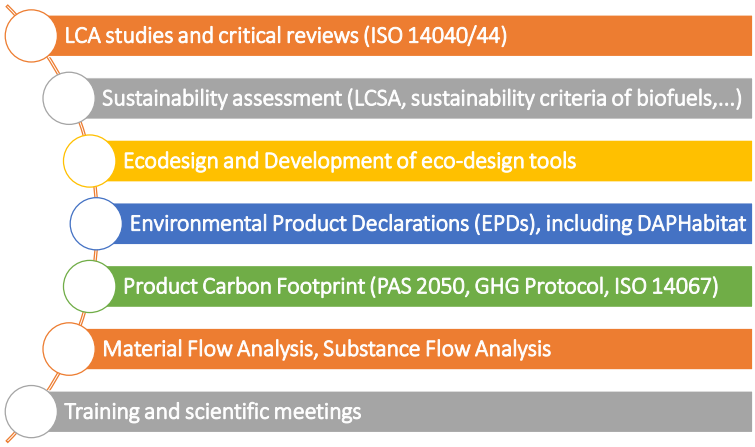
Services



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LCA: introduction

a systematic mapping and evaluation of environmental and resource impacts throughout the entire life-cycle of a product, from resource extraction to final disposal

ISO 14040:2006 (second edition 2006-07-01)

Environmental management — Life cycle assessment — Principles and framework

Management environnemental — Analyse du cycle de vie — Principes et cadre

LCA addresses the environmental aspects and potential environmental impacts[1)] (e.g. use of resources and the environmental consequences of releases) throughout a product life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave).

[1)] The "potential environmental impacts" are relative expressions, as they are related to the functional unit of a product system.

Purpose of LCA (ISO 14040:2006)

According to ISO 14040:2006, LCA can assist in:

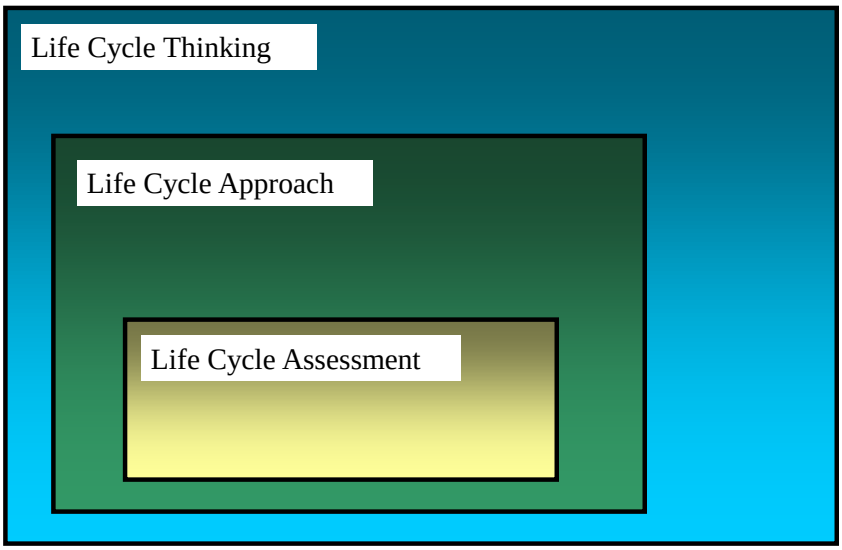
- identifying opportunities to improve the environmental performance of products at various points in their life cycle;
- informing decision-makers in industry, government or non-government organizations (e.g. for the purpose of strategic planning, priority setting, product or process design or redesign);
- the selection of relevant indicators of environmental performance, including measurement techniques; and
- marketing (e.g. implementing an eco-labelling scheme, making an environmental claim, or producing an environmental product declaration).

For practitioners of LCA, **ISO 14044** details the requirements for conducting an LCA.

Purpose of LCA (examples)

- Product and Process development and Improvement.
  - Better understanding of production processes, … as basis for improvement. **Ecodesign**, ….
- Strategic Planning and Public Policy Making
  - Renewable Energy Directive (RED) CE2009/28 & Recast to 2030 (RED II), sustainability & GHG emission criteria that bioliquids used in transport must comply)
  - Influencing the policy making process (e.g. the EU packaging directive)
  - Ecodesign Directive (Directive 2009/125/EC)
- Supporting environmental management & Development of indicators to trace environmental performance
  - Impact indicators, performance indicators & goals
- Strategic positioning in the market. **Marketing & External communication**
  - Environmental Product Declarations (EPDs)
  - **Product Environmental Footprint (PEF):** EU Commission Recommendation 2021/2279 on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations.

