BioEcon meeting
26-Set-2017
INCBR, Pulawy

LCA applications for industrial partners and Research at the Center for Industrial Ecology

Fausto Freire

Center for Industrial Ecology
http://www2.dem.uc.pt/CenterIndustrialEcology/

ADAI-LAETA (Associated Laboratory for Energy, Transports and Aeronautics)
Energy for Sustainability Initiative
University of Coimbra

Center for Industrial Ecology

- Research group in the multi-disciplinary field of Industrial Ecology.
- Develops 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.

Research Agenda

- Environmental life-cycle assessment (Carbon, water, environmental footprints)
- Social LCA, Life-cycle management, LC Costing
- 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
- Circular Economy
- Urban metabolism & Material Flow Analysis, MFA & LCA

Services

- LCA studies and critical reviews (ISO 14040/44)
- Environmental Product Declarations (EPDs), including DAPHabitat
- Product Carbon Footprint (PAS 2050, GHG Protocol, ISO 14067)
- Assessment of sustainability criteria for biofuels
- Sustainability assessment of buildings
- Development of eco-design tools
- Training and scientific meetings

Application areas

Energy

- Renewables: bioenergy, biofuels, solar e other
- Fossil fuels, Conversion systems
- Electricity

Transportation

- Vehicle components and systems, electric vehicles, trains, fleet analysis, batteries
- Sustainable mobility

Buildings and Sustainable Architecture

- Sustainable urban development
- Prefabrication
- Building components
- Thermal insulation
- Sustainable construction and retrofitting

Agrifood and Forestry

- Fruits, vegetables, vegetable oils
- Animal-derived products
- Sustainable diets
- Wood-based materials
- Waste valorization
- Land Use Change

Waste Management

- Waste cooking oil and animal fat
- Demilitarization
- Anaerobic digestion
- Building waste management
- Packaging

Ongoing projects

2017-2019 **CTB Basics: CleanTechBlock – Sustainable Multi-functional Building Block Basics**
Proponent Institution: Jožef Stefan Institute, Slovenia | Coordinator at ADAI-LAETA: Fausto Freire Funding: M-ERA.NET/FCT | M-ERA-NET2/0017/2016 | Funding: 425 884 €

2016-2019 **URBANWINS: Urban metabolism accounts for building waste management innovative networks and strategies**
Proponent Institution: Comune di Cremona | Coordinator at UC: Fausto Freire | Funding Entity: European Union – Horizon 2020 | Grant Agreement No. 690047 | Funding: 4 966 516.25 €

2016-2019 **SUSTAINFOR: Sustainability assessment of forest sector management strategies in the context of a bioeconomy**
Coordinator: Ana Dias (CESAM-UA) | Coordinator at ADAI-LAETA: Fausto Freire | Funding Entity: FCT | PTDC/AGR-FOR/1510/2014 | Funding: 199 992 €

2016-2019 **SABIOS: Sustainability assessment of bioenergy systems: a life cycle multi-criteria decision-support approach, including land use change**
Coordinator: Luis Arroja (CESAM-UA) | Coordinator at ADAI-LAETA: Fausto Freire | Funding Entity: FCT | PTDC/AAG-MAA/6234/2014 | Funding: 199 836 €

2016-2018 **WASHONE: Innovative toilet system combining a washlet system, an integrated water storage and discharge system and an urine separation system**
Proponent Institution: Oliveira & Irmão S.A. | Coordinator at DEM-UC: António Gameiro | Funding Entity: FEDER/COMPETE 2020 | Funding: 460 802 €

2018 **Almost ongoing…**
Ecodesign and Life Cycle Assessment of pharmaceutical packaging
Coordinator: Fausto Freire | Funding Entity: VALORMED

Selected Concluded Projects (I)

- **Funded by Industry**
  - **CIE Plasfil**

    2013-2015: EDIL - EcoDesign and Impact Labelling of automobile plastic components
  - **Portuguese Association of Biofuel Producers – APPB**

    2010-2011: LC GHG emissions for soybean-based biodiesel in Portugal

    2014-2016: LC GHG emissions for rapeseed-based biodiesel in Portugal
  - **ROLLS-ROYCE Environment Advisory Board** |

    2015-16 LifeCycle GHG Analysis of Train Power Systems: Diesel, Hybrid and LNG

- **Projects with international partners**

  2010-2013: **BioTrans** - Capturing Uncertainty in Biofuels for Transportation. Resolving Environmental Performance and Enabling Improved Use. (**USA, MIT**)

  2010-2013: **Economic and Environmental Sustainability of Electric Vehicle Systems** (**USA, MIT)**

  2013-2015: LC Environmental Sustainability Assessment of Bioenergy (**Brazil, USP**)

  2010-2012: **BIOACV** - Comparison of the LCA of the Biodiesel Produced from Soybean Oil and Animal Fat, Methylic and Ethylic Routes (**Brazil, USP**).

Selected Concluded projects (II)

- National projects
  - 2016-2017: **BIO2URBAN**- Biodiesel blends for road vehicles in urban areas
  - 2012-2015: **BioHeavy** - Extended “well-to-wheels” assessment of biodiesel for heavy transport vehicles
  - 2013-2015: **BioSustain** - Sustainable mobility: Perspectives for the future of biofuel production-Sustainable mobility: Perspectives for the future of biofuel production
  - 2007-2011: Biofuel systems for transportation in Portugal: A "well-to-wheels" integrated multi-objective assessment
  - 2012-2015: **EMSURE** - Energy and Mobility for Sustainable Regions (CENTRO-07-0224-FEDER-002004)
  - 2011-2013: EcoDeep - Eco-efficiency and Eco-management in Agro-industry (Funded by COMPETE - QREN)

WashOne

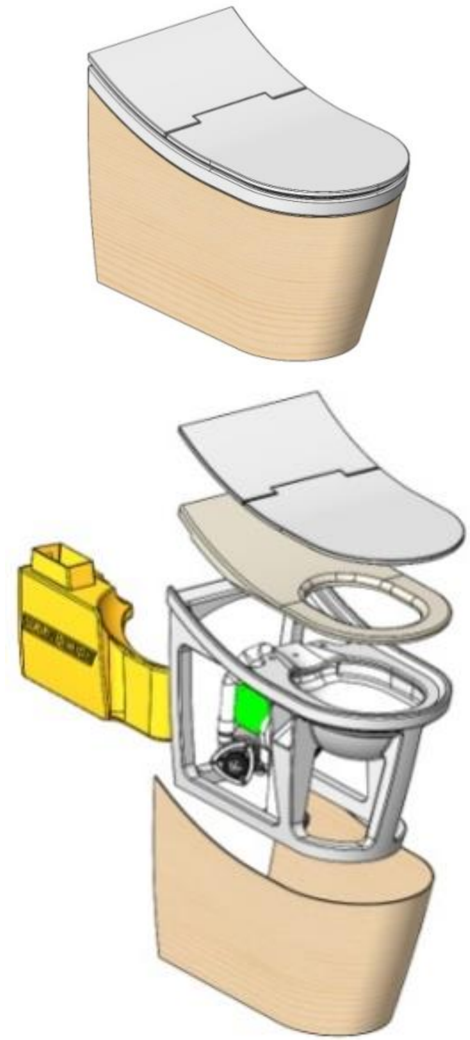
Innovative toilet system combining a washlet system, an integrated water storage and discharge system and an urine separation system

- GOAL: conception, technical development, prototyping and final validation of an innovative toilet that includes a number of features, namely a 'washlet' system, an integrated system for storing and flushing the water, and an urine separation system.

- Partners:

- **OLI**: a leading firm in Portugal in the manufacture of toilet cisterns and accessories for sanitary ware;
- **Sanindusa:** a relevant Portuguese manufacturer of sanitary ware;
- **EVOLEO**: a SME with acknowledged experience in developing complex electronic systems;
- **ITeCons**: a research and innovation systems institution geared to developing new construction systems and processes;
- **ANQIP:** research and innovation systems institution devoted to the assessment of the quality and efficiency of facilities installed in buildings;
- **University of Aveiro**: which has sound experience in developing and validating hydromechanical systems;
- **University of Coimbra**: experience in the simulation of engineered systems and life-cycle assessment.

WashOne – Innovative toilet combining multiple comfort, cleaning and sustainable functions



Main functions:

- Washlet (cleaning and drying system)
- Integrated systems for water storing and flushing
- Urine separation system

Additional functions:

- Odor extraction
- Seat heating
- Automatic lid
- Orientation light
- Remote control unit

Partners:

OLI sanindusa lifemoments EVOLEO SERVICES U C universidade de aveiro theoria poiesis praxis ITeCons ANQIP

SABIOS

Sustainability assessment of bioenergy systems: a life cycle multi-criteria decision-support approach, including land use change

- Coordinator: Luis Arroja (CESAM-UA) | Coordenador@ADAI-LAETA: Fausto Freire | INESCC: Luís Dias | Funding Entity: FCT

- GOAL: Develop a framework for Sustainability Assessment of bioenergy systems, able to inform industry actors, policy makers and stakeholders, and to support bioenergy systems management.
- The methodology aims to innovate and advance the state of the art along three interrelated lines:
  - The assessment of bioenergy alternatives will be based on the complementary use of Multi-Criteria Decision Analysis (MCDA) and LCA
  - Uncertainty analysis will be embedded throughout all models to be developed, an important aspect since there is considerable uncertainty regarding the type, scale and timing of indirect LUC
  - The LCA will account for the indirect Land Use Changes (LUC) effects

SUSTAINFOR

Sustainability assessment of forest sector management strategies in the context of a bioeconomy

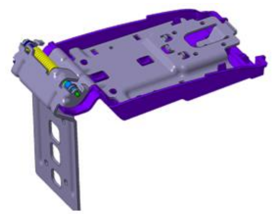
- Coordinator: Ana Dias (CESAM-UA) | Coordenador@ADAI-LAETA: Fausto Freire | Funding Entity: FCT
- GOAL: To assess, for the first time, the effects of the transition to a bioeconomy on the eucalypt and maritime pine forest sectors in Portugal, in order to provide insights for improved policy and decision-making concerning the choice of more sustainable solutions taking into account the three pillars of sustainability (environmental, economic and social).

- The project will provide answers to the following questions:

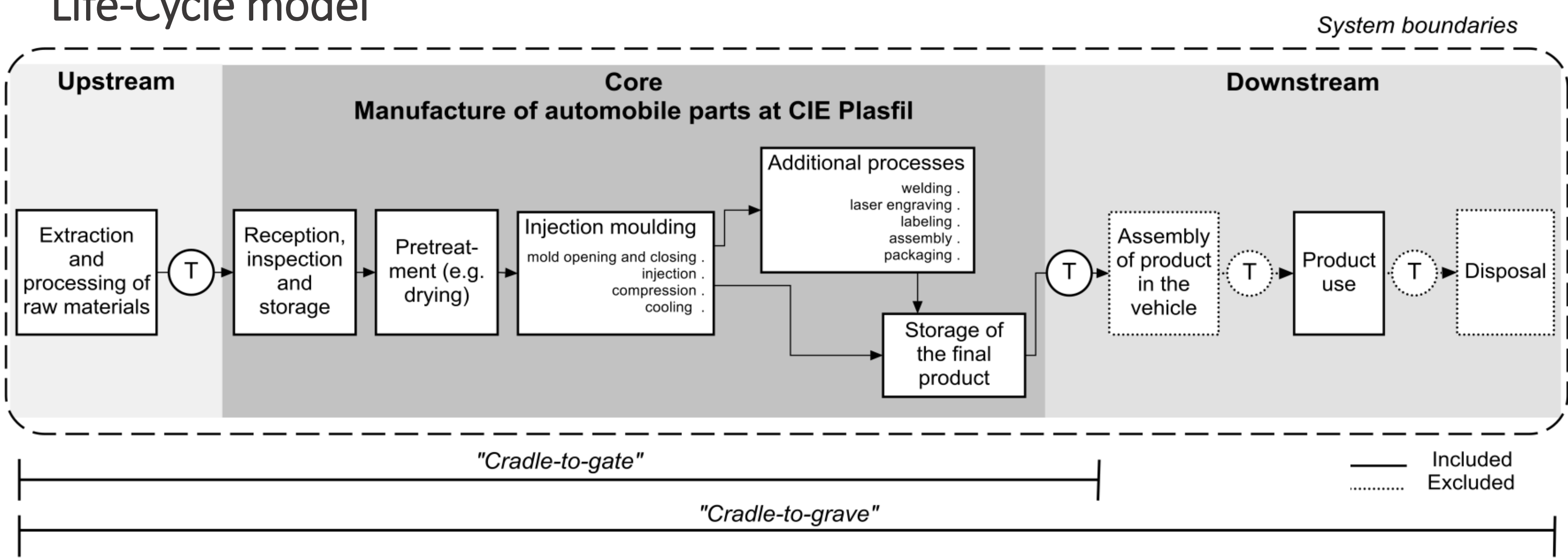
- What are the current total environmental, economic and social impacts of the eucalypt and maritime pine forest sectors in Portugal?
- How these current impacts can be decreased?
- What are the possible alternative management strategies for these forest sectors in the future?
- What are the environmental, economic and social impacts of those possible future scenarios?
- What are the most sustainable scenarios that should be adopted in the future?

