

BioEcon Workshop “BIOECONOMY IN AGRICULTURE”

Institute of Soil Science and Plant Cultivation, Pulawy , June 2016



# Insights from the Center for Industrial Ecology - University of Coimbra

Fausto Freire



# Outline

- University of Coimbra, Portugal
- CIE: history, team, Research Agenda, projects ....
- Selected Research examples:
  - Agri-food and Forestry
  - Biofuels
  - Electricity in Portugal

# UNIVERSITY OF COIMBRA

## UNESCO WORLD HERITAGE LIST



Porto

Coimbra

Lisboa

Founded in 1290, more than 20 000 students, 1500 Professors



- **Research group** in the multi-disciplinary field of **Industrial Ecology**, part of ADAI-**Associated Lab for Energy, Transports & Aeronautics**.
- Team of faculty, researchers, Doctoral candidates, and visiting scholars. Research is carried out in collaboration with other institutions and with international partners.
- The CIE is actively involved in the **Energy for Sustainability Initiative** at the **Univ. of Coimbra** and in the MIT-Portugal program (PhD in Sustainable Energy Systems).
- Develops and applies tools to enhance the **sustainability** of **products and systems supported by life-cycle thinking**.
- Takes a **holistic and systematic** approach to promote **sustainable systems** and **R&D&I** with industry, public authorities, organizations...



CIE  
CENTER FOR  
INDUSTRIAL  
ECOLOGY

# Team



## CIE team

### Coordinator



**Fausto Freire**, CIE Coordinator, Assistant Professor at University of Coimbra  
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Fausto Freire is an assistant Professor (with tenure) at the University of Coimbra, Portugal, with research and teaching focusing on the emerging field of Industrial Ecology. He holds a PhD and a MSc (Energy) degrees in Mechanical Engineering from IST, Lisbon, and a Mech. Eng. Degree (specialization Thermodynamics and Fluids) from the University of Coimbra. Faculty at the MIT-Portugal program. Member of the coordination committee of the Energy for Sustainability initiative, the Ecoment Editorial Board, the executive committee of the Ibero American Life-Cycle network. Prof. Freire's research and teaching focuses on the development and application of life-cycle models to enhance the sustainability of products and systems (energy, industry, agriculture, buildings...). He has developed a novel approach integrating LCA and economic optimization models. He is a senior member and expert in energy of "Ordem de Engenharia", where he coordinates the Mechanical Engineering Center Region college. Prof. Freire is co-author of more than 200 publications (book chapters, ISI articles and conference papers, Scopus H index=11).

**Research areas:** Industrial Ecology, Life Cycle Assessment (LCA) and Management; Ecodesign; Uncertainty in LCA; Energy and Environmental Management; Life Cycle Sustainability Assessment; Applications to various systems (energy, industrial, agricultural, buildings...).

### Senior Researchers



**Érica Geraldes Castanheira**, Post-doctoral Researcher  
Email: [erica.geraldes@dem.uc.pt](mailto:erica.geraldes@dem.uc.pt) | Phone.: + 351 239 790 708 | [CV](#) | [DeGóis](#) | [ORCID](#) | [Scopus ID](#)

Érica Castanheira holds a PhD in Sustainable Energy Systems (MIT-Portugal Program, University of Coimbra), a MSc in Energy and Environmental Management (University of Aveiro) and an Environmental Engineering Degree (Polytechnic Institute of Coimbra-IP, School of Agriculture). She is a researcher in various PhD projects at ADALIA-LETA and the University of Coimbra. Her research focuses on the sustainability assessment of bio-based products (e.g., food, bioenergy), adopting metrics that relate environmental and social life-cycle impacts with economic added value along the products supply chain. In the past, she was invited researcher at the Brazilian Reference Center on Biomass-CEBRIOBIOEUSP (2011, 2014), researcher and Assistant Professor at IPC (2004-2009), visiting Professor at the Agostinho Neto University, Namibe, Angola (2008), visiting researcher at the Federal University of Mato Grosso, Cuiabá, Brazil (2007) and visiting student (ERASMUS) at the Faculty of Organic Agriculture Sciences, University of Alcala, Segurra (2001).

**Research areas:** Industrial ecology, life-cycle assessment, land-use change, biogeochemical cycles, environmental management, sustainability, agricultural products.



**João Malça**, Adjunct Professor at the Polytechnic Institute of Coimbra  
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João Malça holds a PhD (Mechanical Engineering), MSc (Heat Transfer) and Mechanical Engineering Degree (Thermodynamics and Fluids) from the University of Coimbra. Malça has over ten years of teaching experience in the College of Engineering of the Polytechnic Institute of Coimbra (DEM, PIC), covering a wide variety of subjects: Renewable Energy Systems, Energy and Environment, Heat Transfer Fundamentals and Applications, Industrial Refrigeration and Air Conditioning, Thermodynamics, Thermal Machines, Mechanics, Computer Aided Design, and Introduction to Programming. He is a senior member of the Portuguese Association of Industrial Refrigeration and Air-Conditioning Engineers. Malça's research interests include air energy, environmental and technical assessment of renewable energy systems, in particular HVAC systems and transport fuels production and use. Malça has also participated in projects addressing relevant technologies for developing countries (e.g., pumping water systems). In the past, Malça has been Head of the HVAC group at DEM, PIC (2004-2005), visiting researcher at the Instituto Nacional de la Reheime Agronomica (INRA), Paris (2002), and member of the Executive Board of DEM, PIC (1999-2002).

**Research areas:** Renewable and Sustainable Energy Systems; HVAC & Refrigeration Systems; Life Cycle Assessment.



**Rita García**, Post-doctoral Researcher  
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Rita Garcia holds a PhD in Sustainable Energy Systems (MIT-Portugal Program, University of Coimbra, 2016) and a MSc in Environmental Engineering (University of Coimbra, 2010). She is a researcher in several PhD projects at ADALIA-LETA and the University of Coimbra. Her research interests include life cycle modeling and assessment of energy and biomass-based systems, consequential modeling and fleet modeling.

**Research areas:** Life cycle assessment of energy, biomass-based and electric vehicle systems; consequential modeling; fleet modeling; Industrial Ecology; environmental management; environmental product declarations; product carbon footprint.

### Visitors



**Luiz Kulay**, Assistant Professor of Chemical Engineering Department at the Polytechnic School of the University of S. Paulo, Brazil  
Email: [luc.kulay@usp.br](mailto:luc.kulay@usp.br) | [CV](#)

Luiz Kulay holds a degree in Chemical Engineering (Maua Institute of Technology, Brazil, 1989), MSc in Chemical Engineering (Polytechnic School of the University of São Paulo, Brazil, 2000) and a PhD in Chemical Engineering (Polytechnic School of the University of São Paulo, Brazil, 2004). Additionally, he worked in the private sector as Environmental Control Engineer at the Suzano Pulp and Paper Co. (SPC) from 1990 to 1998. Currently he is Assistant Professor in the Department of Chemical Engineering of the Polytechnic School of the University of São Paulo, teaching the following undergraduate subjects: "Loss prevention in the chemical industry", "Chemical topics for Environmental Engineering I and II" and "Complementary Training - Fundamental Aspects". His teaching experience also includes the Post-Graduate Program in Chemical Engineering (PQIEUSP), in which he is responsible for the subject of "The Industry of Chemical Processes and Sustainability". Considering his capacities in both professional and academic spheres, Luiz has dedicated efforts and developments along the environmental area for nearly two decades, looking for basins in both environmental control and pollution prevention. Two thirds of his period were particularly dedicated to the research and implementation of Life Cycle Assessment in Brazil. He visited the Center for Industrial Ecology (CIE-UC) in 2014-2016 under several research projects.

**Research areas:** Life cycle assessment (LCA), Pollution prevention, Environmental management, Environmental optimization of industrial processes.



**Roland Clift**, Emeritus Professor of Environmental Technology, University of Surrey, UK  
Email: [r.clift@surrey.ac.uk](mailto:r.clift@surrey.ac.uk) | [CV](#)

Emeritus Professor of Environmental Technology and founding Director of the Centre for Environmental Strategy at the University of Surrey, previously Head of the Department of Chemical and Process Engineering at the University of Surrey, Visiting Professor in Environmental System Analysis at Chalmers University, Göteborg, Sweden, Adjunct Professor in Chemical and Biological Engineering at the University of British Columbia, Vancouver, Canada, past President and Executive Director of the International Society for Environmental Engineering and Technology, past member of the UK Royal Commission on Environmental Pollution, Ecotabelling Board and Science Advisory Council of the Department of the Environment, Food and Rural Affairs (DEFRA). Prof. Clift's research is concerned with systems approaches to environmental management and industrial ecology, including life cycle assessment and energy systems. He visited the University of Coimbra as invited Professor of the Energy for Sustainability initiative in April 2014, and March and November 2015, and collaborated in several research projects with CIE-UC.

**Research areas:** Environmental System Analysis, including Life Cycle Assessment, Industrial Ecology and Sustainable Energy Systems; Bioenergy; Sustainable Supply Chain; Engineering Ethics.



**Stuart Batterman**, Professor at University of Michigan, USA  
Email: [stuartb@umich.edu](mailto:stuartb@umich.edu) | [CV](#)

Stuart Batterman is Professor of Environmental Health Sciences at the University of Michigan (UM) School of Public Health. He also holds, or has held appointments in Civil and Environmental Engineering at UM, the Faculty of Science and Medicine at the University of Coimbra, Portugal, and at the Hebrew Medical School of Medicine in Kura-Zulu Natal, Durban, South Africa. He has a B.S. in Environmental Sciences from Rutgers University, and M.S. and Ph.D. in Civil and Environmental Engineering from the Massachusetts Institute of Technology. He has been engaged in research and technical research, teaching and service for over 25 years, including serving as associate editor for the ASCE Journal of Environmental Engineering, and the Journal of Environment and Public Health. He is currently the Director of the UM Center for Occupational Health and Safety Engineering. He was Fulbright Visiting Professor to the University of Coimbra (May-August 2012).

**Research areas:** Air quality and air pollution control engineering, environmental impact and risk analysis, exposure assessment, emerging contaminants, hazardous waste management, and environmental epidemiology.

### Former Researchers and Visitors

### Researchers



**Carla Caldeira**, PhD candidate in Sustainable Energy Systems (University of Coimbra, MIT Portugal Program)  
Email: [carla.caldeira@dem.uc.pt](mailto:carla.caldeira@dem.uc.pt) | Phone.: + 351 239 790 708 | [CV](#) | [DeGóis](#) | [LinkedIn](#) | [ORCID](#)

Degree in Technological Chemistry, Faculty of Sciences University of Lisbon (2001) and Master on Environment Science and Technology Life Cycle (2009). She had a Grant Research in Heterogeneous Catalysts at Instituto Superior Técnico, Lisboa / Universidade Pierre et Marie Curie - Laboratoire de Recherche, Paris (2001-2002) and was Senior Technical Specialist - Chemical Analyst at INCM (2002-2012) and researcher at SIM - CCIAM, Climate Change Impact, Adaptation & Mitigation at Faculty of Sciences University of Lisbon (2010-2012). She was a researcher at [INESC-Coimbra](#) on the BioTrans project (May - Dec 2012) and is currently a PhD student in Sustainable Energy Systems at the University of Coimbra.