LCA and Life-Cycle Approaches



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Sustainability approaches based on LCA

Life-Cycle Sustainability Assessment (LCSA)

- Broadens the scope of current LCA to cover all 3 dimensions of sustainability (environmental, social and economic)
- Deepens current LCA to also include other than just technological relations, e.g. physical (scarcity) relations, econonomical and behavioral relations.

Life Cycle Costing (LCC), Techno-Economic Analysis (TEA)
TEA + ex-ante LCA, relevant for emergent technologies, low TRL)

Social LCA (SLCA)

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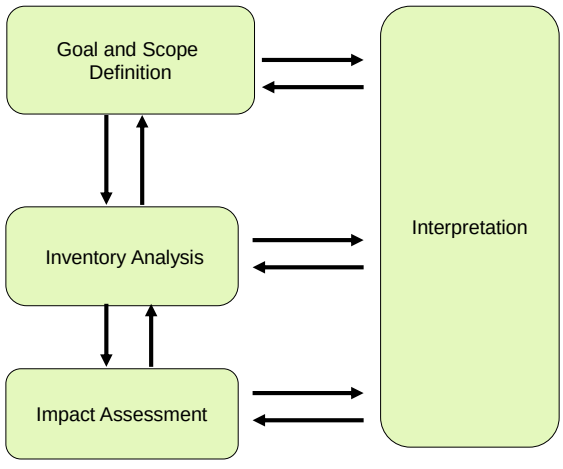
LCA Phases* (ISO 14040:2006)



*__Phases__ (not stages) corrected in Amendment 1 (ISO 14040:2006/Amd 1:2020)

LCA Phases

There are **four phases** in an LCA study:

The scope, including the system boundary and level of detail, of an LCA depends on the subject and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA.

The life cycle inventory analysis phase (LCI phase) is the second phase of LCA. It is an inventory of input/output data with regard to the system being studied. It involves collection of the data necessary to meet the goals of the defined study.

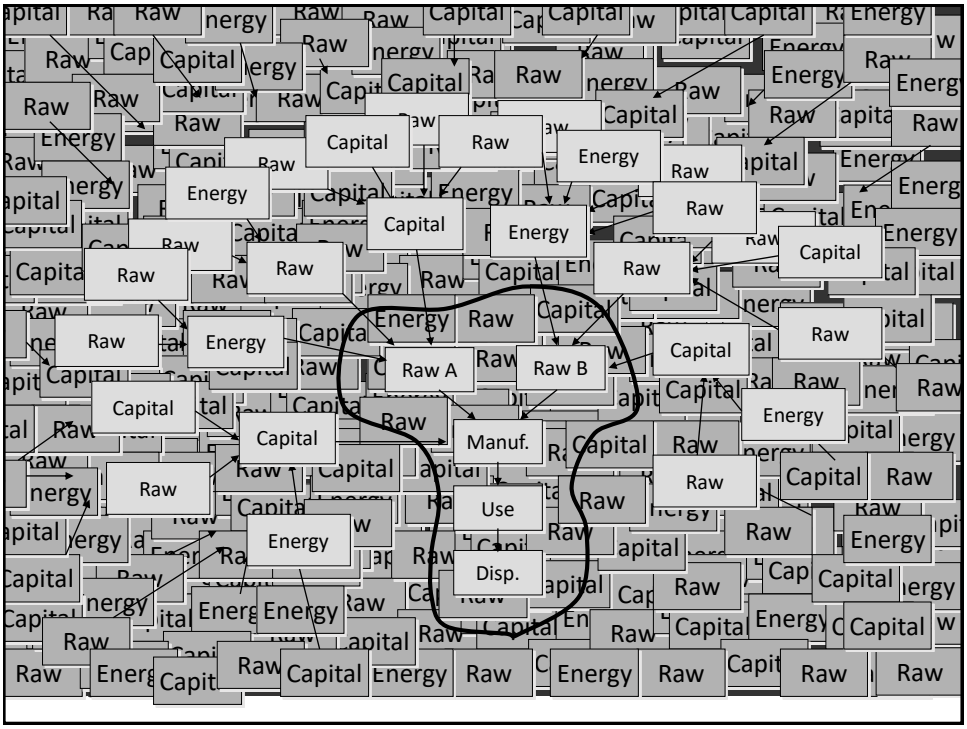
The life cycle impact assessment phase (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system LCI results so as to better understand their environmental significance.