Ecodesign of a passenger car armrest

Structural elements of the armrest



Life-Cycle model



EDIL project (EcoDesign and Impact Labelling, FCOMP–05–0128–FEDER–018643)

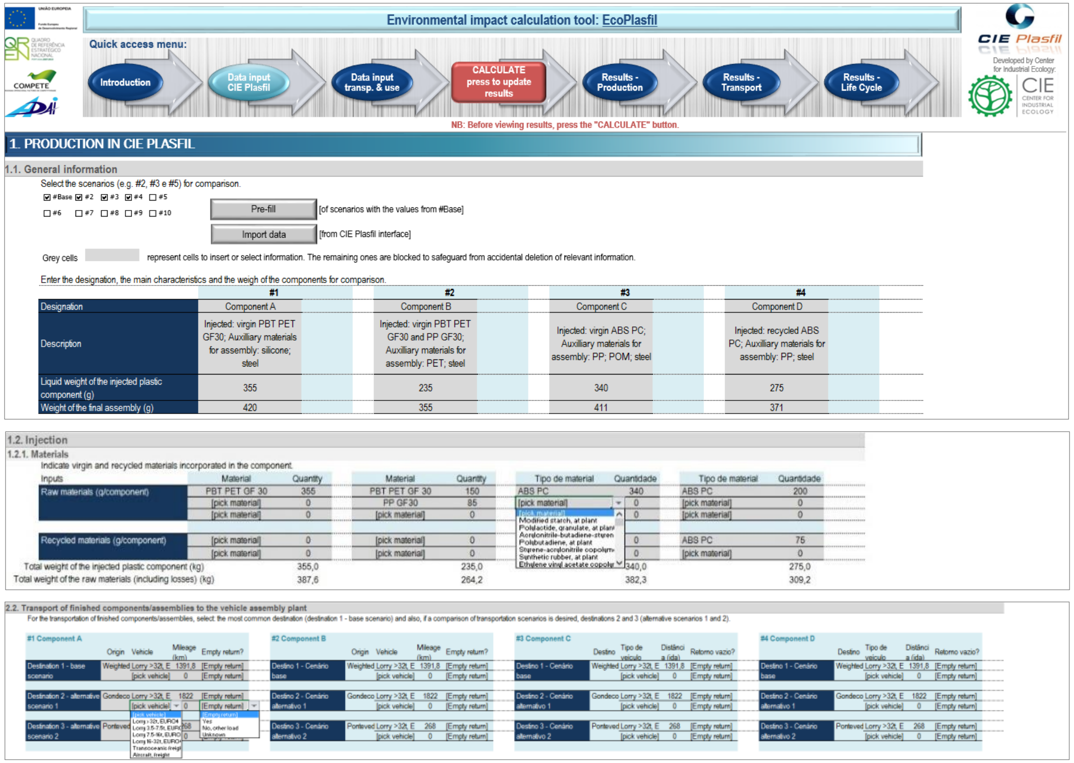
Development of an Ecodesign tool

Screen capture of the "EcoPlasfil" tool:

a) Interactive menu;

b) selection of materials for the injection molding process;

c) transportation modes (and distances) for finished components/sets

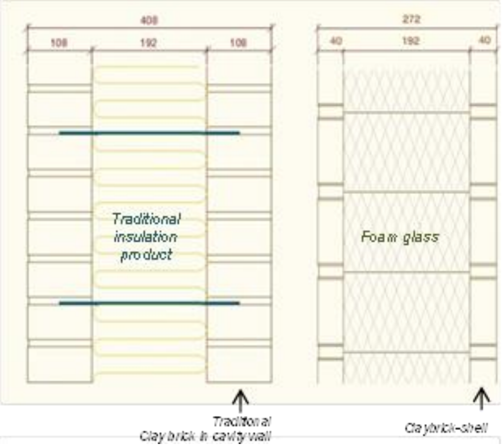


CTB Basics

CleanTechBlock – Sustainable Multi-functional Building Block Basics

- GOAL: the development of a new preparation method for a foam glass with superior thermal insulation properties and its integration into a new building block – CleanTechBlock (CTB), a multifunctional sandwich-block solution based on the combination of two clay brick shells and a foamed recycled-glass core.

- EU-Partners:



- Jožef Stefan Institute, Slovenia: experience in the field of synthesis and processing of ceramic and glass(y) materials, (micro) structural characterization and evaluation of functional properties.

- ADAI-CIE (University of Coimbra)

- CellMat Technologies, Spain: reference company in the transfer of both know-how and technology to the industrial sector. CMT implements advanced technologies in the production plants of companies in the plastics sector in two specific areas: Cellular Materials and Bioplastics.

CTB Basics concept

CTB prototype

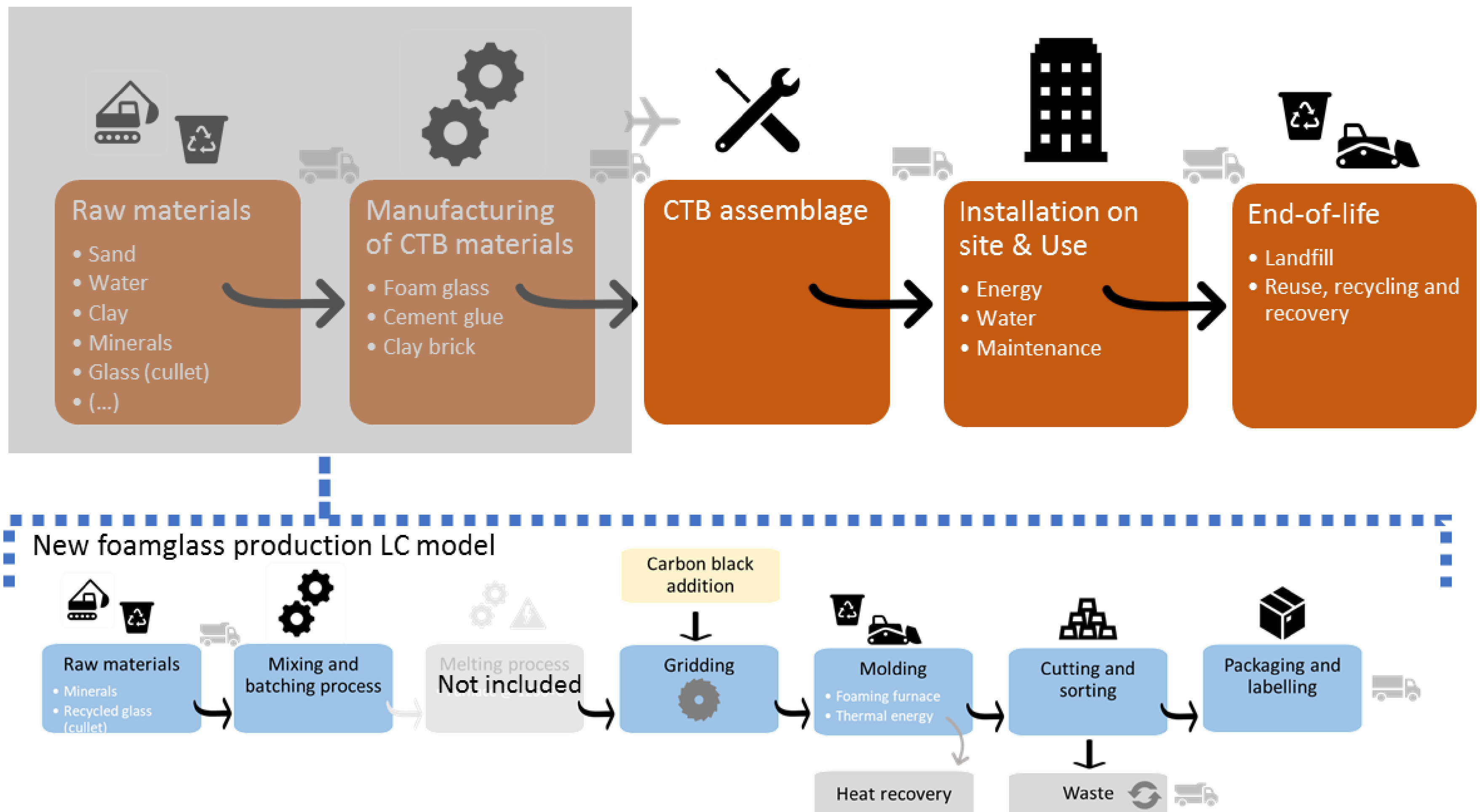
CTB wall mock-up

1. More than 50% reduction in the brick thickness,
2. Use of recycled materials in the production of foam glass,
3. Less energy intensive foam glass production,
4. Less energy required for construction due to faster construction,
5. Less energy required for transportation to the construction site,
6. Consumption of cement minimized (10-times less than traditional structure),
7. No organic components included.
8. Prolonged lifespan of the insulation element (200 years),
9. Minimum maintenance,
10. Lower consumption of raw materials,
11. Recyclability of the materials after demolition,
12. Composed of inert mineral materials.

- In CTB concept we take advantage of the superior insulation stability, load-bearing capacity, and sustainability of foam glass produced from cullet, and combine these with the durability, optimum indoor properties and minimal maintenance requirements of the traditional clay bricks.

- The new foam-glass preparation process enables the production of foam glass exclusively from waste glass and provides superior heat-insulation properties.

CTB Basics – life-cycle model



Research: selected results

- Biofuels
- Agri-food and Forestry

other topics, not in this presentation: Energy systems, Transportation, Buildings, Waste management, Demilitarization

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

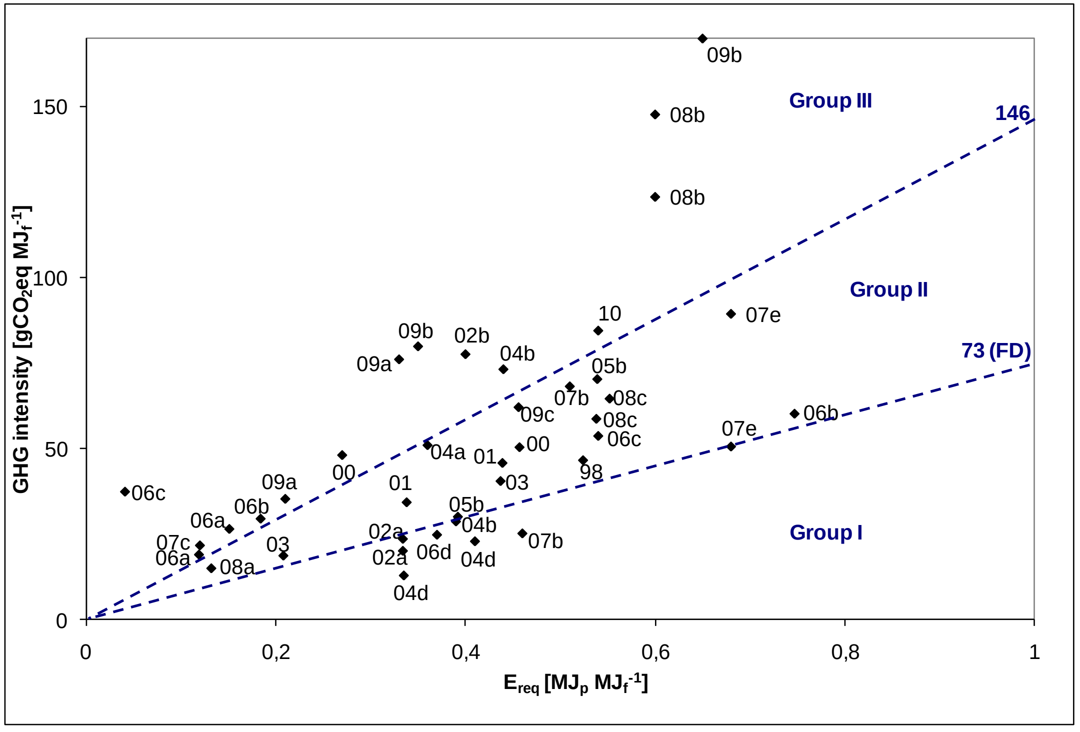
LCA of biofuels: sources of uncertainty

Methodological Challenges affecting the Results of Biofuel LC Studies

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.