**Research areas:** Life Cycle Assessment, Uncertainty, Multi Objective Optimization, Blending Models, Biofuel Systems



**Carla Rodrigues**, PhD candidate in Sustainable Energy Systems (University of Coimbra, MIT Portugal Program)  
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Graduated in Architecture by University of Coimbra (2008). Currently she is a MSc Student in Energy for Sustainability (University of Coimbra) with focus in Energy in Buildings and Urban Environment and a PhD student in Sustainable Energy Systems (University of Coimbra).

**Research areas:** Sustainable construction and retrofit, Life Cycle Assessment of buildings and building components, building sustainability assessment and certification systems, Life Cycle Costing, Streamlined environmental and cost LCA approaches.



**Carlos Ferreira**, PhD candidate in Mechanical Engineering (University of Coimbra) and researcher at ADA  
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Carlos Ferreira holds an MSc in Environmental Engineering (University of Coimbra, 2010). He is currently a PhD student in Mechanical Engineering (University of Coimbra), researcher at CIE on the project ERM (Environmentally Responsible Munitions), and also a Technical Team member in the NATO RTO AT/1177/175 Task Group. His research interests include recycling systems in ammunition, multifunctional systems and environmental improvement of ammunition systems.

**Research areas:** Life cycle assessment; Industrial ecology; Demilitarization; Valorization of energetic material; management of ammunition systems; toxicological impacts.



**Chongyang Du**, PhD candidate in Sustainable Energy Systems (University of Coimbra, MIT Portugal Program)  
Email: [yangyongce@tjmail.com](mailto:yangyongce@tjmail.com) | Phone.: + 351 939 954 588 | [LinkedIn](#)

Chongyang Du earned her Bachelor degree on Environmental Science from Renmin University of China (Beijing, China), and her Master degree on Environmental Management with the focus on Energy and the Environment from Duke University (Durham, USA). Currently she is a PhD candidate in the University of Coimbra under the MIT Portugal Program. Her PhD thesis subject is Integrating Multi-Criteria Decision Analysis in Life Cycle Sustainability Assessment. Chongyang is broadly interested in sustainable development, life cycle modeling, multi-criteria decision analysis, and biofuel.

**Research areas:** Life cycle sustainability assessment, multi-criteria decisions analysis, biofuel.



**Helena Monteirol**, PhD candidate in Sustainable Energy Systems (University of Coimbra, MIT Portugal Program)  
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Helena Monteirol holds a MSc in Energy for Sustainability by the University of Coimbra and an Architecture degree by the University of Porto. She is currently a PhD candidate on Sustainable Energy Systems Course from the MIT Portugal Program; she is a researcher in CIE (UC) and has spent a half year as a visiting student at the Building Technology Laboratory in MIT under Prof. John Fernandez co-supervision, where she was a member of Sustainability/MIT group and ASHRAE Boston Student chapter member.

**Research areas:** Sustainable construction, Bioclimatic architecture, Life cycle assessment of buildings and building components, Thermal simulation of buildings, Life Cycle Cost and study of maintenance activities in buildings



**Joana Bastos**, PhD candidate in Sustainable Energy Systems (University of Coimbra, MIT Portugal Program)  
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Joana Bastos has a degree in Architecture by the Faculty of Architecture, University of Lisbon (2008). She is currently a PhD candidate in Sustainable Energy Systems (MIT Portugal Program).

**Research areas:** Sustainable construction and refurbishment, Life cycle assessment of buildings and building components, Sustainable Urban Development



**Pedro Marques**, Researcher  
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He holds a MSc in Environmental Engineering, University of Coimbra (2010). Currently, he is a researcher at CIE working in the "BioHeavy - Extended 'wello- wheels' assessment of biodiesel for heavy transport vehicles" project (PTDC/SEN-TRA/117251/2010).

**Research areas:** Life cycle assessment, vehicles.



**Shiva Saadatian**, PhD candidate in Sustainable Energy Systems (University of Coimbra, MIT Portugal Program)  
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Graduated in Industrial Engineering by AZAD University of Tehran (2009). She holds a MSc in Energy for Sustainability (University of Coimbra, 2014). Currently she is a PhD candidate in the University of Coimbra.

**Research areas:** Sustainable construction and refurbishment, Life Cycle Assessment of building components, building sustainability assessment, Life-cycle analysis of fenestrations.



**Vanessa Tavares**, PhD candidate in Sustainable Energy Systems (University of Coimbra, MIT Portugal Program)  
Email: [vanessamtavares@tjmail.com](mailto:vanessamtavares@tjmail.com) | Phone.: + 351 914 726 892 | [ORCID](#)

Architecture degree by University of Porto, Post-graduated in Energy for Sustainability by University of Coimbra.

**Research areas:** Sustainable construction and refurbishment, life cycle assessment of buildings and building components, energy and waste management in buildings, off site construction (prefab architecture), sustainability certification of buildings.

# 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

Urban metabolism & Material Flow Analysis, MFA & LCA

# Main Application areas

- **Energy** | Bioenergy, biofuels, & other renewables, electricity, natural gas,
- **Agrifood and Forestry** | fruits, vegetables, vegetable oils, animal-derived products, sustainable diets, wood-based materials, LUC
- **Transportation** | sustainable mobility, vehicle components and systems (electric vehicles, trains, fleet analysis, batteries), powertrains
- **Buildings and Sustainable Architecture** | building components, prefabrication, sustainable construction and retrofit, thermal insulation, sustainable urban development
- **Waste management** | waste cooking oil, demilitarization, wastewater management, anaerobic digestion, building waste management, beef tallow
- **Industrial Systems, Packaging**

# Ongoing projects

|           |                                                                                                                                          |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------|
| 2016-2019 | SABIOS: Sustainability assessment of bioenergy systems: a life cycle multi-criteria decision-support approach, including land use change |
| 2016-2019 | SUSTAINFOR: Sustainability assessment of forest sector management strategies in the context of a bioeconomy                              |
| 2016-2019 | UrbanWins: Urban metabolism accounts for building waste management innovative network strategies                                         |
| 2016-2017 | BIO2URBAN: Biodiesel blends for road vehicles in urban areas                                                                             |
| 2018      | LCA and Ecodesign of packaging for pharmaceutical products                                                                               |

# Concluded projects

## Funded by Companies

- **ROLLS-ROYCE Environment Advisory Board**  
2015-16: Lifecycle GHG Analysis of Train Power Systems: Diesel, Hybrid and LNG
- **Portuguese Association of Biofuel Producers – APPB**  
2014-16: LCA of GHG emissions for rapeseed-based biodiesel in Portugal  
2010-11: LCA of GHG emissions for soybean-based biodiesel in Portugal
- **CIE Plasfil – Automotive Plastic components producer**  
2013-15: EDIL - EcoDesign and Impact Labelling

## with international partners

- 2010-14: Capturing Uncertainty in Biofuels for Transportation, **MIT, USA,**
- 2010-14: Economic and Env. Sustainability of Electric Vehicle Syst. **USA, MIT**
- 2013-15: LC Environmental Sustainability Assessment of Bioenergy **USP, Brazil**
- 2011-13: **BIOACV** – Comparative LCA of Biodiesel from Soybean Oil and Animal Fat, Methylic and Ethylic Routes **USP, Brazil**
- 2011-15 Environmentally Responsible Munitions, several EU

# Concluded projects

## National projects

- 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
- 2011-2013: **EcoDeep** - Eco-efficiency and Eco-management in Agro-industry



# Selected Research from

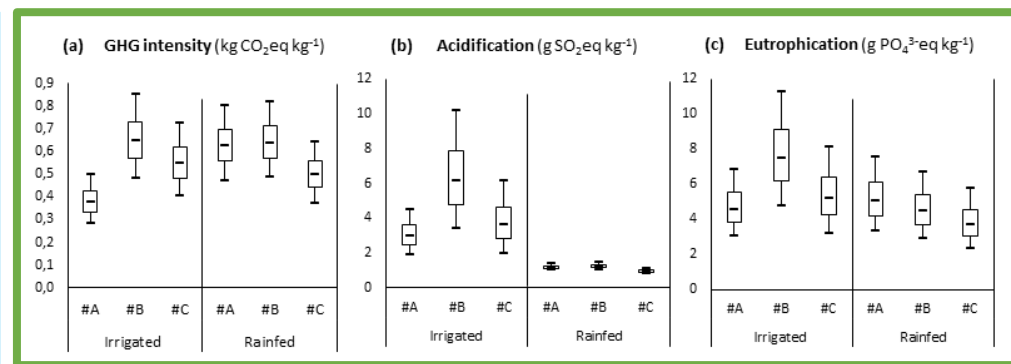
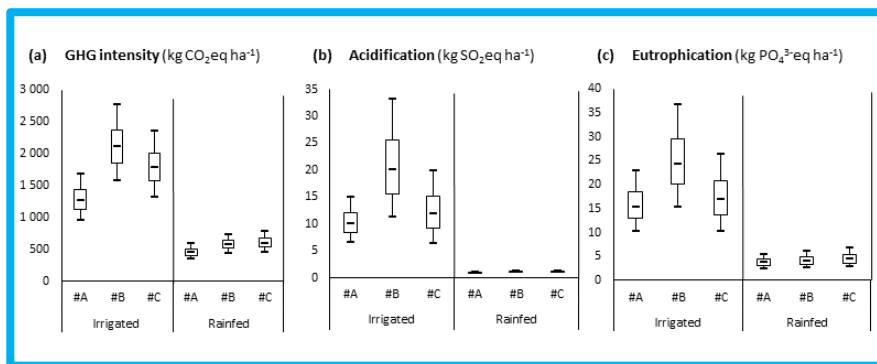
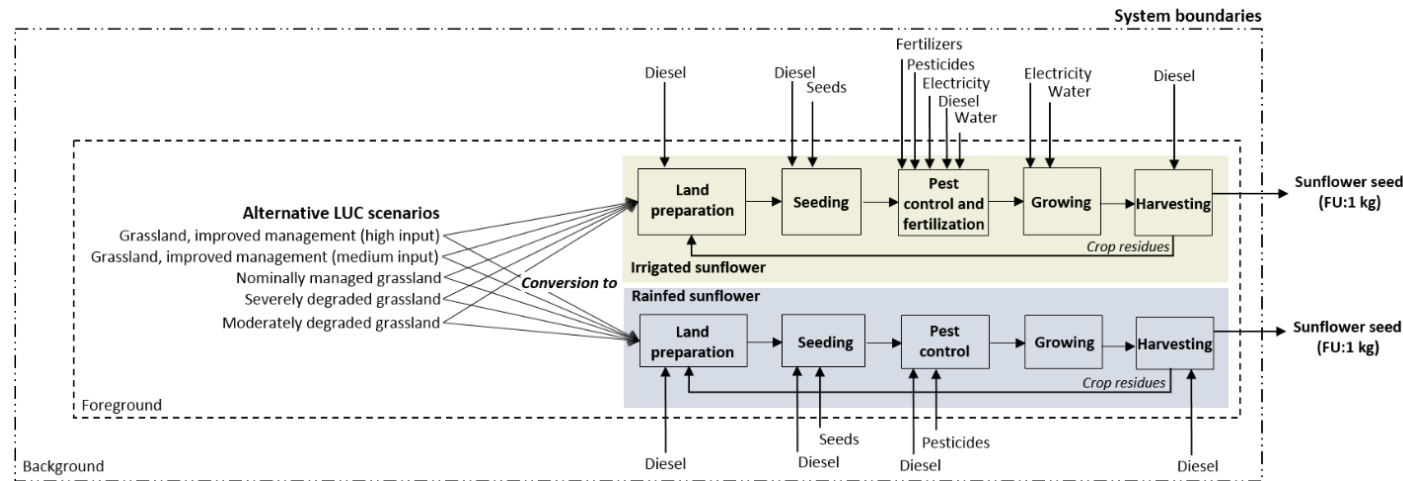
- Agri-food and Forestry
- Biofuels
- Electricity in Portugal