Life cycle interpretation is the final phase of the LCA procedure, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

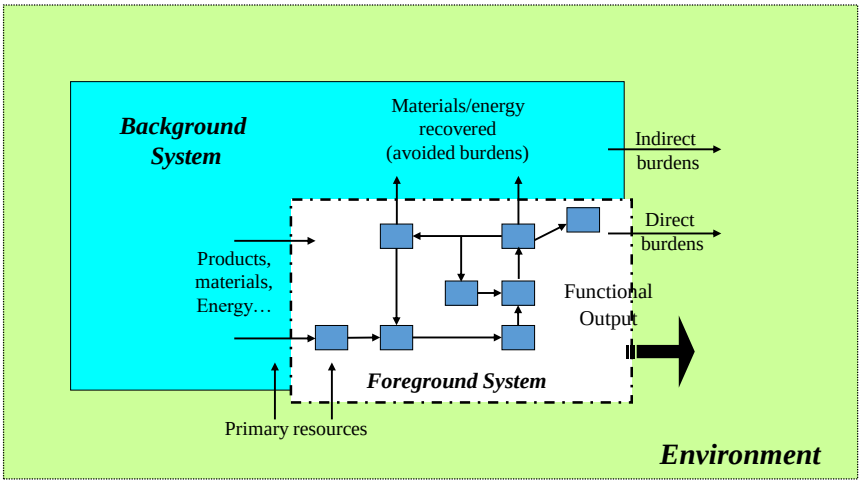
Goal and Scope definition

The first LCA phase involves defining the purpose of the study, its scope, data quality requirements and functional unit.

- **LCA study objectives**
  - Why is the study performed, what will results be used for, who should be involved, and who will have interest in the results?
- **Function and Functional Unit**
  - Products deliver function(s) to their users, so how do you define it?
- **Product system**
  - Cradle-to-grave, cradle-to-gate, gate-to-gate?
  - How do you set its borders towards the surroundings?
- **Alternative options**
  - Depends on the study objectives. Do you want to improve a given product, evaluate different products, assess future possibilities?
- **Empirical data**
  - Good data will be needed (garbage in garbage out), and its quality depends on the study objectives. Primary vs. secondary data?
- **Multi functionality (substitution, allocation, …)**
  - How do you take into consideration co-production, combined waste treatment and (open loop) recycling?



Foreground and Background system in LCA



Examples of LCA for sustainability evaluation in biofuels

LCA of biodiesel:

- Virgin oils – rapeseed, palm, soybean, sunflower
- Microalgae
- Waste cooking oils
- Beef tallow

LCA of bioethanol:

- Wheat
- Sugar beet
- Sugarcane

- **Well-to-Tank & Tank-to-Wheels analysis**
- Heavy duty vehicles
- LUC
- Agriculture practices and pathways
- **Uncertainty analysis**
- **Multicriteria decision analysis**
- **Multi-objective optimization**
- Social impacts
- Water footprint
- **Multifunctionality**

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LCA of biofuels: sources of uncertainty

METHODOLOGICAL CHALLENGES AFFECTING THE RESULTS OF BIOFUEL LC STUDIES

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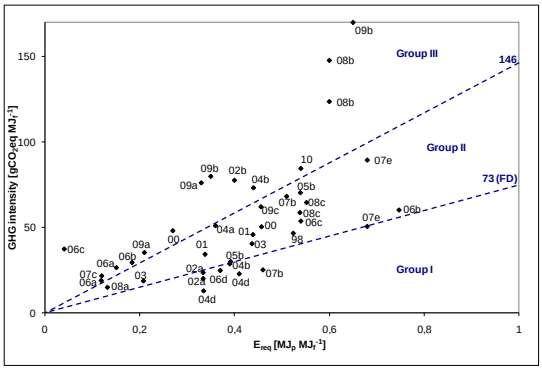
*Malça, J., Freire, F. (2010). "**Uncertainty Analysis in Biofuel Systems: An Application to the Life Cycle of Rapeseed Oil**". Journal of Industrial Ecology 14 (2), 322-334.*

LCA of EU Rape methyl esther A Review

- Biofuel LC studies have varying and sometimes contradictory conclusions, even for the same biofuel type and pathway.
- Significant disagreement and controversy exist regarding the actual benefits of biofuels displacing fossil fuels.