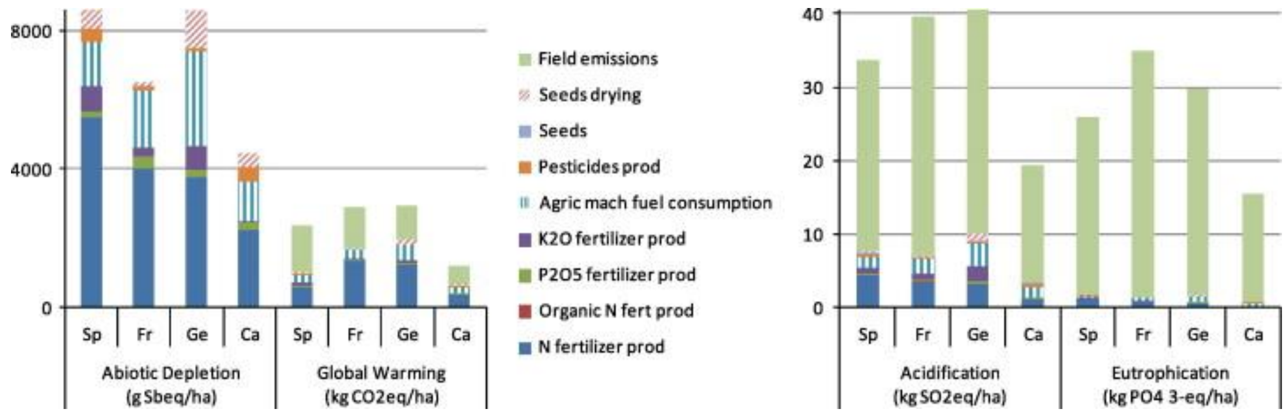


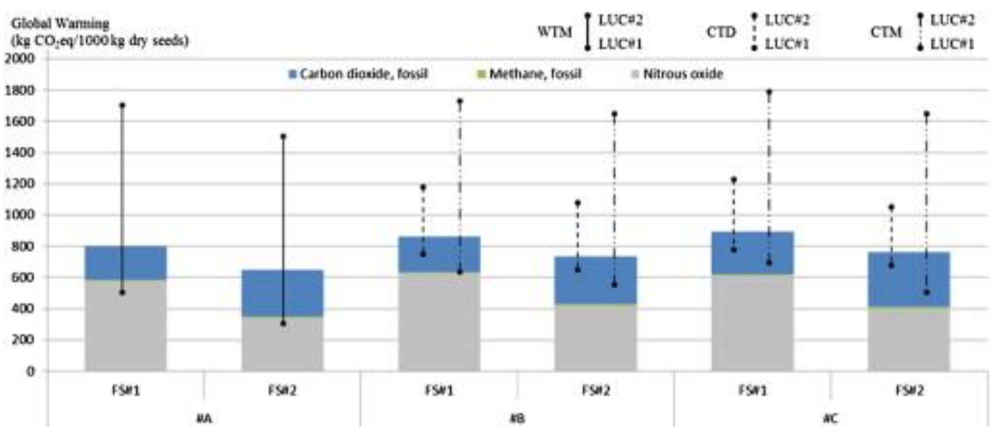
Group	Key modeling issues addressed	GHG intensity per nonrenewable primary energy use requirement ($gCO_2eq\ MJ_p^{-1}$)		
		< 73	73 – 146	> 146
III	soil carbon emissions + soil N_2O emissions (↑, high uncert.) + fossil CO_2 emissions			10, 09b, 08b
II	soil N_2O emissions (↓ or ↑) + fossil CO_2 emissions		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	

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.

LCA of rapeseed biodiesel

Main contributions to the environmental impacts of rapeseed cultivation in various countries





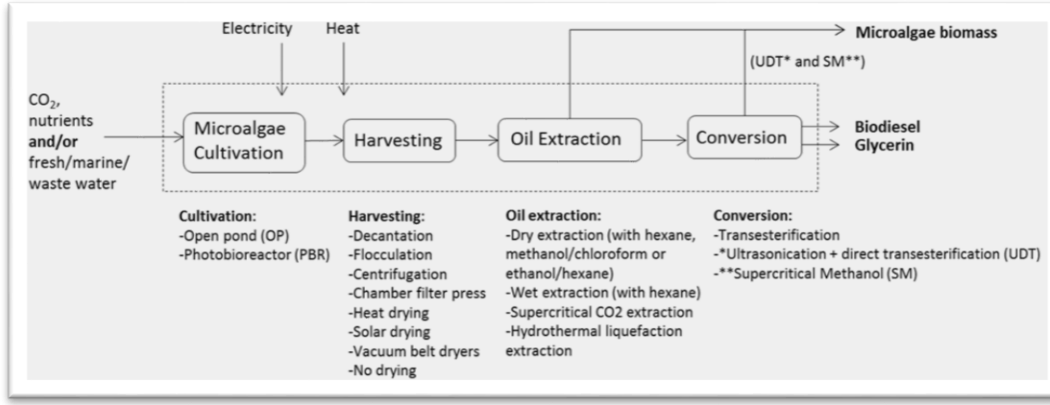
- Contribution of substances to GW
  - **LUC scenarios**: LUC#1 (low inputs) and LUC#2 (high inputs)
  - **Climates**: WTM - warm temperate moist; CTD - cool temperate dry; CTM - cool temperate moist)
  - **Fertilization scenarios:** FS#1 (N as NPK+CAN)and FS#2 (N as NPK+U)

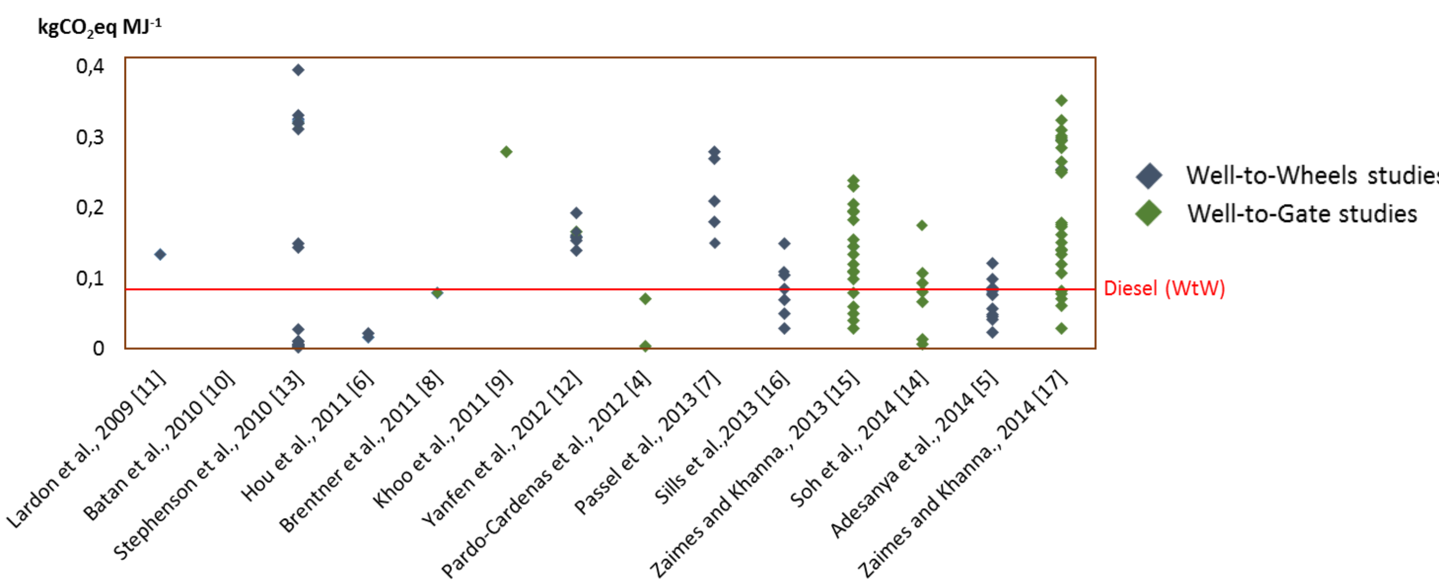
Queirós, J., Malça, J., Freire, F. (2015). "Environmental Life-Cycle Assessment of Rapeseed Produced in Central Europe: Addressing Alternative Fertilization and Management Practices". JClP 99, 266-274.
Malça, J., Coelho, A., Freire, F. (2014). "Environmental Life-Cycle Assessment of rapeseed-based biodiesel: alternative cultivation systems and locations". AppEn 114, 837-844.
Malça, J., Freire, F. (2009). "Energy and Environmental Benefits of Rapeseed Oil Replacing Diesel." Int. J Green Energy 6 (3), 287-301.