# Agrifood and Forestry

- Sunflower
- Chestnut
- Olive oil
- Dairy products
- Wood-based materials

# LCA of sunflower cultivation in PT

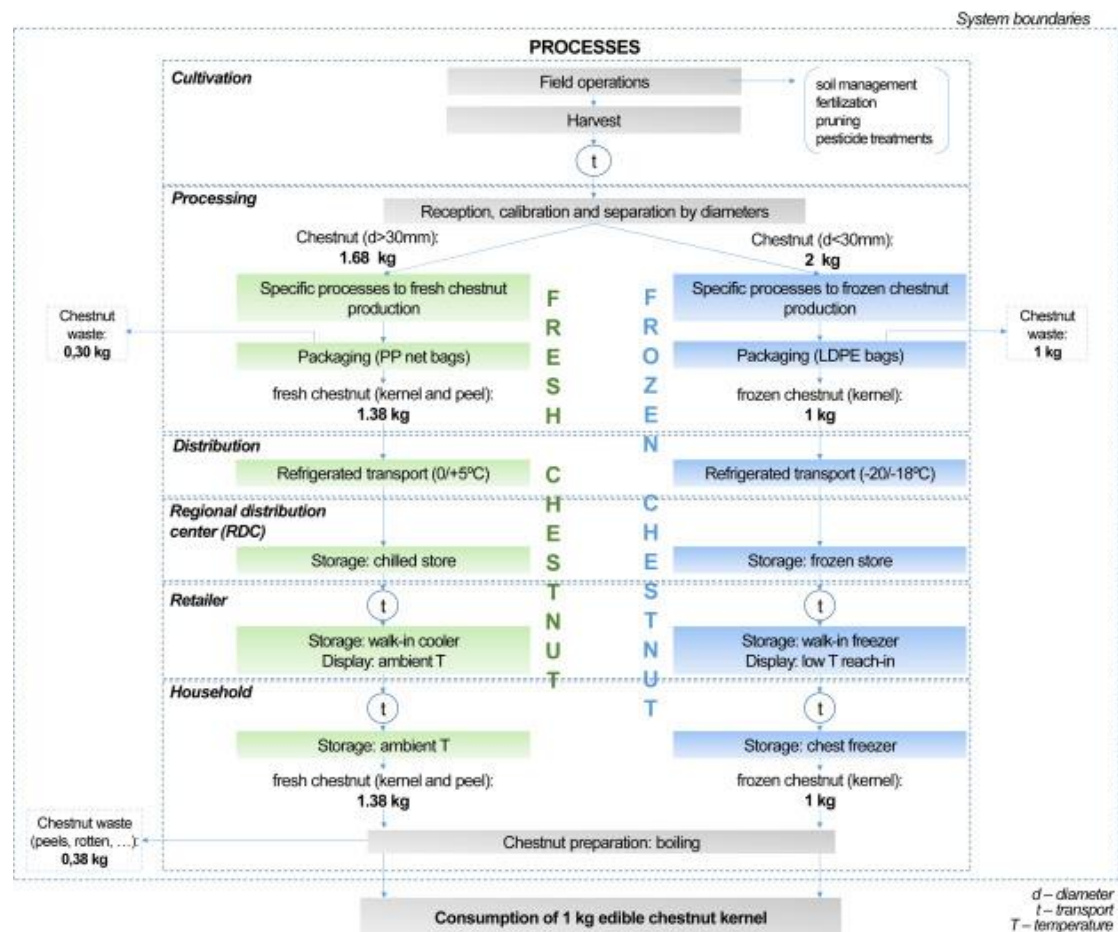
- Irrigated vs rainfed
- LUC scenarios
- Different functional units (kg and ha)
- Uncertainty analysis



# LCA of fresh and frozen chestnut

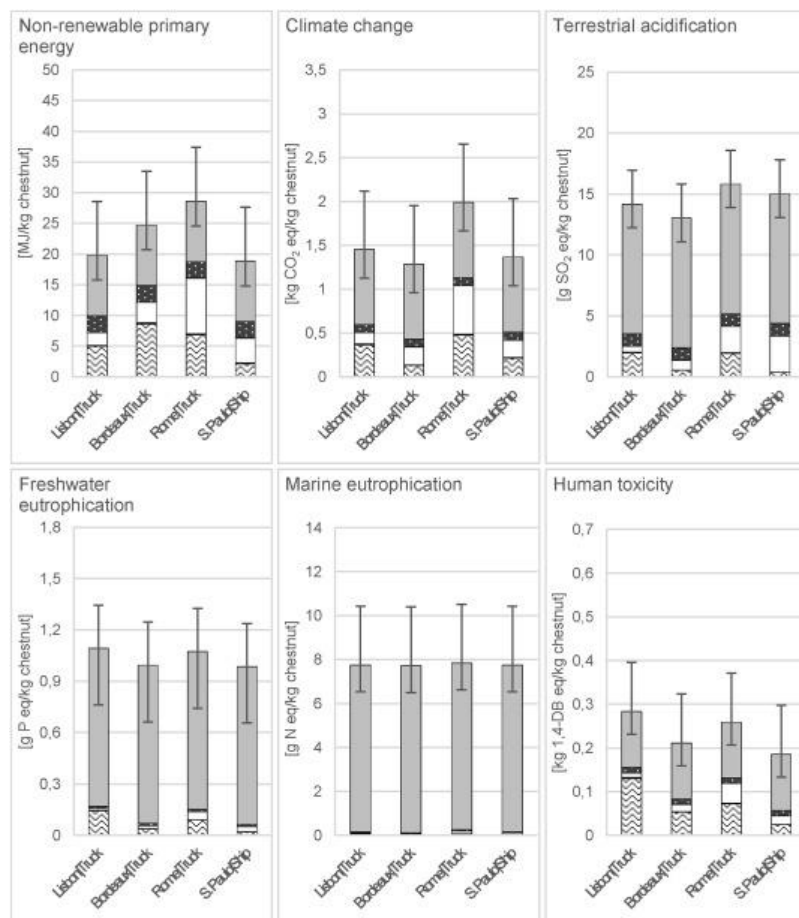
- Portugal is the 3rd largest producer of chestnut in Europe (EU 28)
- Annual production of 27 thousand tons
- Orchard area of 35 thousand hectares
- 70-80% of Portuguese chestnut is exported

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



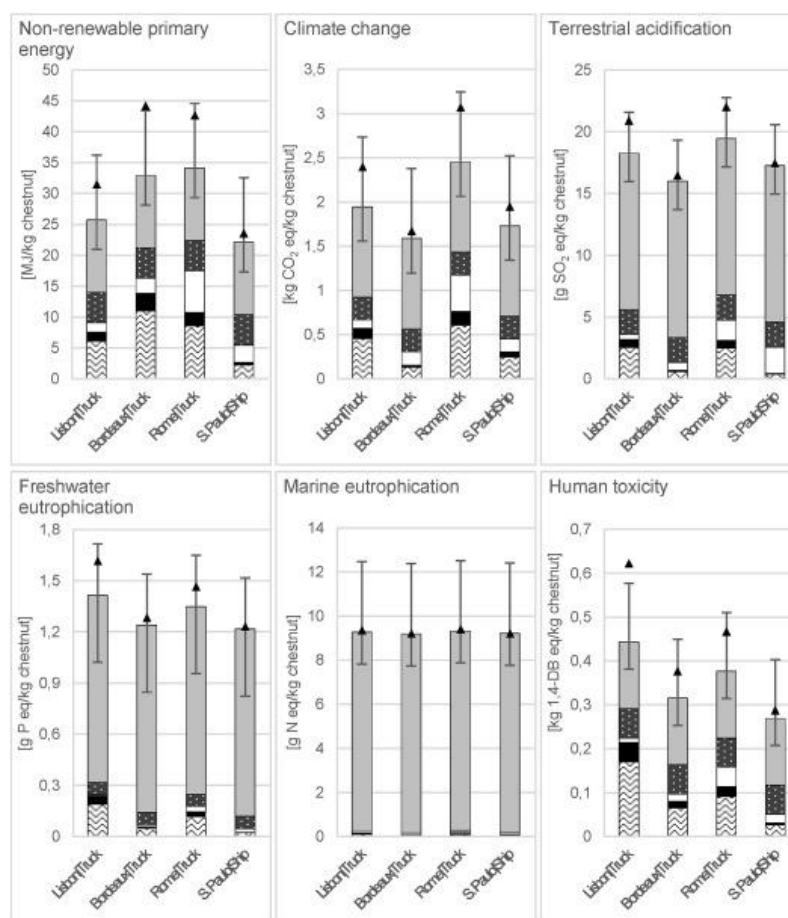
# LC impacts of fresh and frozen chestnut