Group	Key modeling issues addressed	GHG intensity per nonrenewable primary energy use requirement ($gCO_2eq\ MJ_p^{-1}$) < 73	73 – 146	> 146
III	soil carbon emissions + soil N_2O emissions (↑, high uncert.) + fossil CO_2 emissions			10, 09b, 08b
II	soil N_2O emissions (↓ or ↑) + fossil CO_2 emissions		09c, 08c, 08a, 07e, 07b, 06c, 06b, 05b, 04b, 04a, 03, 01, 00	09a, 07c, 06c, 06a, 02b
I	soil N_2O emissions (0 or ↓) + fossil CO_2 emissions	06d, 04d, 02a	98	

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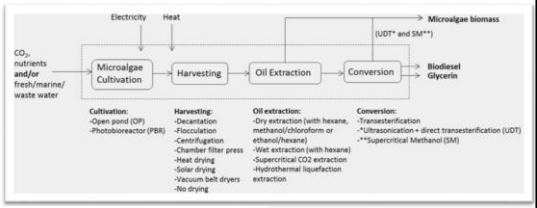
*Malça, J., Freire, F. (2011). "**Life-cycle studies of biodiesel in Europe: A review addressing the variability of results and modeling issues**". RSER 15 (1), 338–351.*

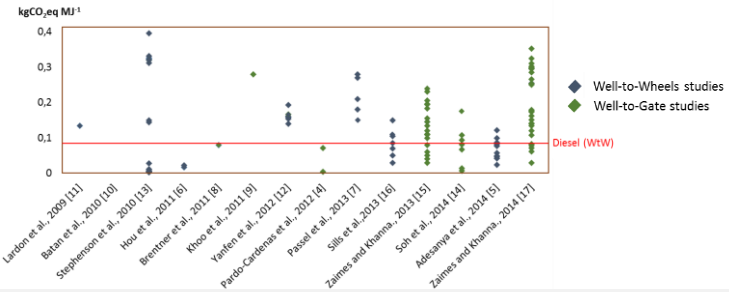
Biofuels

Microalgae biodiesel: a review

Comprehensive review of published LCAs for biodiesel produced from microalgae

- Identify the main causes for the high variability of GHG intensity



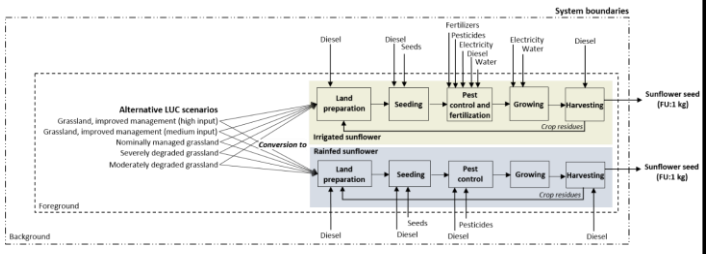


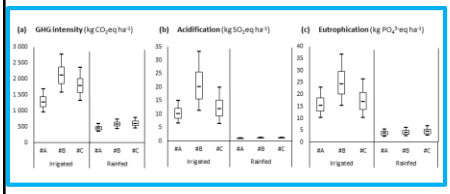
Garcia, R., Figueiredo, F., Brandão, M., Hegg, M., Castanheira, É., Malça, J., Nilsson, A., Freire, F. (2020). **A meta-analysis of the life cycle greenhouse gas balances of microalgae biodiesel**. International Journal of Life Cycle Assessment 25, 1737–1748. https://doi.org/10.1007/s11367-020-01780-2

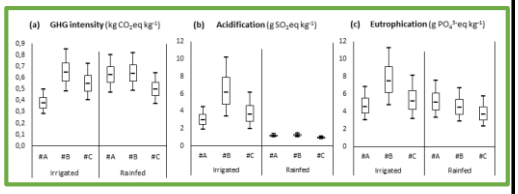
IEA, 2016. 2016 State of Technology Review – Algae Bioenergy. IEA Bioenergy Algal Bioenergy Assessment Project

LCA of sunflower cultivation in PT

- Irrigated vs rainfed
- LUC scenarios
- Different functional units (kg and ha)
- Uncertainty analysis