Microalgae biodiesel

Comprehensive review of published LCAs for biodiesel produced from microalgae

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

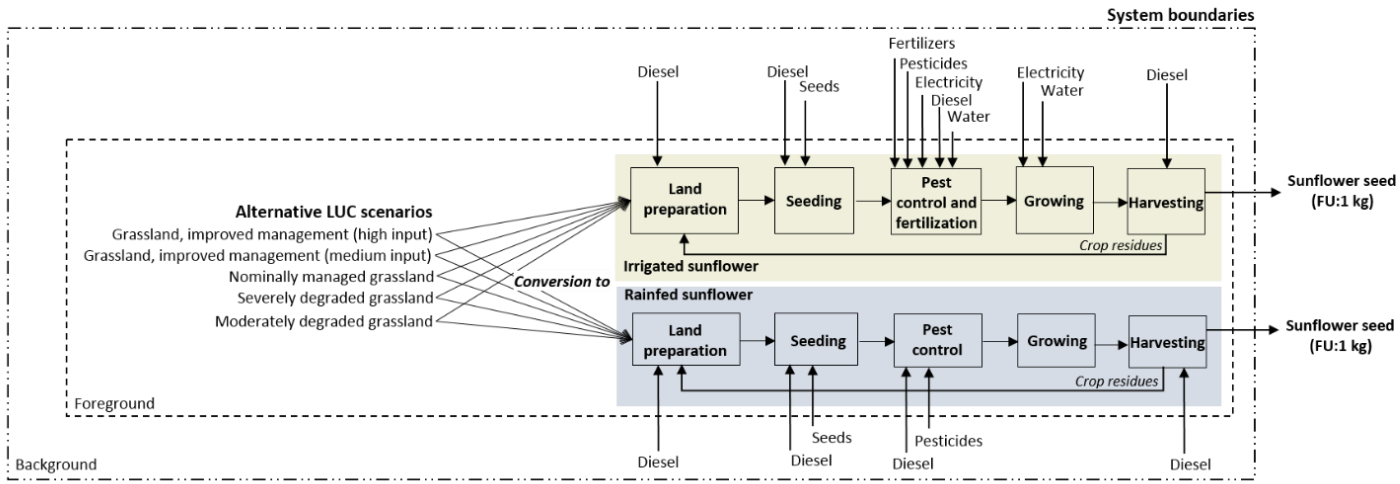


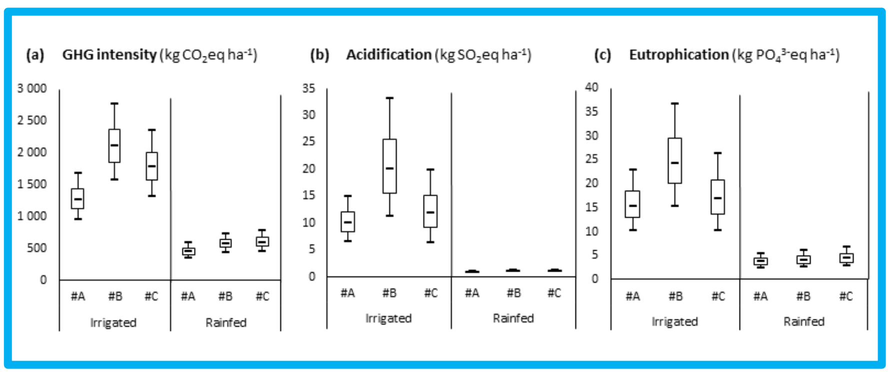


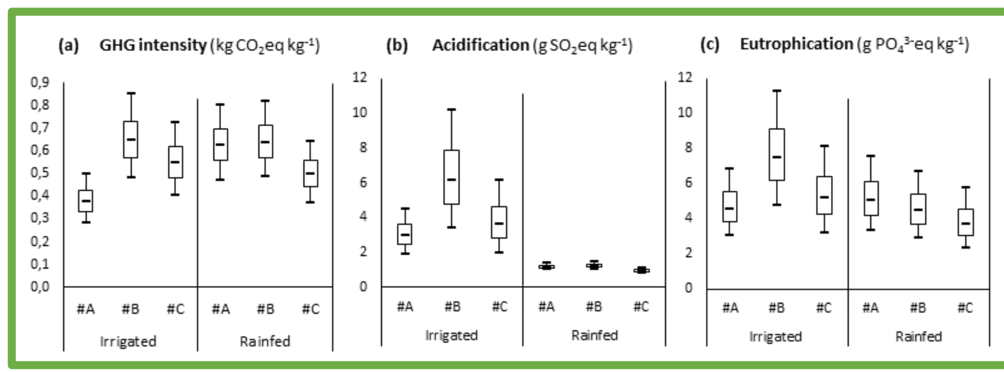
IEA, 2016. 2016 State of Technology Review – Algae Bioenergy. IEA Bioenergy Algal Bioenergy Assessment Project (in preparation).

LCA of sunflower cultivation in PT

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



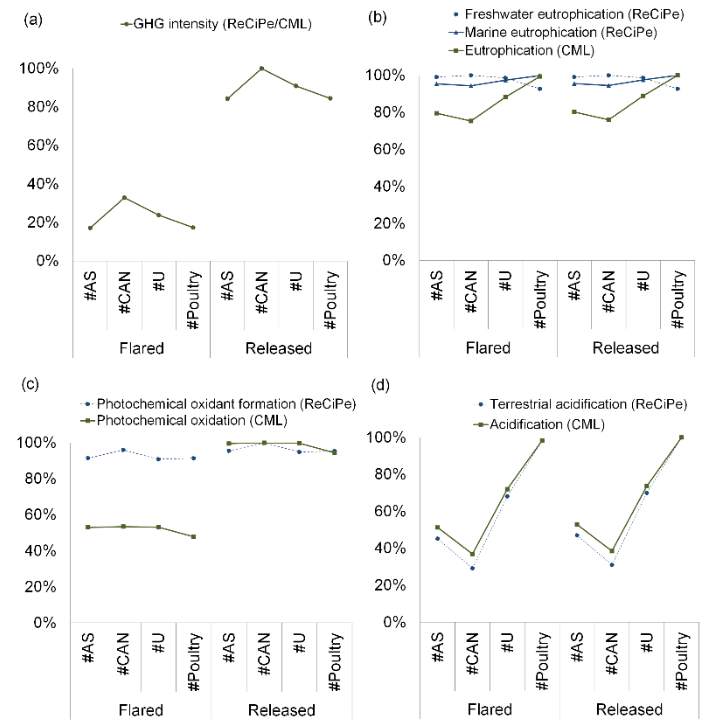


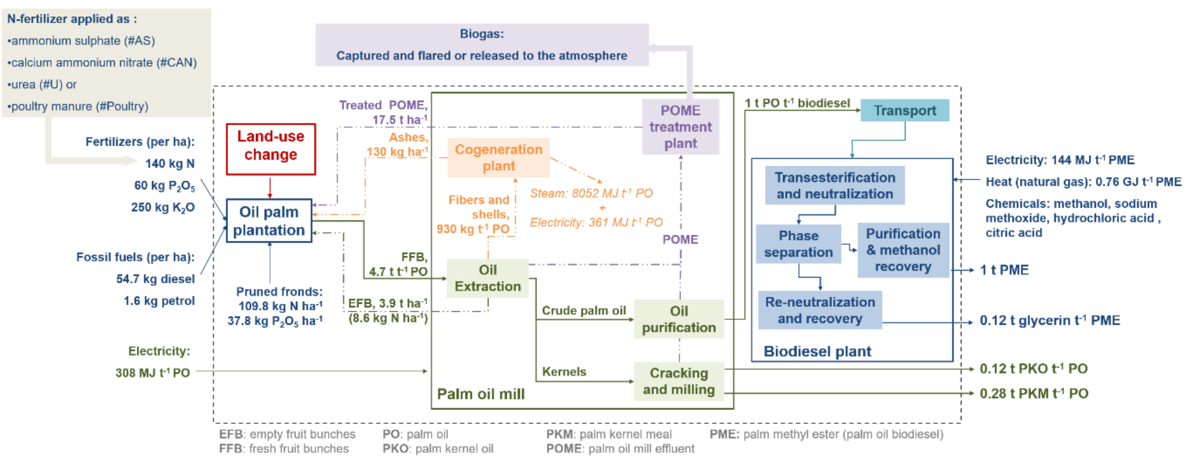


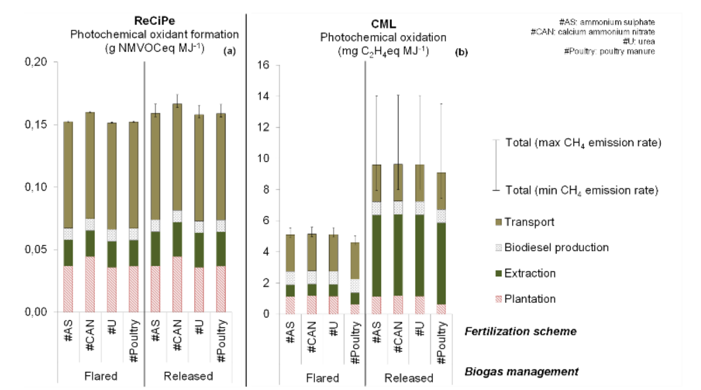
Figueiredo, F., Castanheira, É.G., Freire, F. (2016). "Life-cycle assessment of irrigated and rainfed sunflower addressing uncertainty and land use change scenarios". JCIP (under review).

LCA of biodiesel produced with palm oil from Colombia

- Alternative fertilization schemes:
  - Ammonium sulphate - #AS
  - Ammonium nitrate - #AN
  - Calcium ammonium nitrate - #CAN
  - Urea - #U
  - Poultry manure - #Poultry
- Comparison of LCIA methods
- Biogas captured and flared vs released



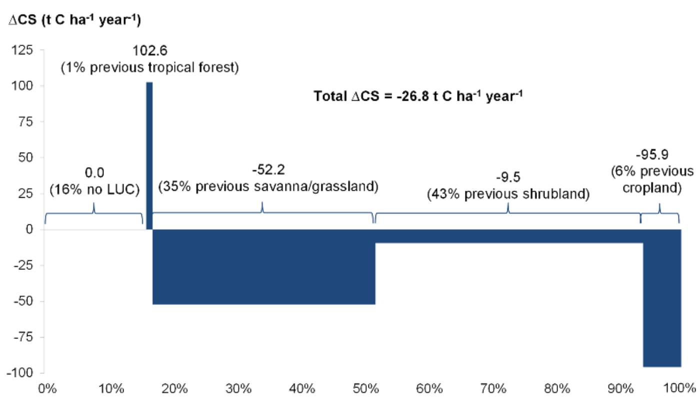


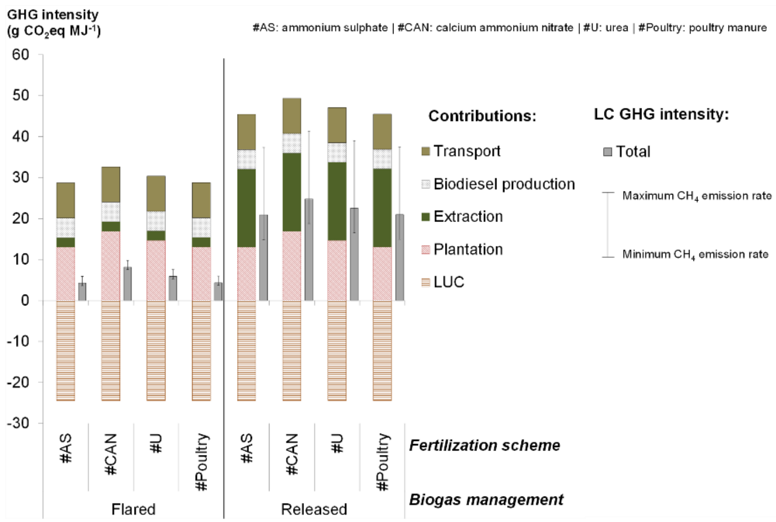


Castanheira, É., Freire, F. (2016). "Environmental life-cycle assessment of biodiesel produced with palm oil from Colombia", IJLCA (in press)

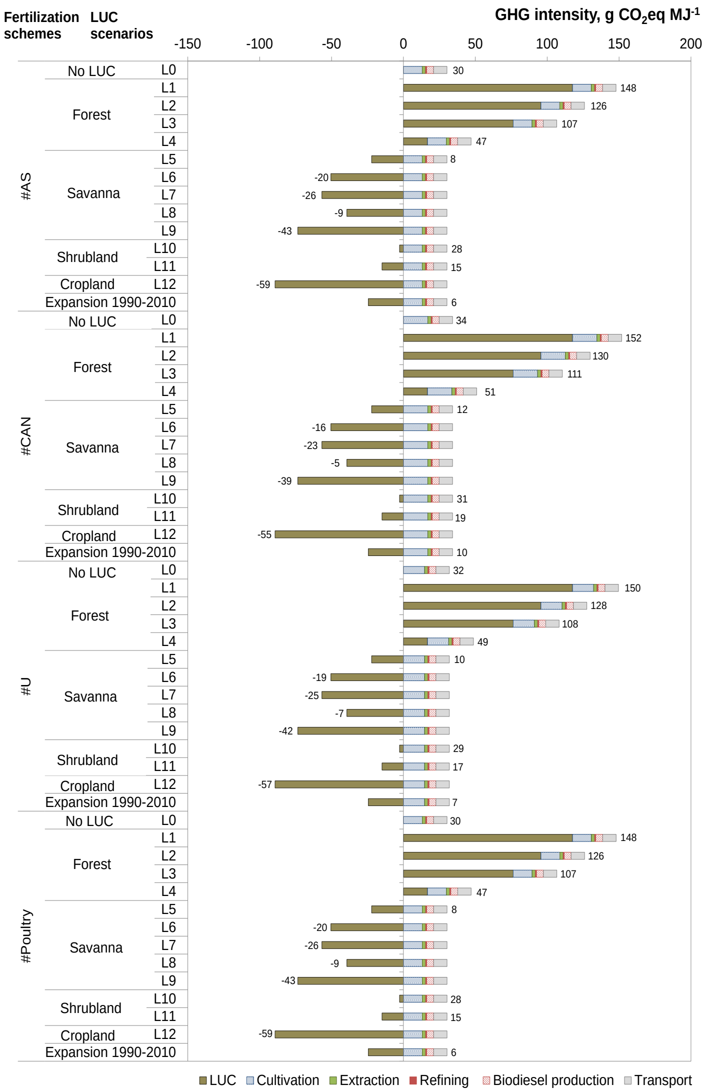
LCA of biodiesel produced with palm oil from Colombia