## Fresh chestnut kernel



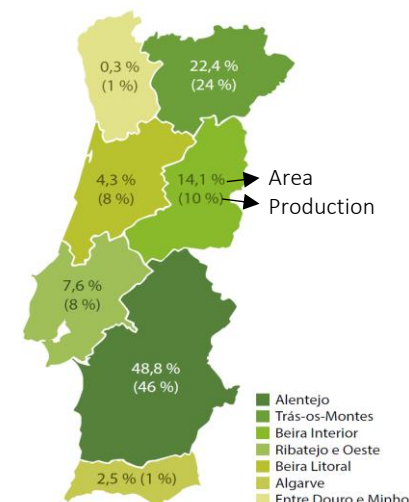
July 18, 2016

## Frozen chestnut kernel



# LCA of olive oil addressing alternative production systems

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



Three-phase

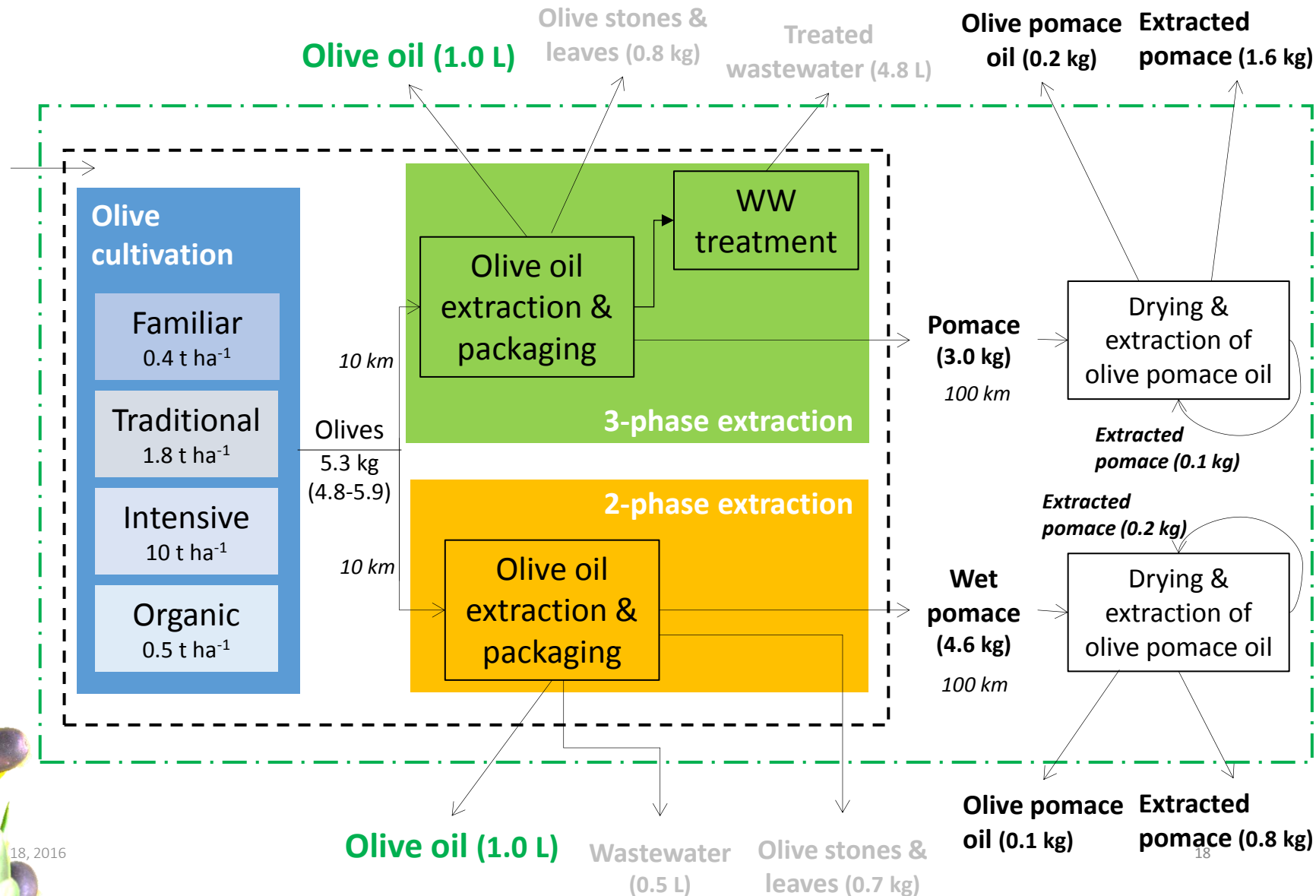
Olive oil, pomace & wastewater

Two-phase

Olive oil & wet pomace

Olive pomace is recovered to produce olive pomace oil & extracted pomace (chemical extraction with hexane)

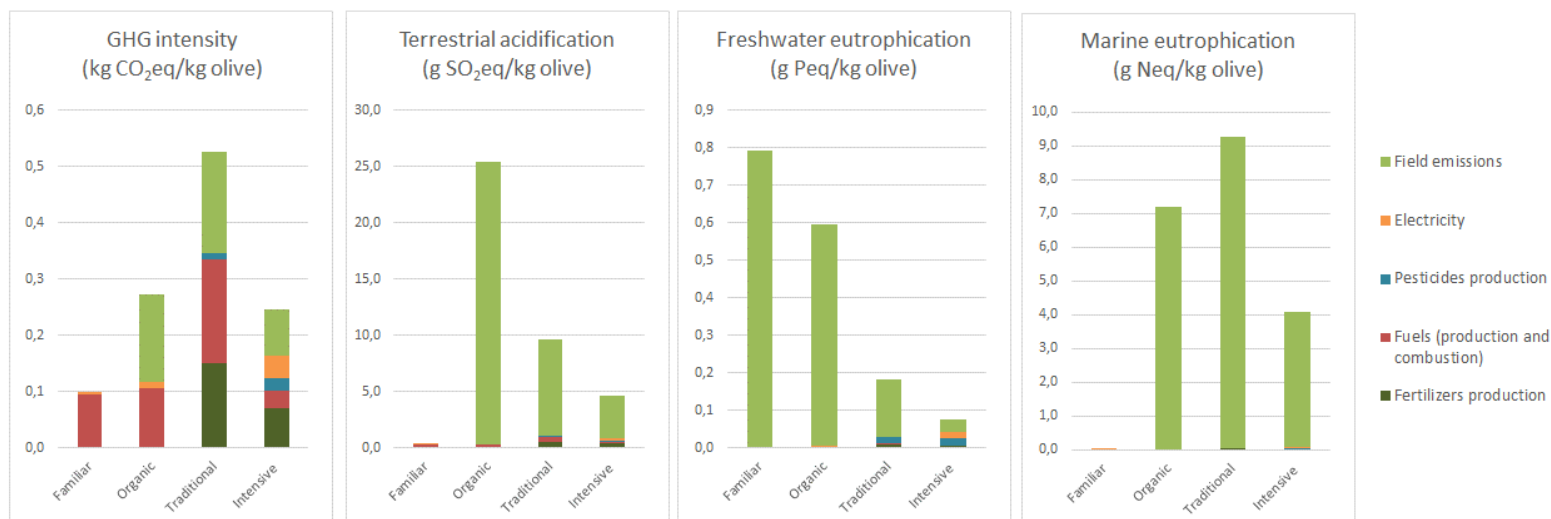
# LC model addressing valorization of pomace



# LCA of olive oil

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

## Impacts of different olive cultivation systems



**But:** How comparable are the different systems and types of olive oils? (organic, familiar, intensive)

# Biofuels

## ○ LCA of biodiesel:

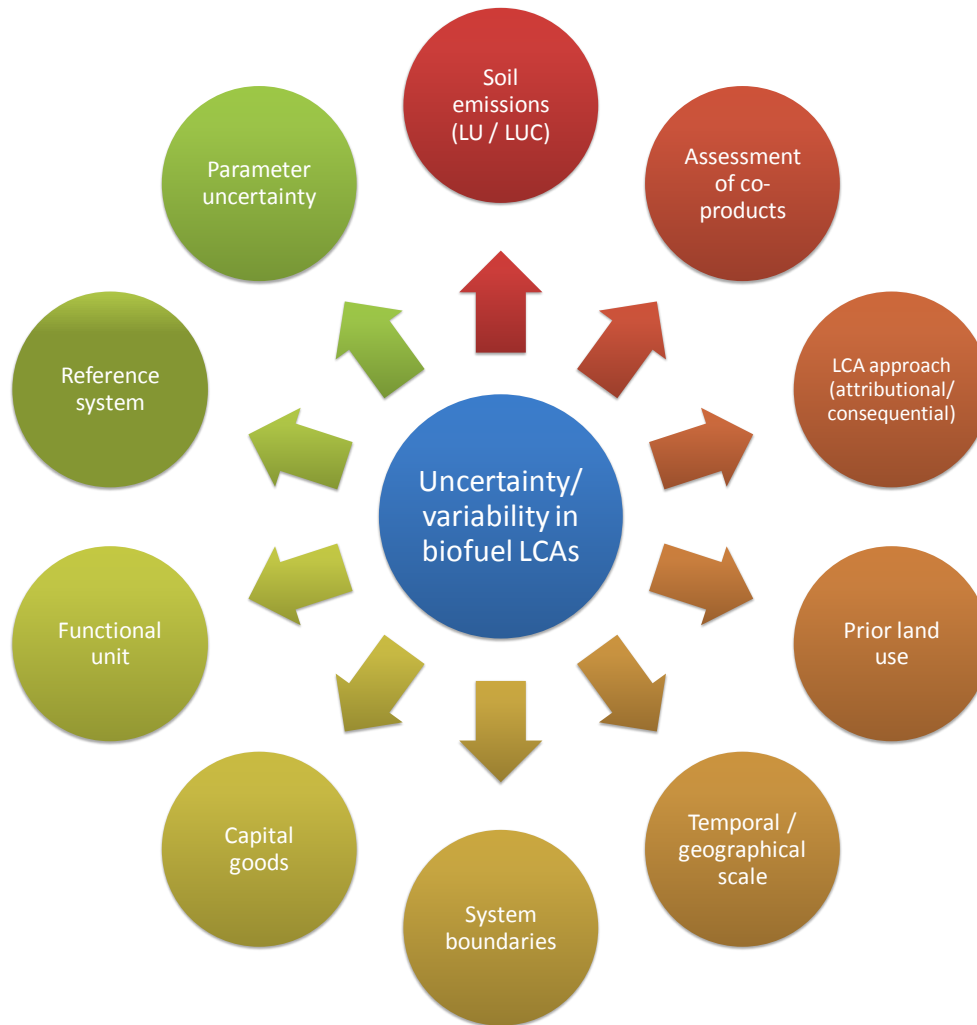
- Virgin oils – rapeseed, palm, soybean, sunflower
- Microalgae
- Waste cooking oils
- Beef tallow