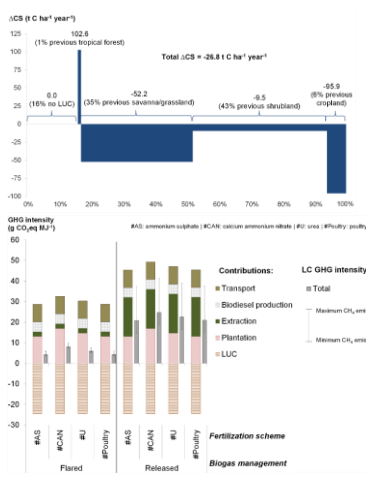






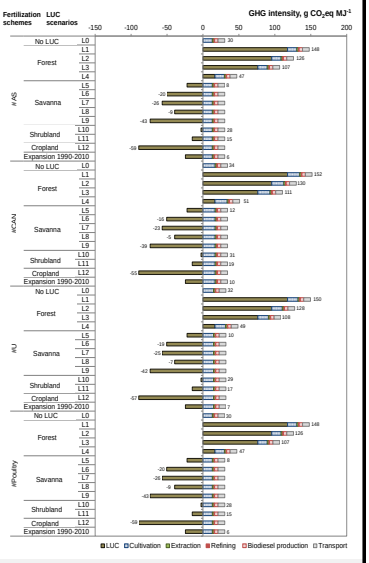
Figueiredo, F., Castanheira, É.G., Freire, F. (2017). **Life-cycle assessment of irrigated and rainfed sunflower addressing uncertainty and land use change scenarios**. Journal of Cleaner Production, vol. 140 (2), pp. 436–444. http://dx.doi.org/10.1016/j.jclepro.2016.06.151

LCA of biodiesel produced with palm oil from Colombia



LUC @ Colombia (1990-2010)

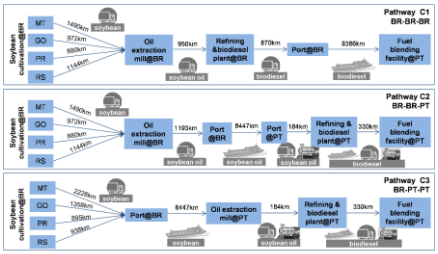
LUC scenarios



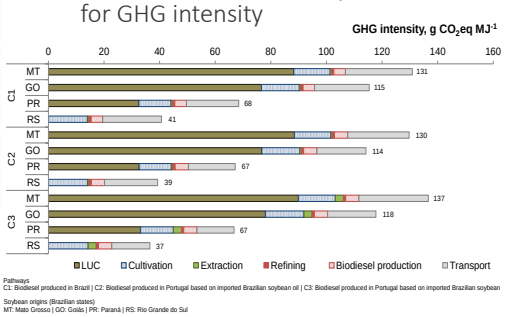
Castanheira, É., Freire, F. (2016). "Environmental life-cycle assessment of biodiesel produced with palm oil from Colombia", IJLCA
Castanheira, É.G., Acevedo, H., Freire, F. (2014). "Greenhouse gas intensity of palm oil produced in Colombia addressing alternative land use change and fertilization scenarios". Applied Energy 114, 958-967.

LC GHG intensity of soybean biodiesel

- Three pathways and four Brazilian soybean origins

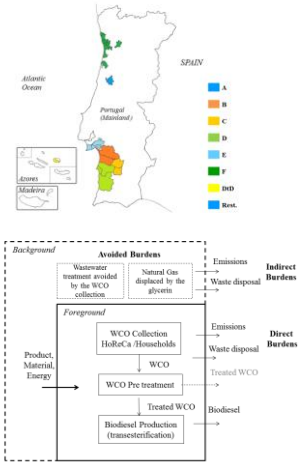


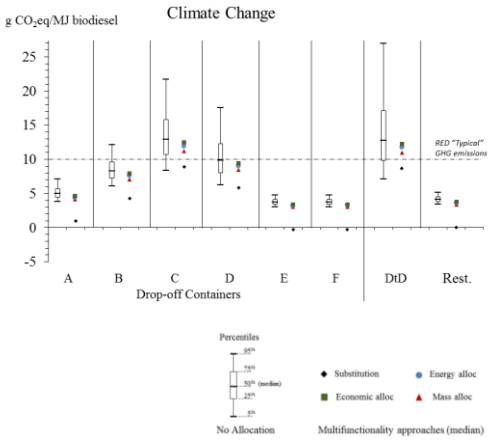
- Contribution of each LC phase for GHG intensity



Castanheira, É., Grisoli, R., Coelho, S., Silva, G.A., Freire, F. (2015). "Life-cycle assessment of soybean-based biodiesel in Europe: comparing grain, oil and biodiesel import from Brazil". JCIP 102, 188-201
Castanheira, É.G., Grisoli, R., Freire, F., Coelho S. (2014). "Environmental sustainability of biodiesel in Brazil". Energy Policy 65, 680–691.
Castanheira, É.G., Freire, F. (2013). "Greenhouse gas assessment of soybean: implications of land use change and different cultivation systems". JCIP 54, 49-60.

LCA of Waste Cooking Oil biodiesel addressing uncertainty





Caldeira, C., Queirós, J., Noshadravan, A., Freire, F. "Incorporating uncertainty in the Life Cycle Assessment of biodiesel from Waste Cooking Oil addressing different collection systems". Resources, Conservation and Recycling (in press)

Thank you!

Questions, comments?

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For details about the CIE team, projects and publications:
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