LUC @ Colombia (1990-2010)





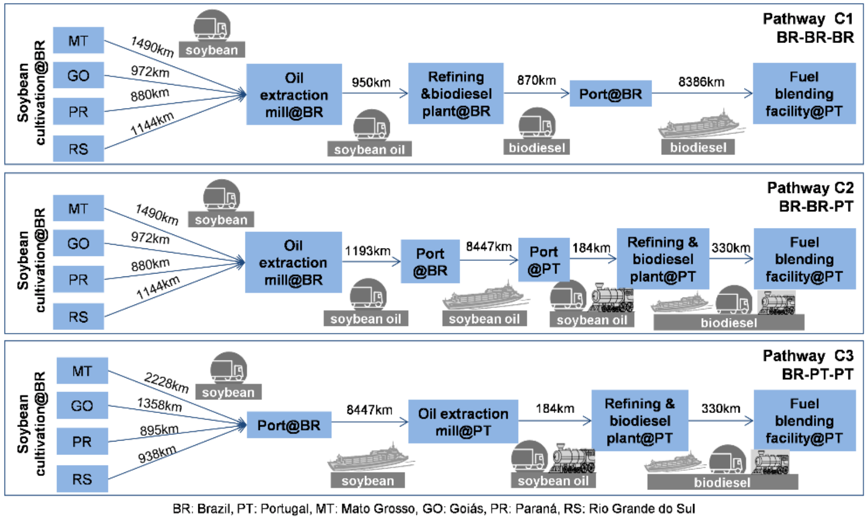
LUC scenarios



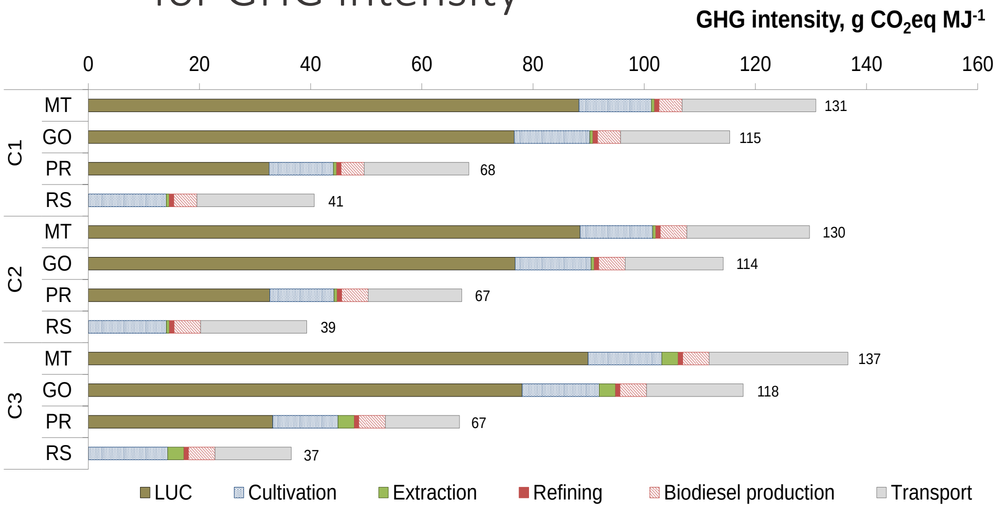
Castanheira, É., Freire, F. (2016). "Environmental life-cycle assessment of biodiesel produced with palm oil from Colombia", IJLCA (in press)
Castanheira, É.G., Acevedo, H., Freire, F. (2014). "Greenhouse gas intensity of palm oil produced in Colombia addressing alternative land use change and fertilization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



Pathways
C1: Biodiesel produced in Brazil | C2: Biodiesel produced in Portugal based on imported Brazilian soybean oil | C3: Biodiesel produced in Portugal based on imported Brazilian soybean

Soybean origins (Brazilian states)
MT: Mato Grosso | GO: Goiás | PR: Paraná | RS: Rio Grande do Sul

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". JClP 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". JClP 54, 49-60.

LCA of soybean cultivation in Brazil

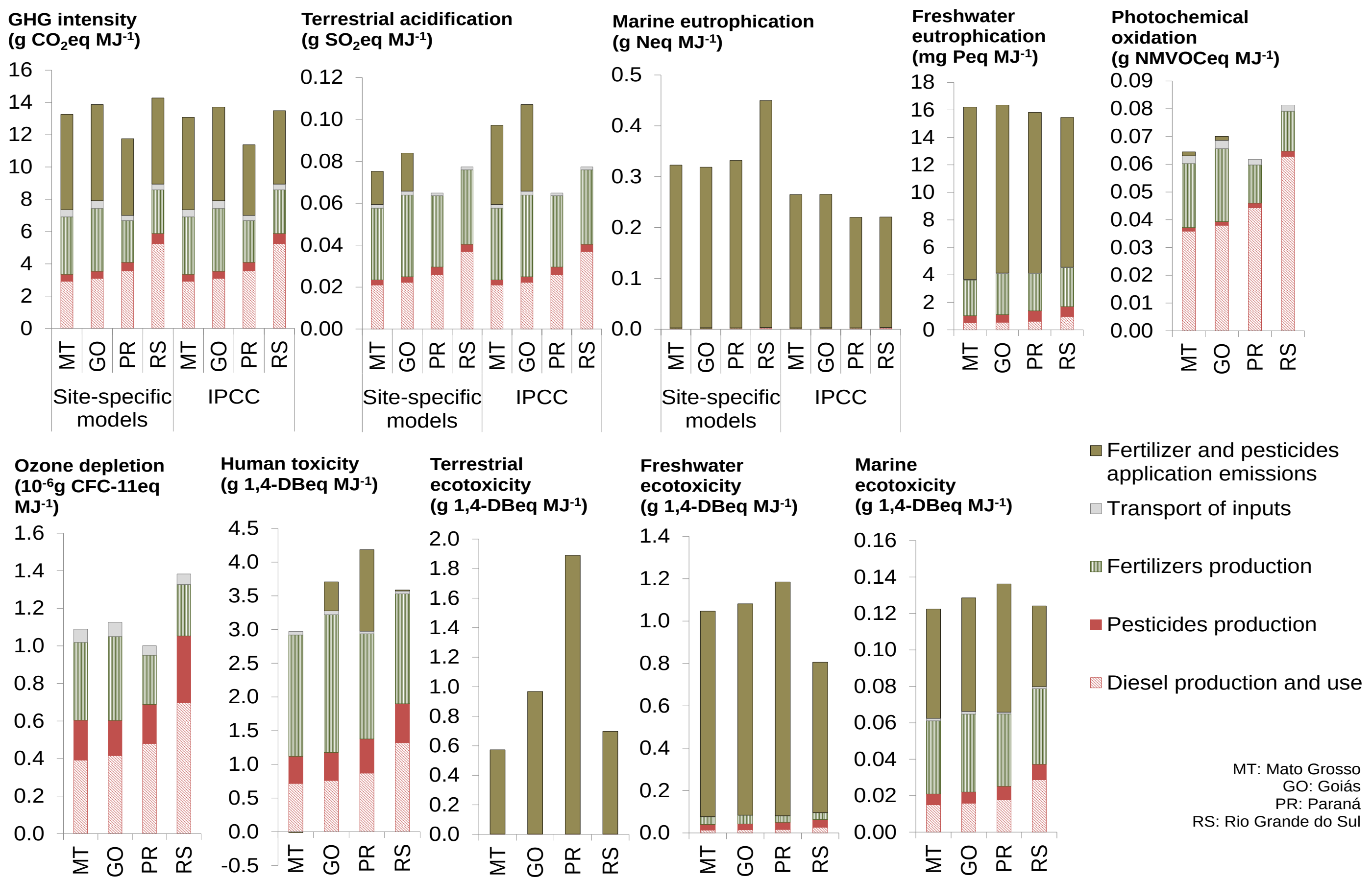
LCIA of soybean cultivation in four Brazilian states:

Mato Grosso

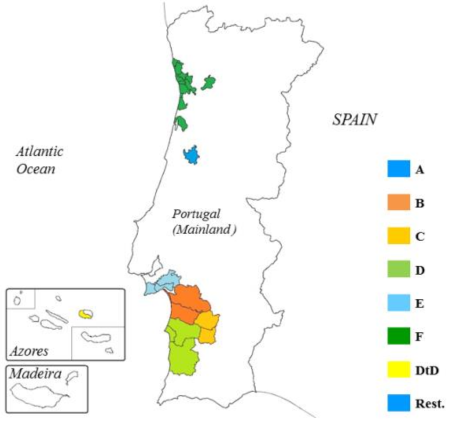
Goiás

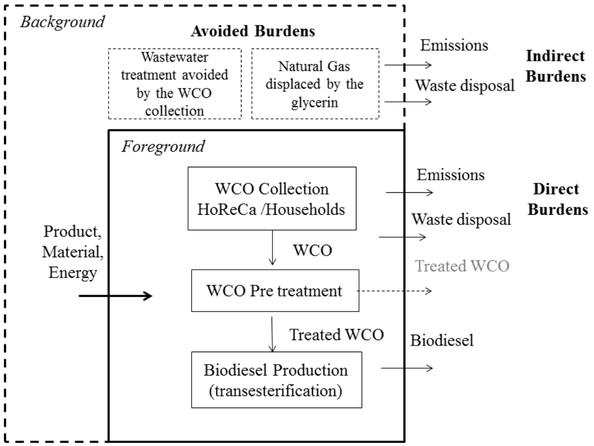
Paraná

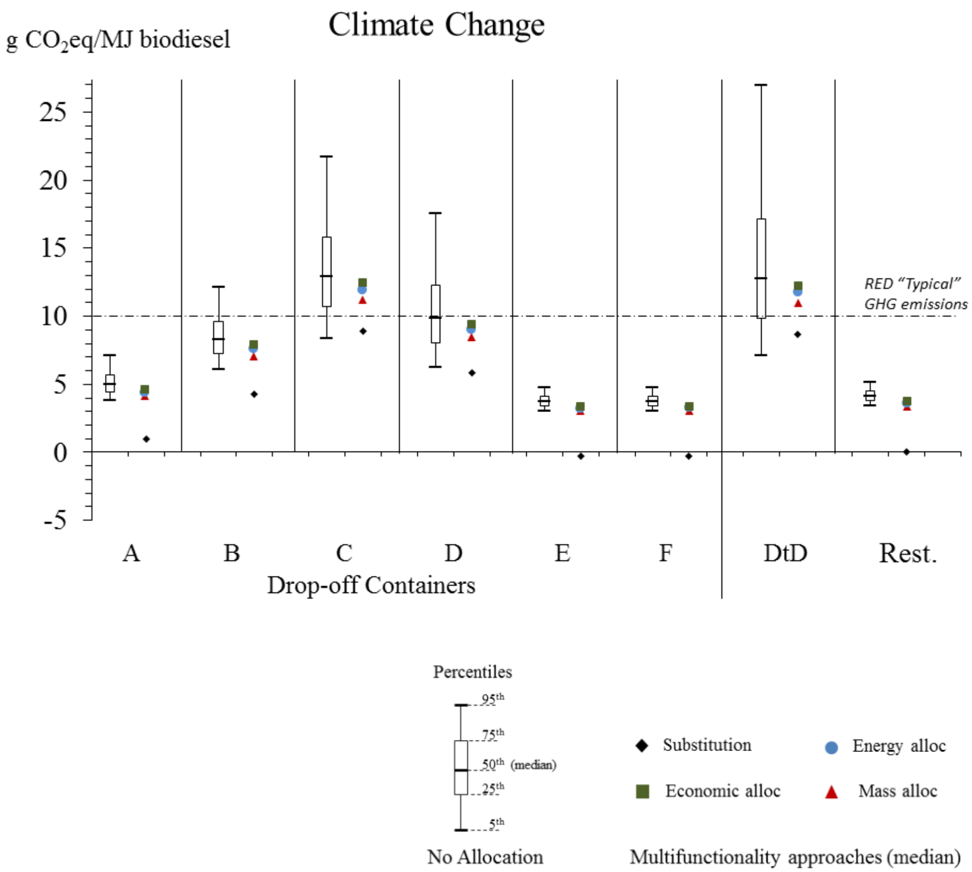
Rio Grande do Sul.