## ○ LCA of bioethanol:

- Wheat
- Sugar beet
- Sugarcane

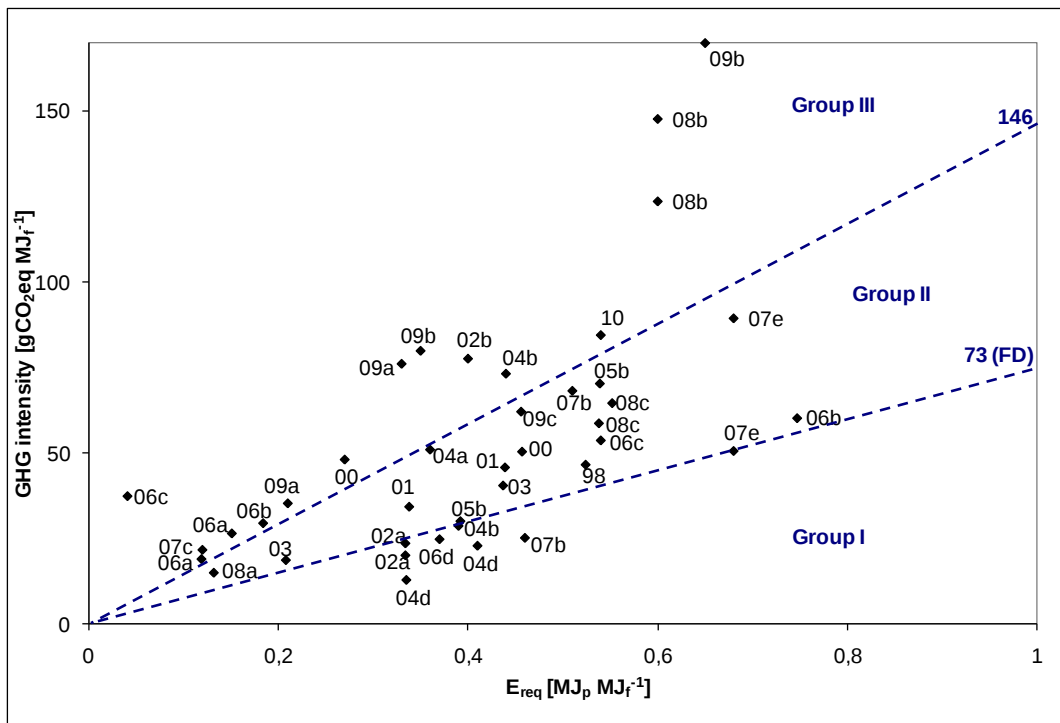
- Well-to-Tank & Tank-to-Wheels analysis
- Land Use Change (LUC)
- Agriculture practices and pathways
- Uncertainty analysis
- Multicriteria decision analysis
- Multi-objective optimization
- Social impacts
- Water footprint
- Multifunctionality

# LCA of biofuels: sources of uncertainty



**METHODOLOGICAL CHALLENGES AFFECTING  
THE RESULTS OF BIOFUEL LC STUDIES**

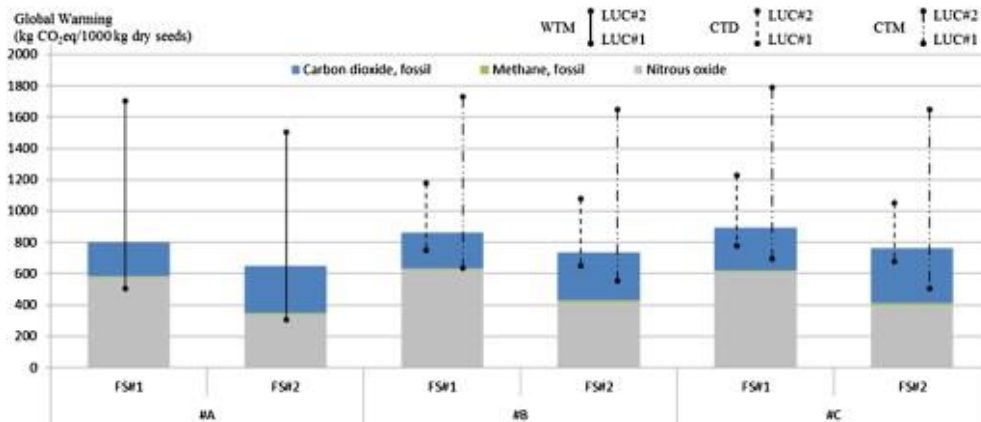
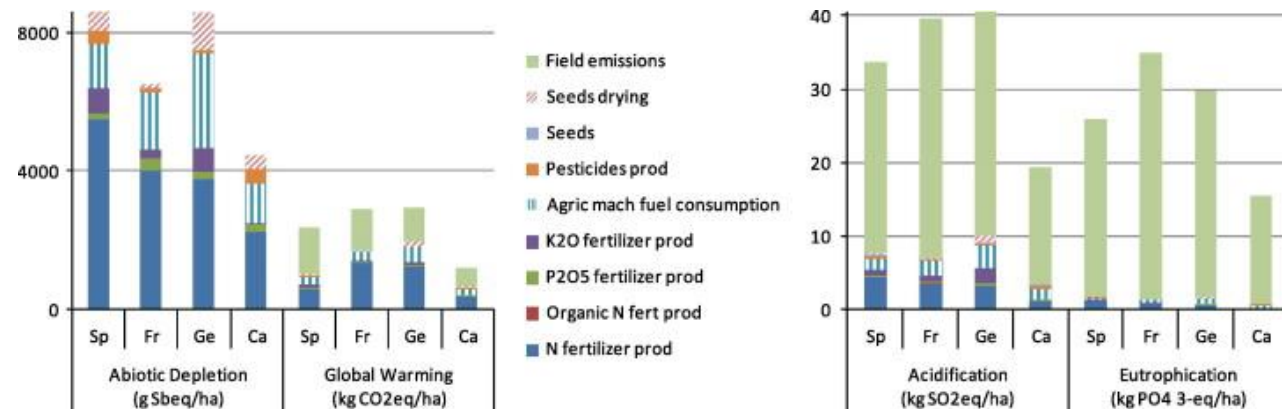
- Biofuel LC studies have varying and sometimes contradictory conclusions, even for the same biofuel type and pathway.
- Significant disagreement and controversy exist regarding the actual benefits of biofuels displacing fossil fuels.



| Group | Key modeling issues addressed                                                                                      | GHG intensity per nonrenewable primary energy use requirement (gCO <sub>2</sub> eq MJ <sub>p</sub> <sup>-1</sup> ) |                                                                    |                            |
|-------|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|----------------------------|
|       |                                                                                                                    | < 73                                                                                                               | 73 – 146                                                           | > 146                      |
| III   | soil carbon emissions +<br>soil N <sub>2</sub> O emissions (↑, high uncert.)<br>+ fossil CO <sub>2</sub> emissions |                                                                                                                    |                                                                    | 10, 09b, 08b               |
| II    | soil N <sub>2</sub> O emissions (↓ or ↑)<br>+<br>fossil CO <sub>2</sub> emissions                                  |                                                                                                                    | 09c, 08c, 08a, 07c,<br>07b, 06c, 06b, 05b,<br>04b, 04a, 03, 01, 00 | 09a, 07c, 06c,<br>06a, 02b |
| I     | soil N <sub>2</sub> O emissions (0 or ↓)<br>+<br>fossil CO <sub>2</sub> emissions                                  | 06d, 04d, 02a                                                                                                      | 98                                                                 |                            |

# 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)

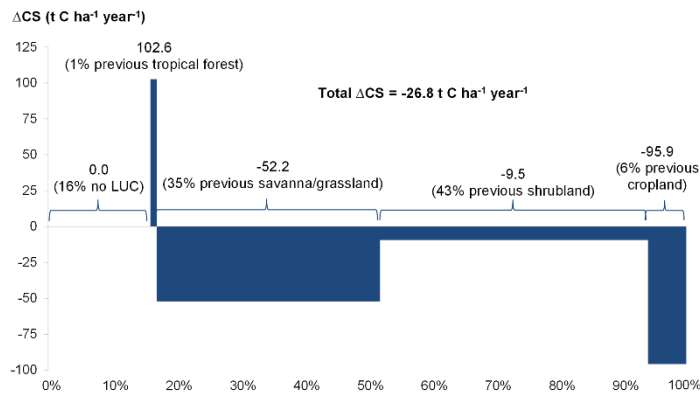
Queirós, J., Malça, J., Freire, F. (2015). "Environmental Life-Cycle Assessment of Rapeseed Produced in Central Europe: Addressing Alternative Fertilization and Management Practices". JCI 99, 266-274.

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.



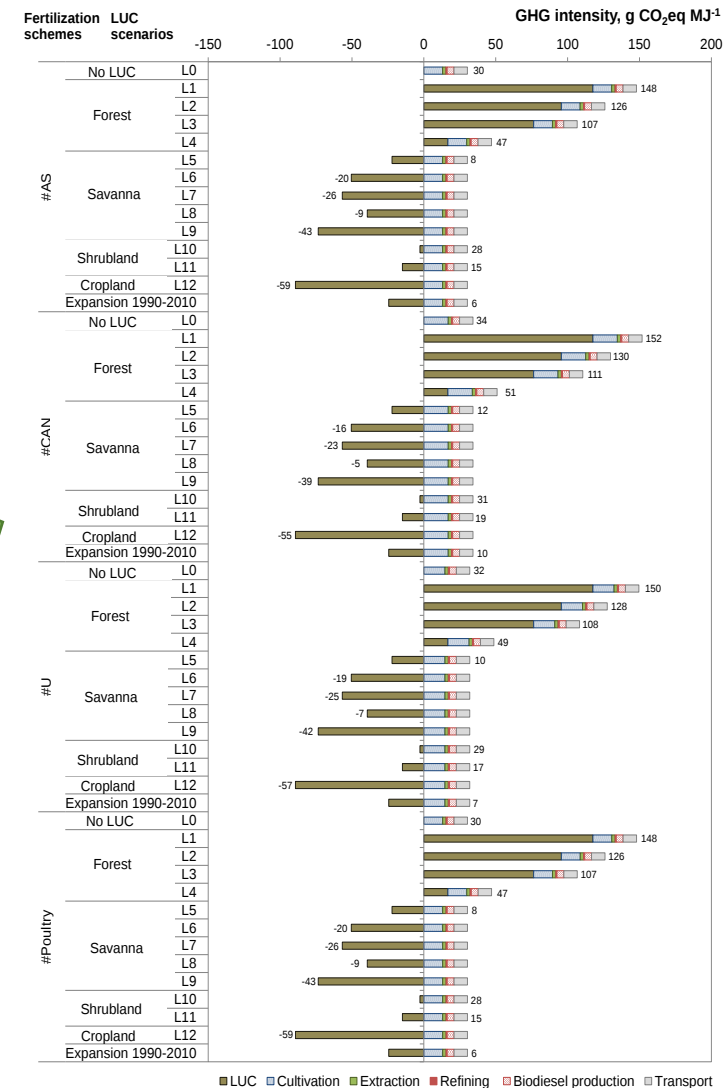
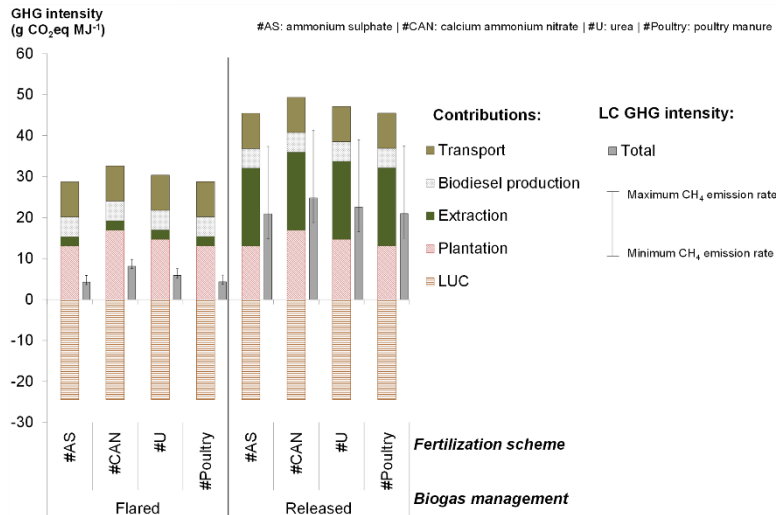
# LCA of biodiesel produced with palm oil from Colombia