LCA of Waste Cooking Oil biodiesel addressing uncertainty



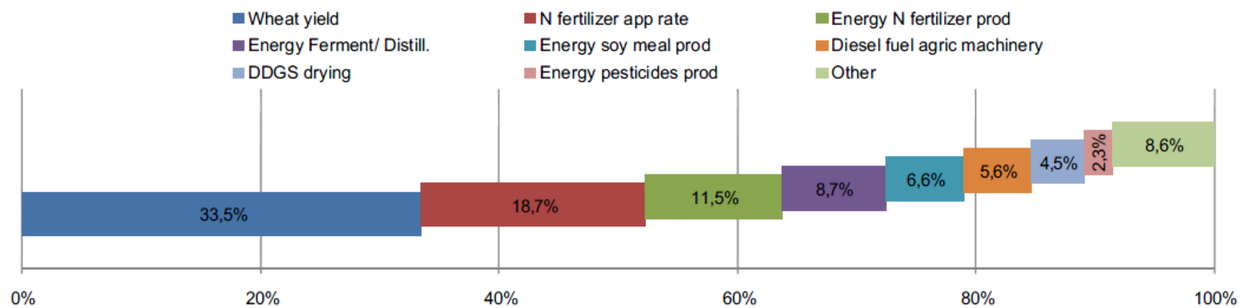




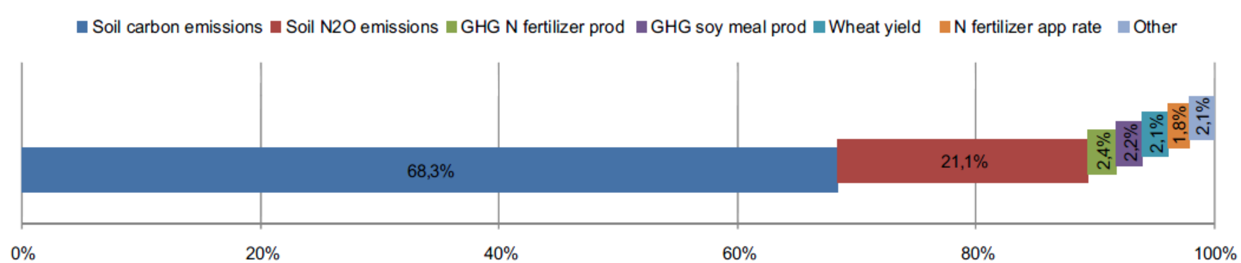
Caldeira, C., Queirós, J., Noshadravan, A., Freire, F. "Incorporating uncertainty in the Life Cycle Assessment of biodiesel from Waste Cooking Oil addressing different collection systems". Resources, Conservation and Recycling (in press)
Caldeira, C., Queirós, J., Freire, F. (2015). "Biodiesel from Waste Cooking Oils in Portugal: alternative collection systems". Waste&Biomass Valoriz 6 (5), 771-779.

LCA of wheat-based bioethanol

Flow chart illustrating the life-cycle chain (well-to-tank) of wheat-based bioethanol.



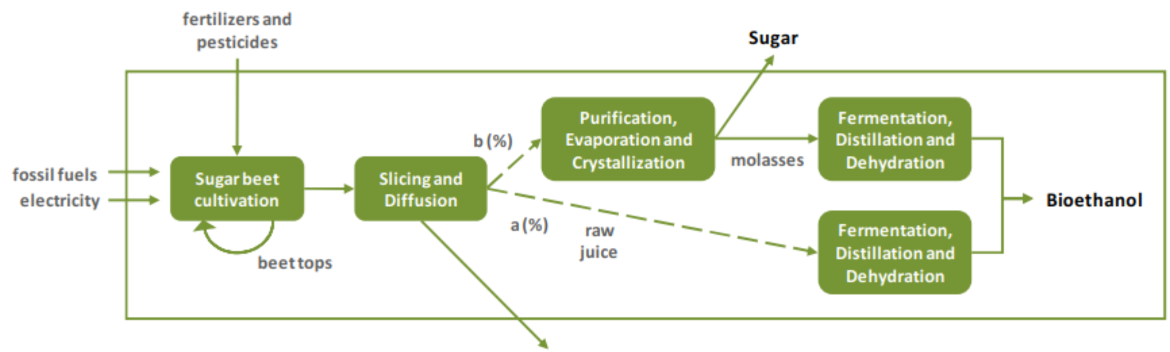
Contribution of input data to the variance of bioethanol ERenEf (substitution method).

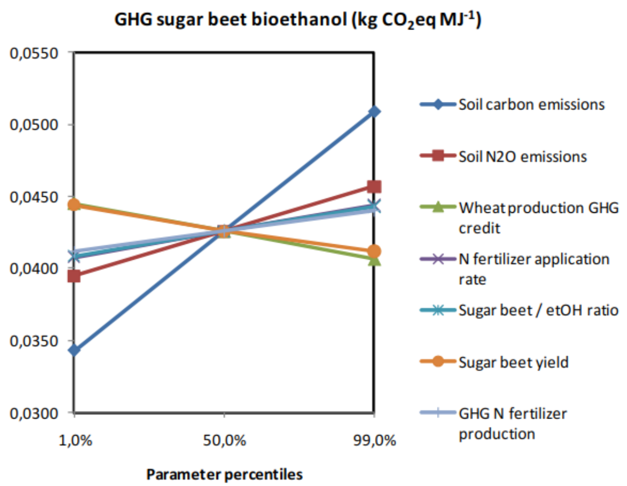


. Contribution of input data to the variance of bioethanol GHG intensity (substitution method; LUC scenario: low-tillage cropland to wheat cultivation).

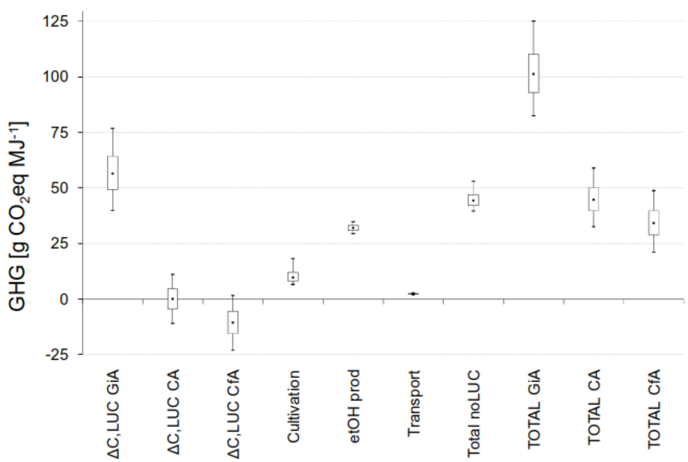
Malça, J., Freire, F. (2012). Addressing land use change and uncertainty in the life-cycle assessment of wheat-based bioethanol. Energy 45 (1), 519-527.

LCA of sugar beet-based bioethanol





Preliminary Sensitivity Analysis

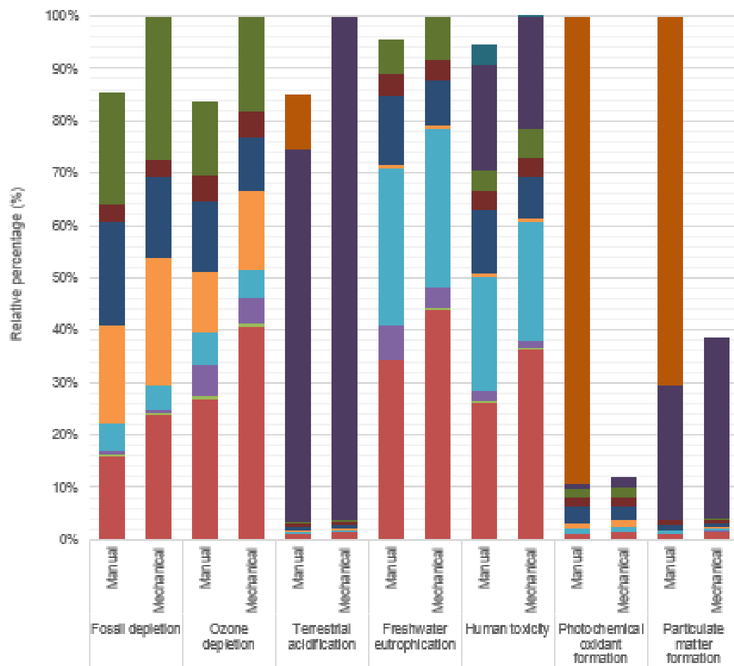


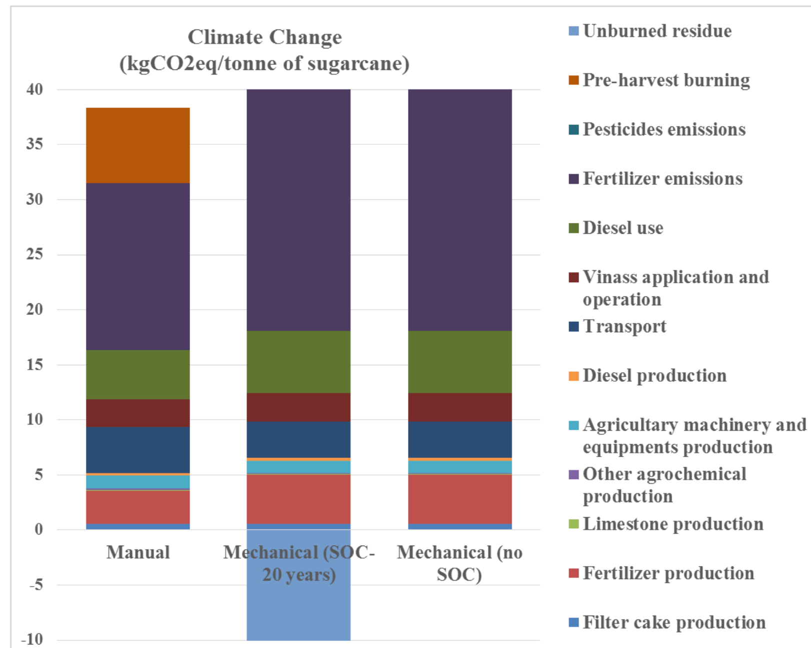
Non-allocated GHG emissions per LC stage

Malça, J., Freire, F. (2006). "Renewability and life-cycle energy efficiency of bioethanol and bio-ethyl tertiary butyl ether (bioETBE): assessing the implications of allocation". Energy 31 (15), 3362-3380.

Sugarcane production in Brazil
Environmental and health impacts

- A comparative LCA was conducted to compare the environmental impacts of manual and mechanical harvesting.
- We calculated characterization factors for particular matter for Brazil to quantify related health risks.



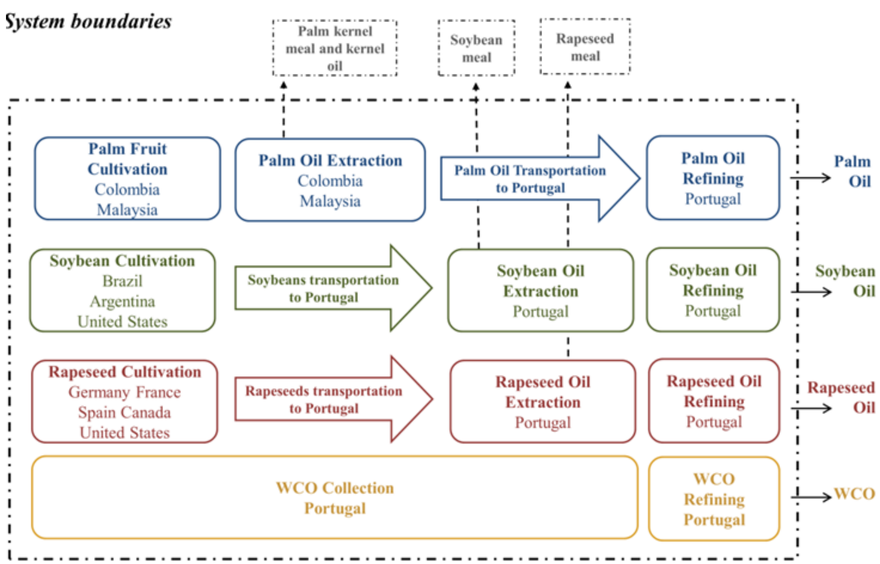


Social impacts: LC social impacts related to sugarcane production in Brazil were also assessed: SHDB and content analysis both identified Labor Rights and Decent Work as the impact category with the highest risk.

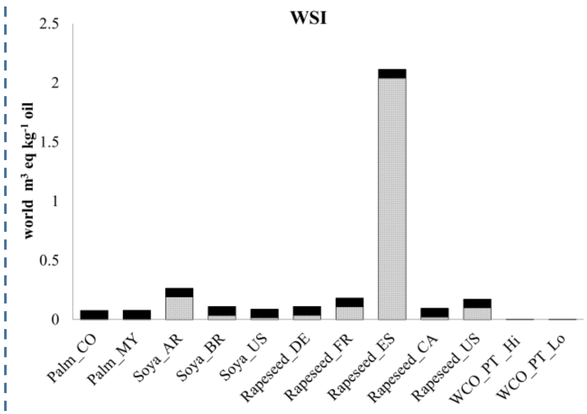
Chongyang Du, Luiz Kulay, Otavio Cavalett, Luis Dias, Fausto Freire (2016). "Environmental and health impacts of mechanical versus manual sugarcane harvesting in Brazil". Submitted to the IJLCA.

Water footprint of biodiesel

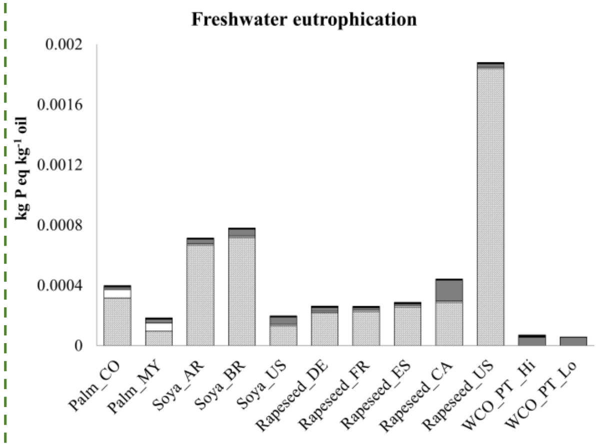
ISO 14046:2014 Environmental management - water footprint - Principles, requirements and guidelines.



Water consumption impacts



Water degradation impacts



and,
Acidification,
Ecotoxicity,
Human Toxicity

Caldeira, C., Quinteiro, P., Castanheira, E., Boulay, A-M, Dias, A.C., Arroja, L., Freire, F. (2016). "Water footprint profile of crop-based vegetable oils and waste cooking oil". (In final review)

Multi-Criteria Decision Analysis (MCDA) and LCA: RME

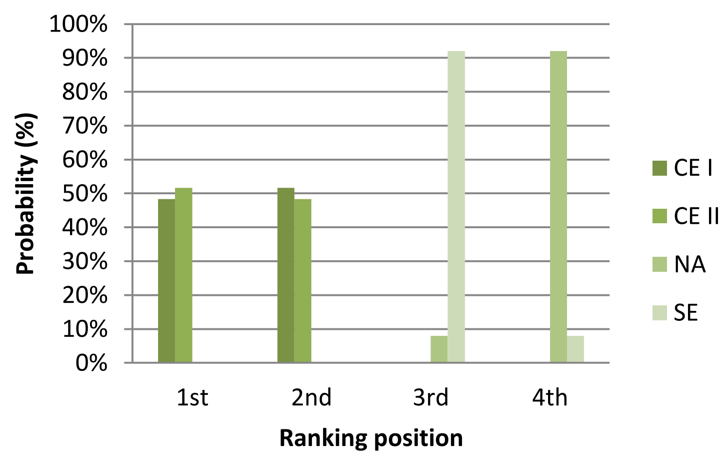
- MCDA can be integrated in LCIA to support robust decisions in the interpretation phase of LCA
- A new LCIA-MCDA approach was applied to a comparative LCA of RME biodiesel to provide insights on the relative ranking of four rapeseed cultivation systems

Variable Interdependent Parameters Analysis (VIP Analysis)

Summary | Range | Confrontation | Max Regret

	Germany	Canada	Spain	France
Germany		0.343	0.257	0.122
Canada	-0.129		0.072	-0.021
Spain	-0.087	0.2		-0.093
France	0.065	0.395	0.195	
Max Regret:	0.065	0.395	0.257	0.122

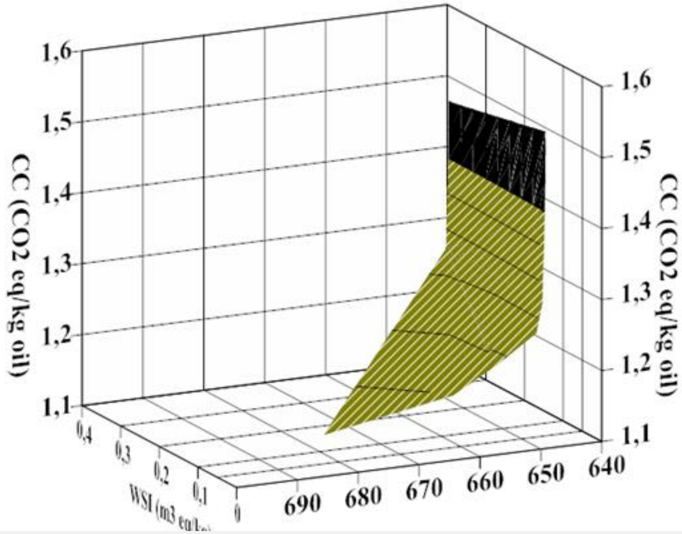
Stochastic Multicriteria Acceptability Analysis (SMAA)



Multi-objective optimization as decision support tool (I)

Objective minimized	Cost Euros/ton	Climate Change (CC) kg CO_2 eq /kg oil	WSI m^3 eq/kg oil	Eutrophication (EU) kg P eq /kg oil (*10^{-4})	Acidification (AC) kg SO_2 eq /kg oil (*10^{-2})	Human Toxicity (HT) CTUh / kg oil (*10^{-11})	Ecotoxicity (ET) CTUhe / kg oil
Cost	**642.7***	**1.48****	**0.354****	4.36	1.87	54.08	6.82
CC	676.4	**1.11***	0.145	3.63	1.44	14.41	3.79
WSI	650.1	1.31	**0.065***	**31.22****	**1.98****	**54.32****	**12.29****
EU	647	1.24	0.101	**1.95***	1.64	23.62	2.55
AC	676	1.13	0.128	3.53	**1.39***	0.90	1.92
HT	**702.6****	1.23	0.143	4.31	1.53	**0.78***	1.74
ET	667.8	1.32	0.089	2.79	1.72	0.91	**0.28***

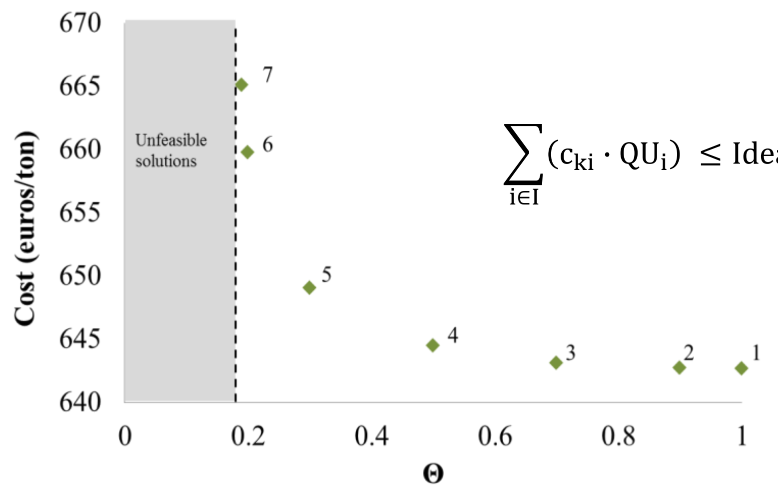
- More than 3 objectives is difficult to visualize



Caldeira, C., Olivetti, E., Kirchain, R., Freire, F., Dias, L., "A life-cycle multi-objective decision aiding tool to assess the use of secondary material in biodiesel production" (in final preparation)

Multi-objective optimization as decision support tool (II)

- We developed an approach to:
  - Facilitate the decision process - decide based on an overall environmental performance
  - Visualize in a simpler manner the tradeoff between cost and environmental impacts
  - Allow the decision-maker to decide based on an overall performance without needing to attribute weights to each of the environmental impacts



$$\sum_{i \in I} (c_{ki} \cdot QU_i) \leq \text{Ideal} + \theta\,(\text{Anti ideal} - \text{Ideal}) \quad \forall k \setminus \{\text{Cost}\}, \theta \in [0,1]$$

Caldeira, C., Olivetti, E., Kirchain, R., Freire, F., Dias, L., "A life-cycle multi-objective decision aiding tool to assess the use of secondary material in biodiesel production" (in final preparation)

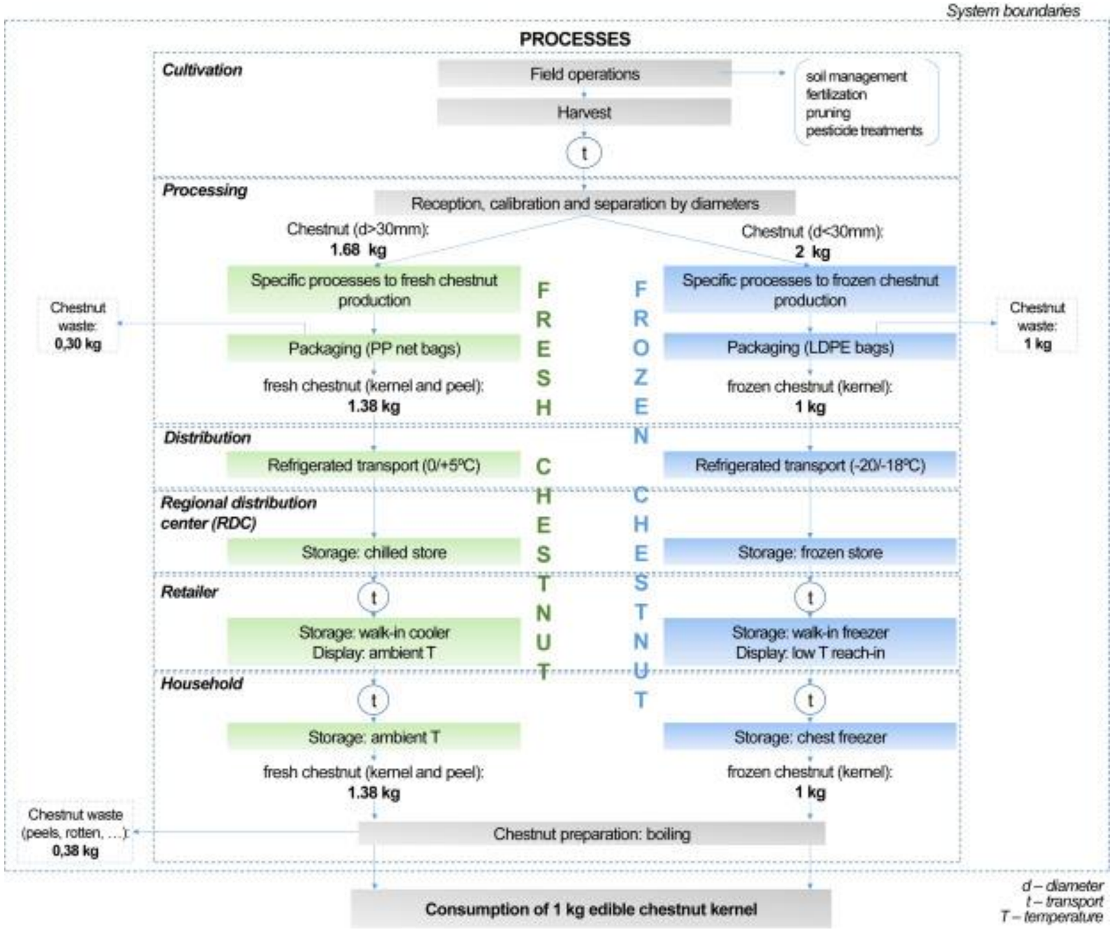
Agrifood

- LCA of fresh and frozen chestnut
- LCA of olive oil addressing alternative production systems
- …

Life-cycle assessment of fresh and frozen chestnut

- Portugal is the 3rd largest producer of chestnut in Europe (EU 28); 7th worldwide.
- Annual production of 24.7 thousand tons.
- Orchard area of 35 thousand hectares.
- About 70-80% of Portuguese chestnut is exported.