LUC @ Colombia  
(1990-2010)



LUC  
scenarios

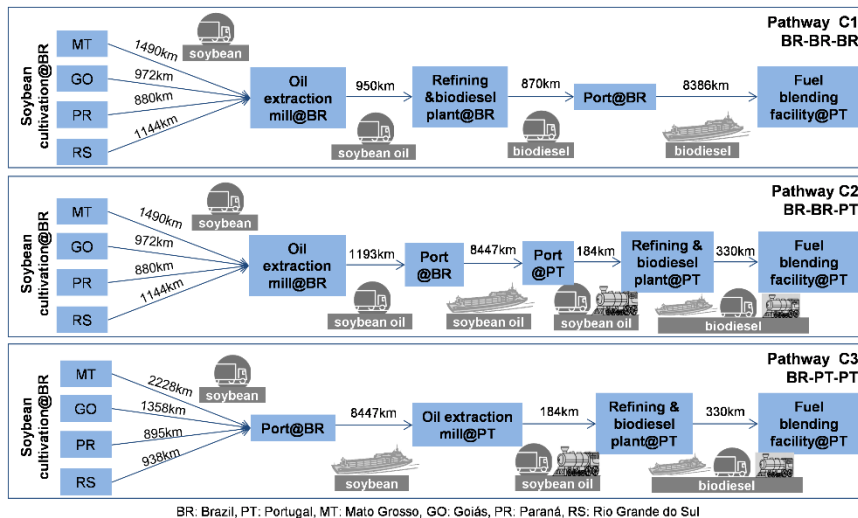


Castanheira, É., Freire, F. (2016). "Environmental life-cycle assessment of biodiesel produced with palm oil from Colombia", IJLCA (in press)

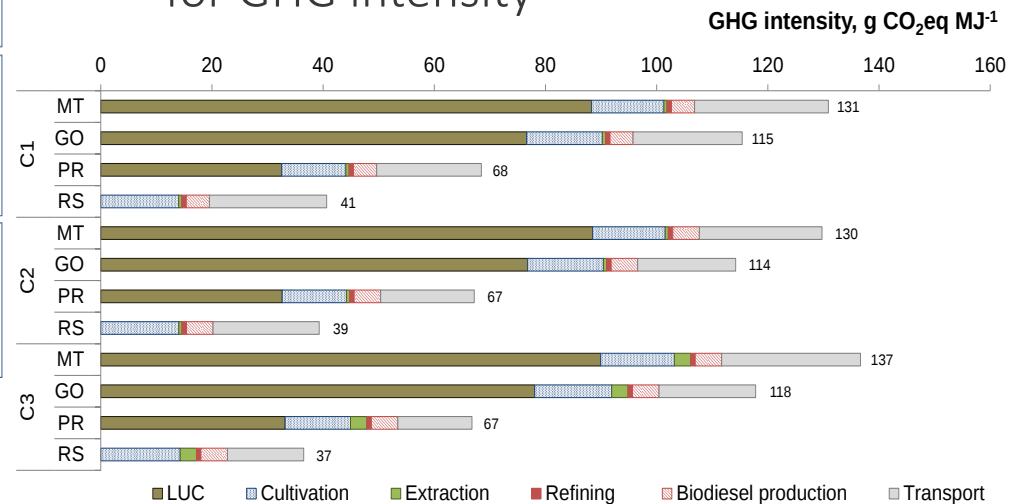
Castanheira, É.G., Acevedo, H., Freire, F. (2014). "Greenhouse gas intensity of palm oil produced in Colombia addressing alternative land use change and fertilization scenarios". *App Energy* 114, 958-967.

# 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". JCI 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". JCI 54, 49-60.

# LCA of soybean cultivation in Brazil

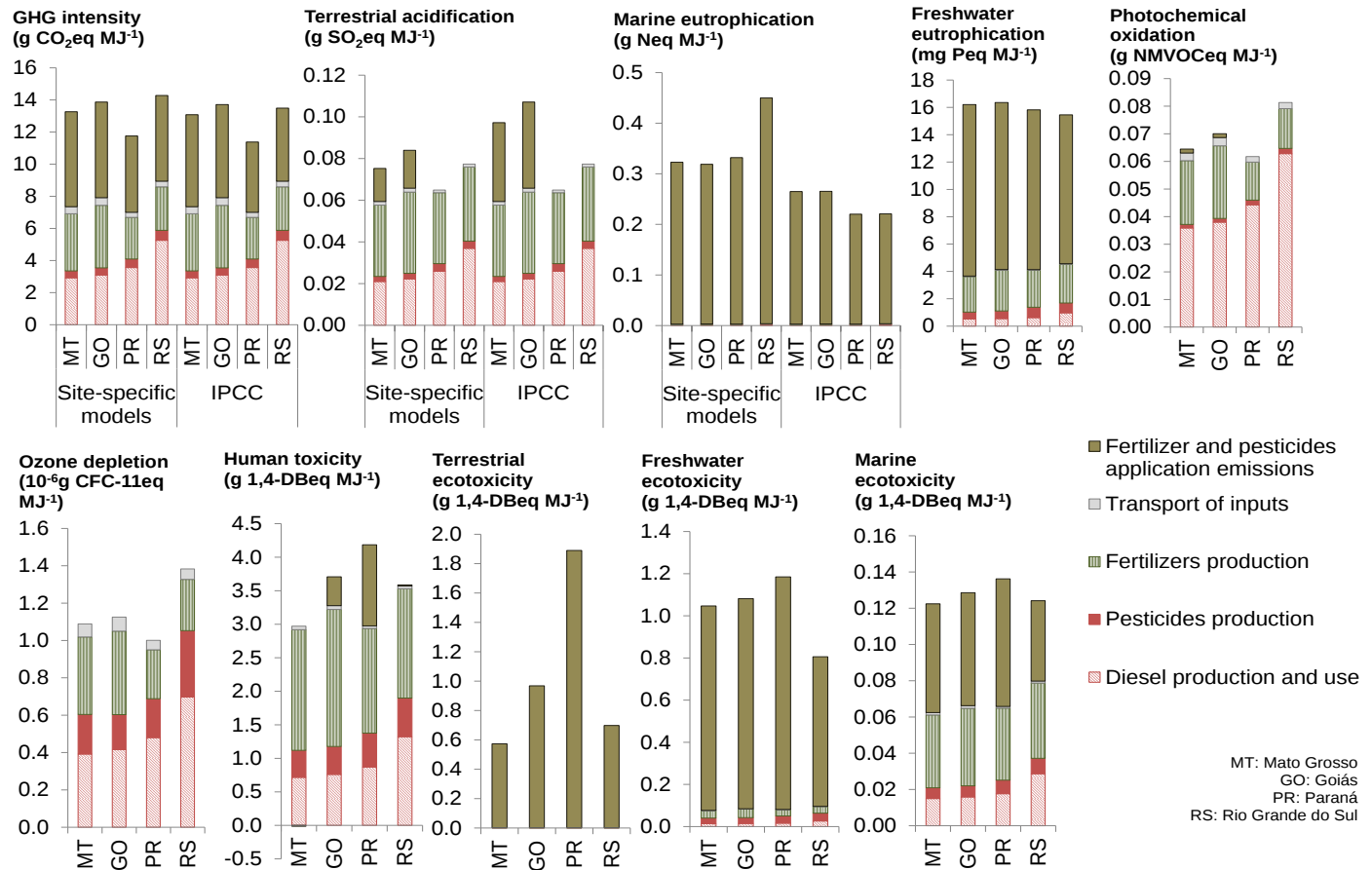
LCA of soybean  
cultivation in four  
Brazilian states:

Mato Grosso

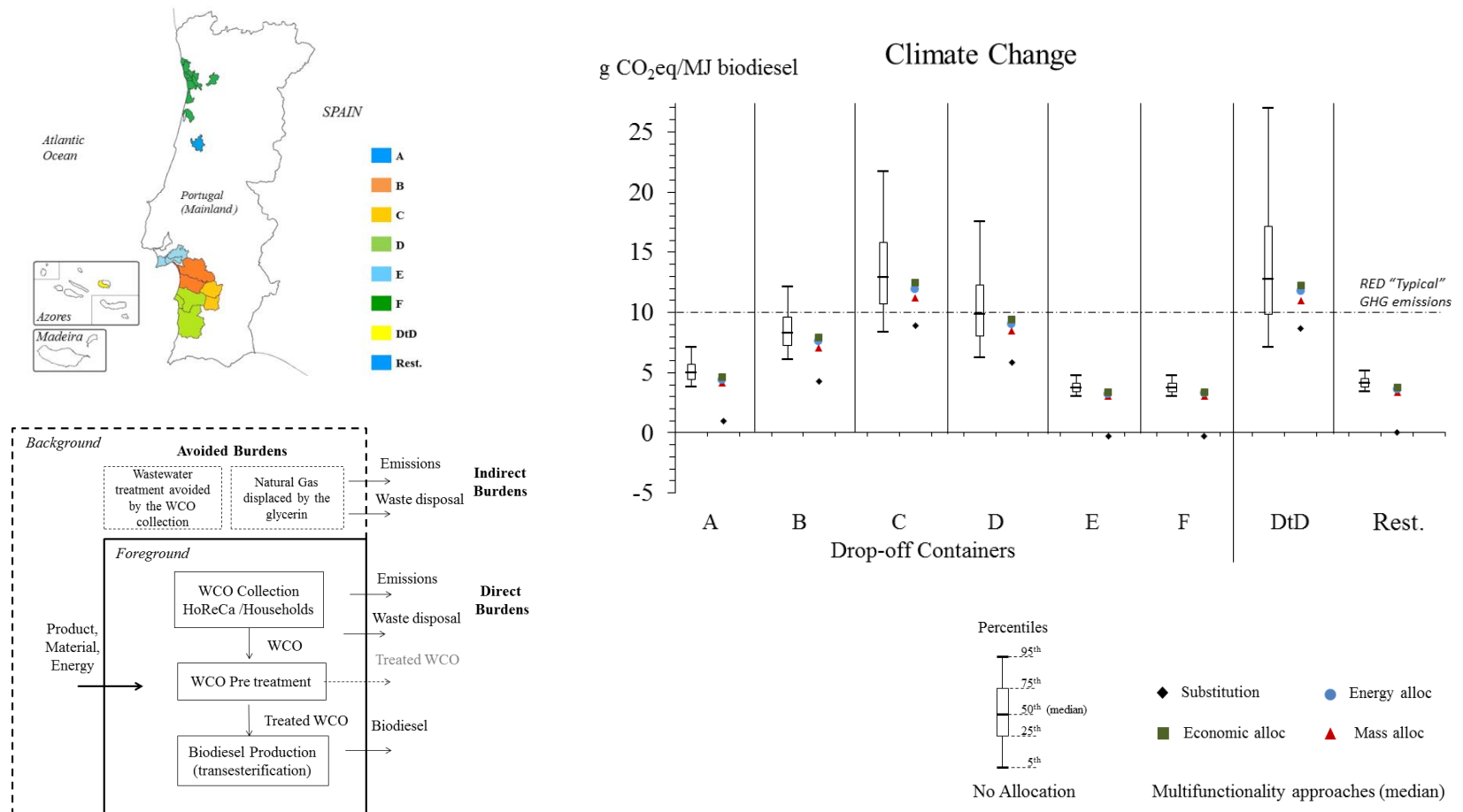
Goiás

Paraná

Rio Grande do Sul.



# LCA of Waste Cooking Oil biodiesel addressing uncertainty



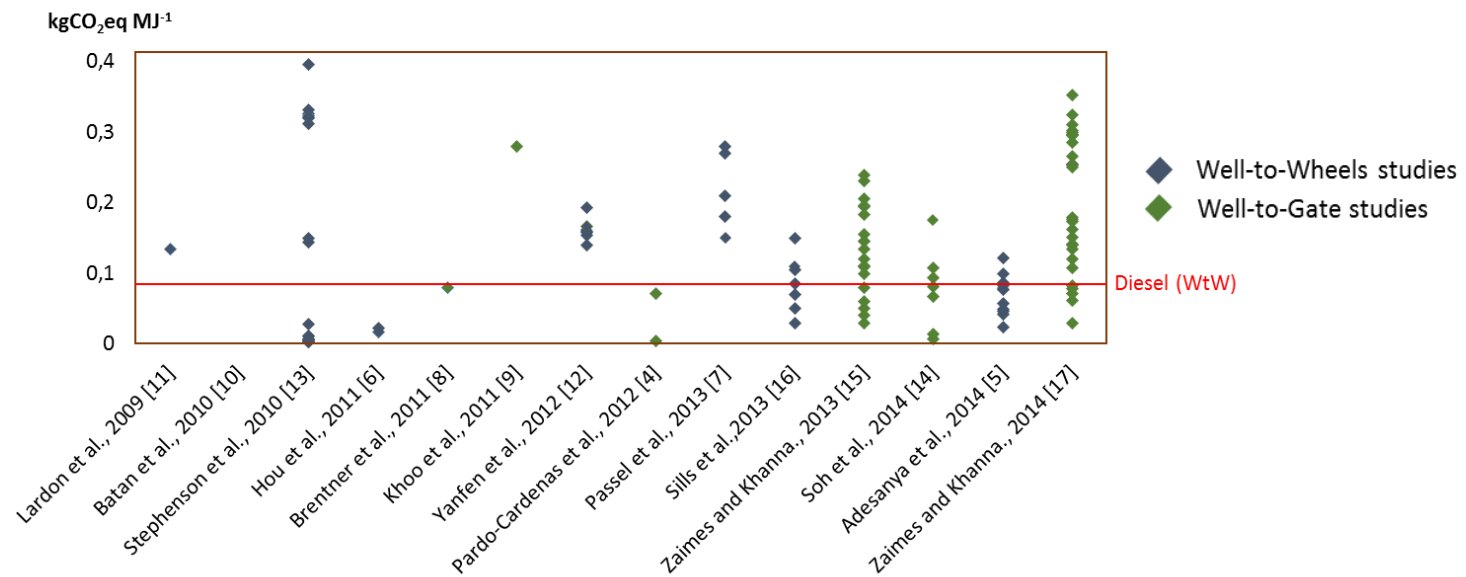
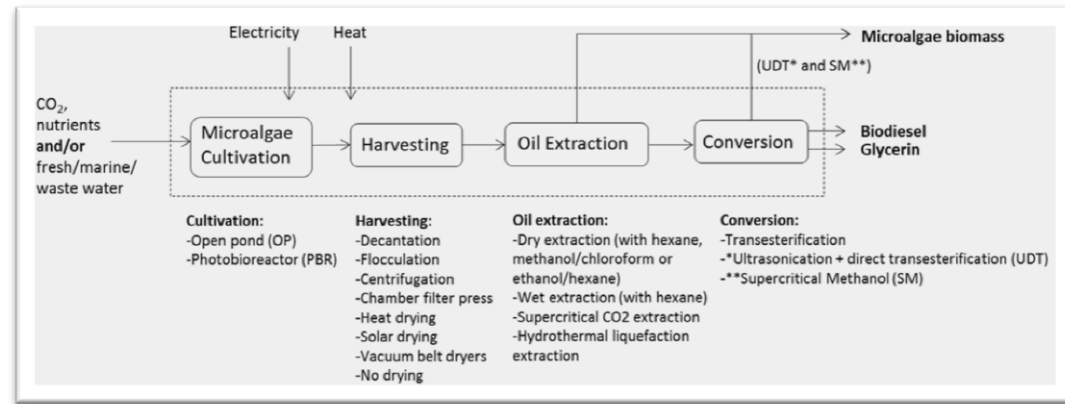
Caldeira, C., Queirós, J., Noshadravan, A., Freire, F. "Incorporating uncertainty in the Life Cycle Assessment of biodiesel from Waste Cooking Oil addressing different collection systems". *Resources, Conservation and Recycling* (in press)

Caldeira, C., Queirós, J., Freire, F. (2015). "Biodiesel from Waste Cooking Oils in Portugal: alternative collection systems". *Waste&Biomass Valoriz* 6 (5), 771-779.

# Microalgae biodiesel

Comprehensive review of published LCAs for biodiesel produced from microalgae

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



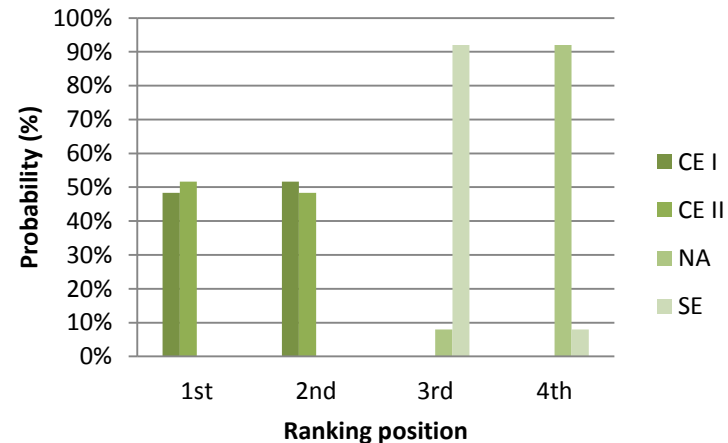
# Multi-Criteria Decision Analysis (MCDA) and LCA: RME

- 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)

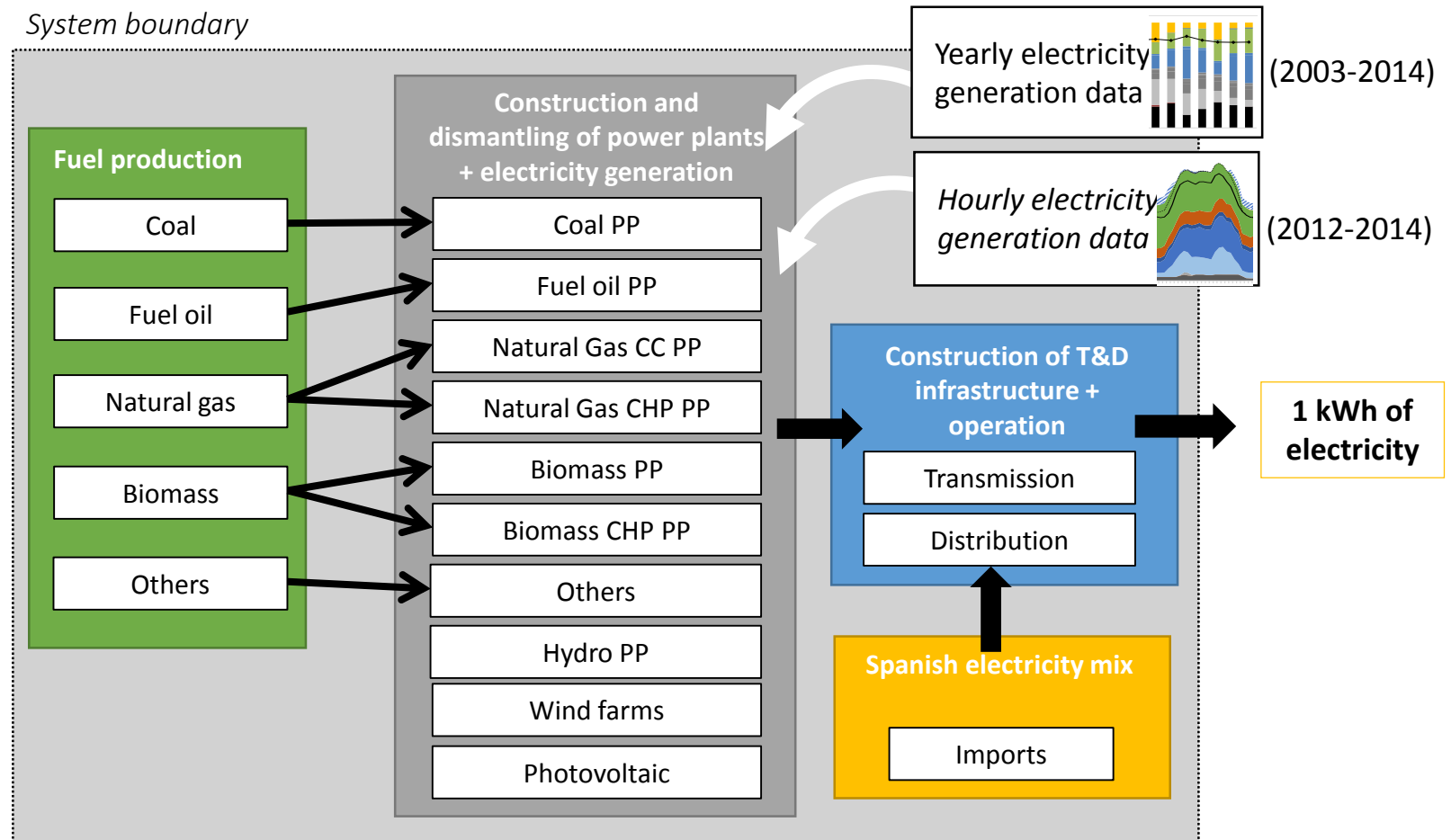
| Summary     | Range   | Confrontation | Max Regret |        |
|-------------|---------|---------------|------------|--------|
|             | Germany | Canada        | Spain      | France |
| Germany     |         | 0.343         | 0.257      | 0.122  |
| Canada      | -0.129  |               | 0.072      | -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)