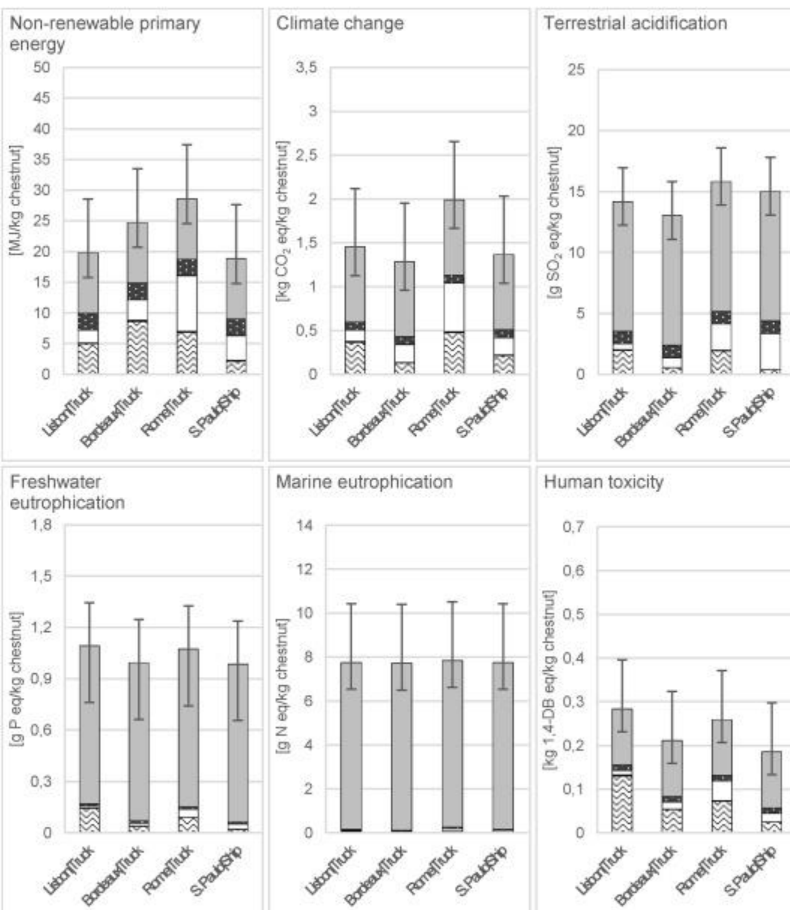
Objective: Compare the environmental impacts of fresh and frozen chestnut produced in Portugal (for exports and national consumption).



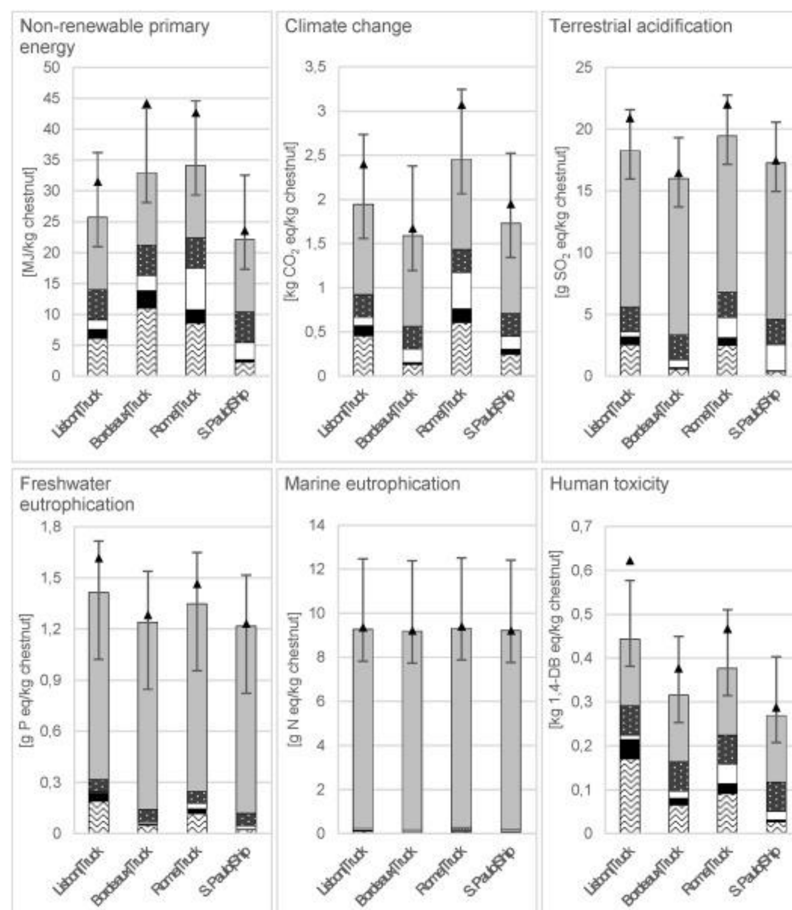
Rosa, D., Figueiredo, F., Castanheira E.G., Freire, F. (2016). "Life-cycle assessment of fresh and frozen chestnut". Journal of Cleaner Production (in press)

LC environmental impacts of fresh and frozen chestnut

Fresh chestnut kernel



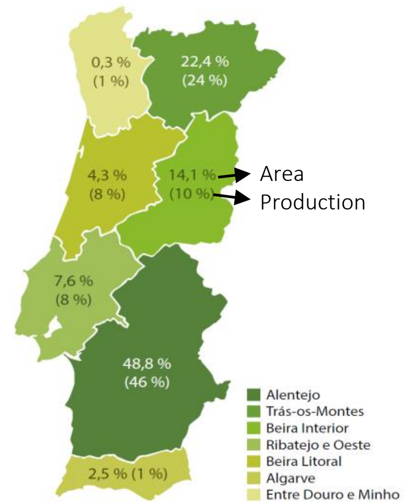
Frozen chestnut kernel



Rosa, D., Figueiredo, F., Castanheira E.G., Freire, F. (2016). "Life-cycle assessment of fresh and frozen chestnut". Journal of Cleaner Production (in press)

LCA of olive oil addressing alternative production systems

- Large variety of cultivation systems (family-level, traditional, intensive and organic)
- Two main technologies for olive oil extraction
- To assess the influence of the multifunctionality approach (allocation vs substitution)



Three-phase

Olive oil, pomace & wastewater

Two-phase

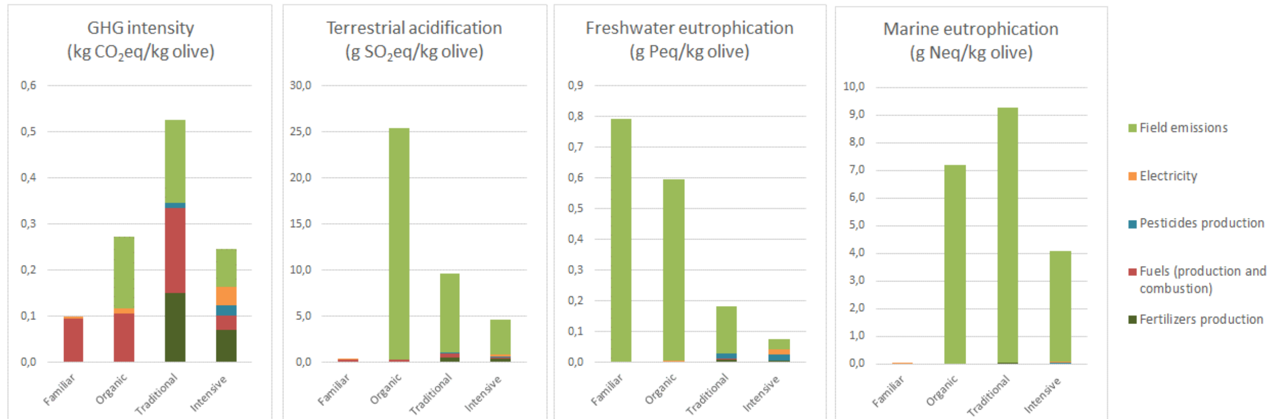
Olive oil & wet pomace

<u>Olive pomace is recovered</u> to produce **olive pomace oil** & **extracted pomace** (chemical extraction with hexane)

LCA of olive oil

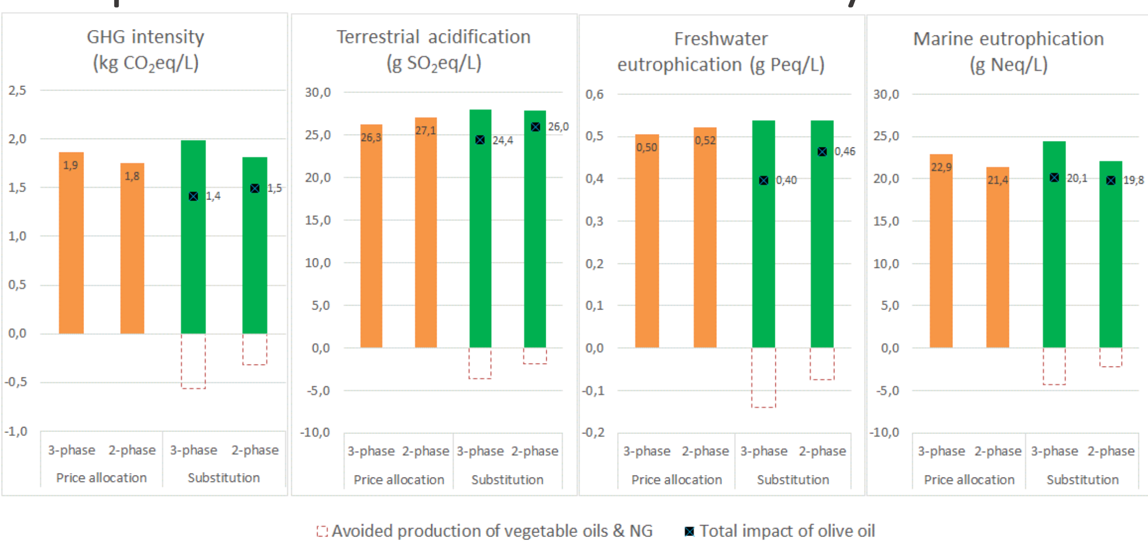
Impacts of different olive cultivation systems

- Cultivation is the LC phase which contributed the most to the overall environmental impacts.
- The high olive productivity of the intensive production system leads to comparatively low impacts.



Allocation vs Substitution

Impacts for the Intensive cultivation system



How comparable are the different types of olive oil systems (organic, familiar, intensive) ?

Thank You!

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For details about the team, projects and publications:

http://www2.dem.uc.pt/CenterIndustrialEcology/