# LCA of electricity in Portugal

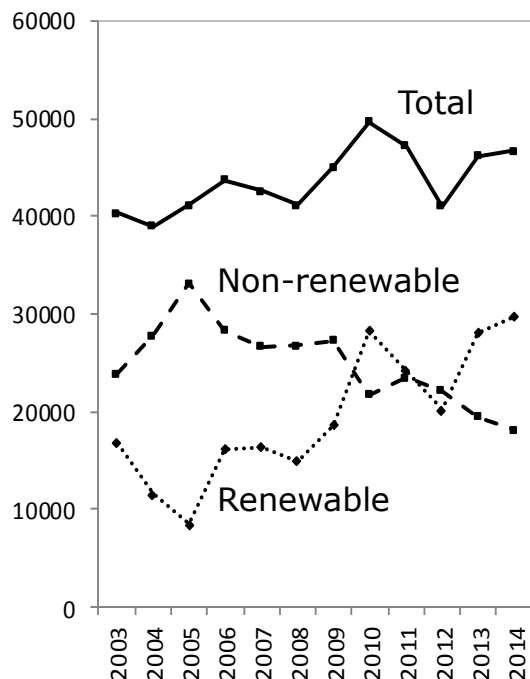
LC model of electricity in Portugal addressing temporal variation – yearly and hourly



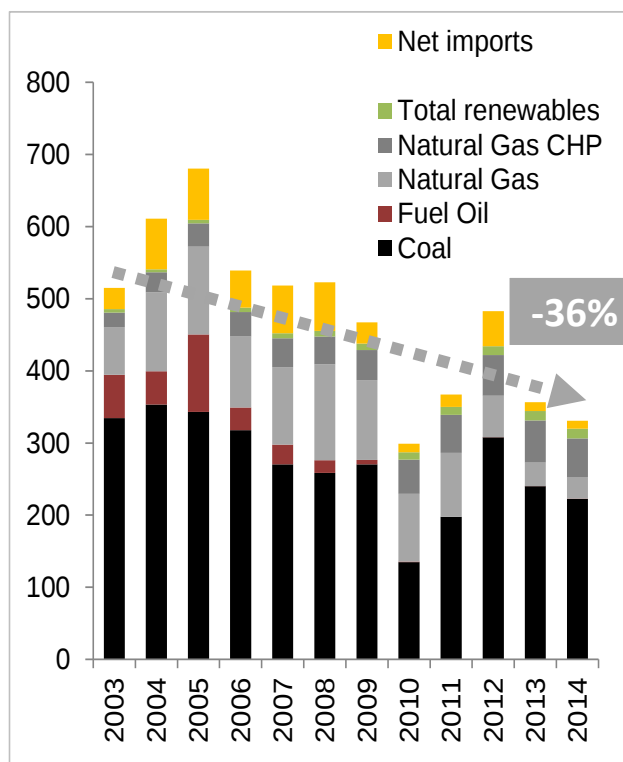
# LCA of electricity in Portugal: GHG emissions and acidification

## Yearly variability (2003-2014)

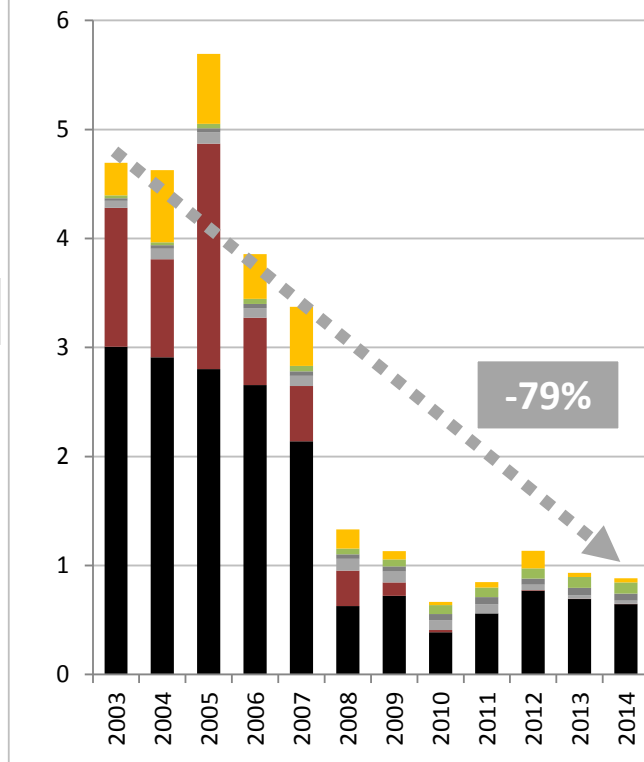
Electricity generation (GWh)



## GHG emissions (kg CO<sub>2</sub> eq MWh<sup>-1</sup>)



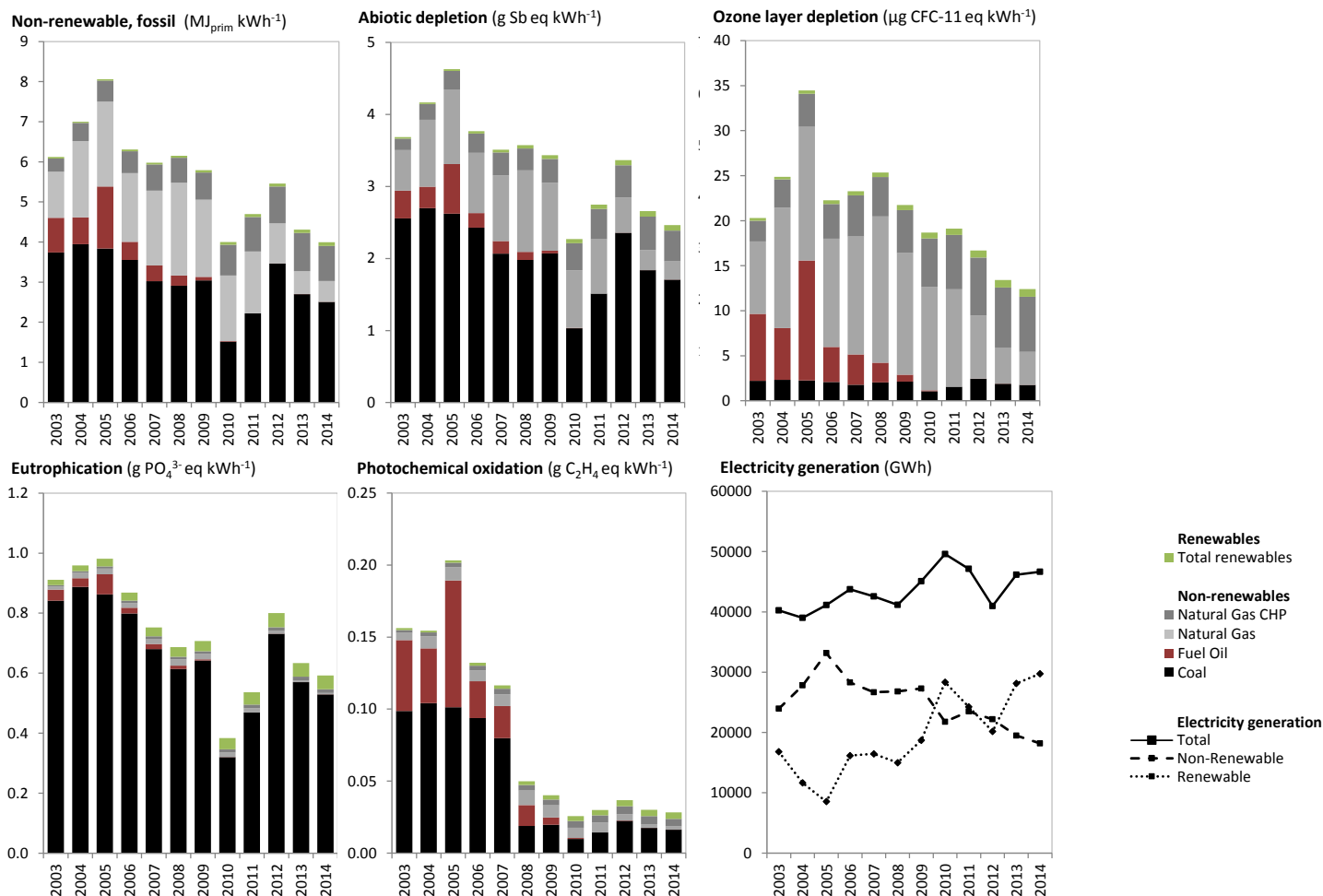
## Acidification (kg SO<sub>2</sub> eq/MWh)



- Renewable share increased
- Variability between years mainly due to yearly variability in hydro generation
- High decrease in acidification impacts mainly due to the installation of gas treatment systems in coal power plants:
  - Desulfurization systems (to remove SO<sub>2</sub>)
  - Denitrification systems (to remove NO<sub>x</sub>)

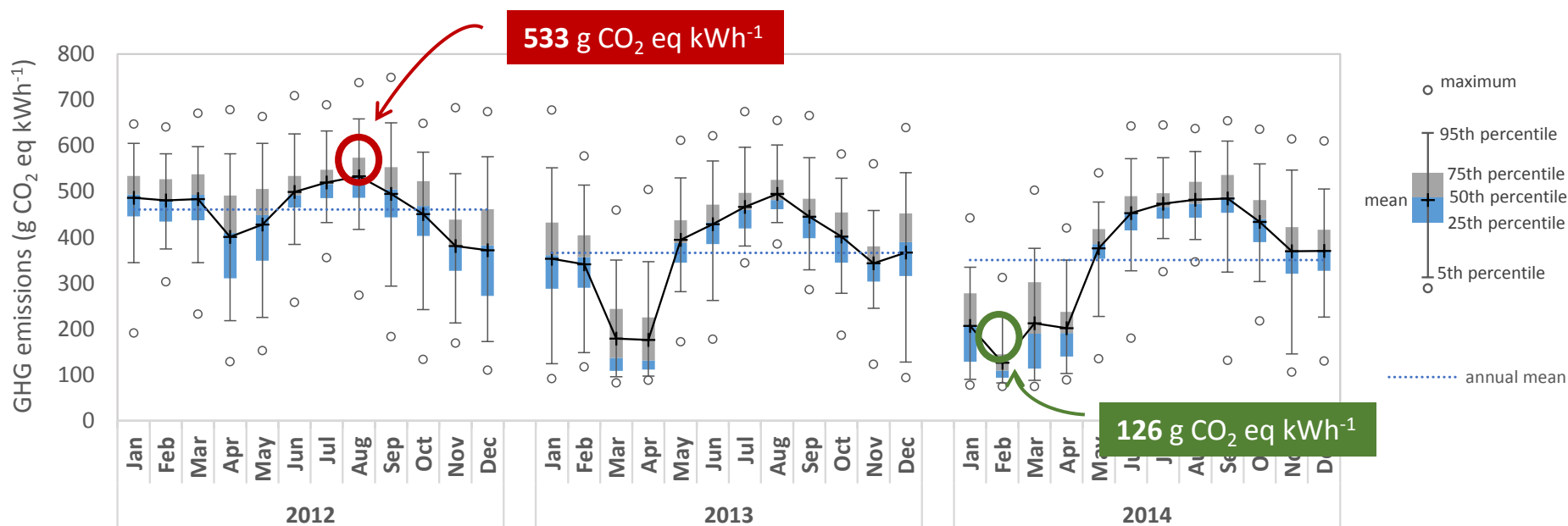
July 18, 2016

# LCA of electricity in Portugal: Environmental impacts



# Electricity GHG emissions

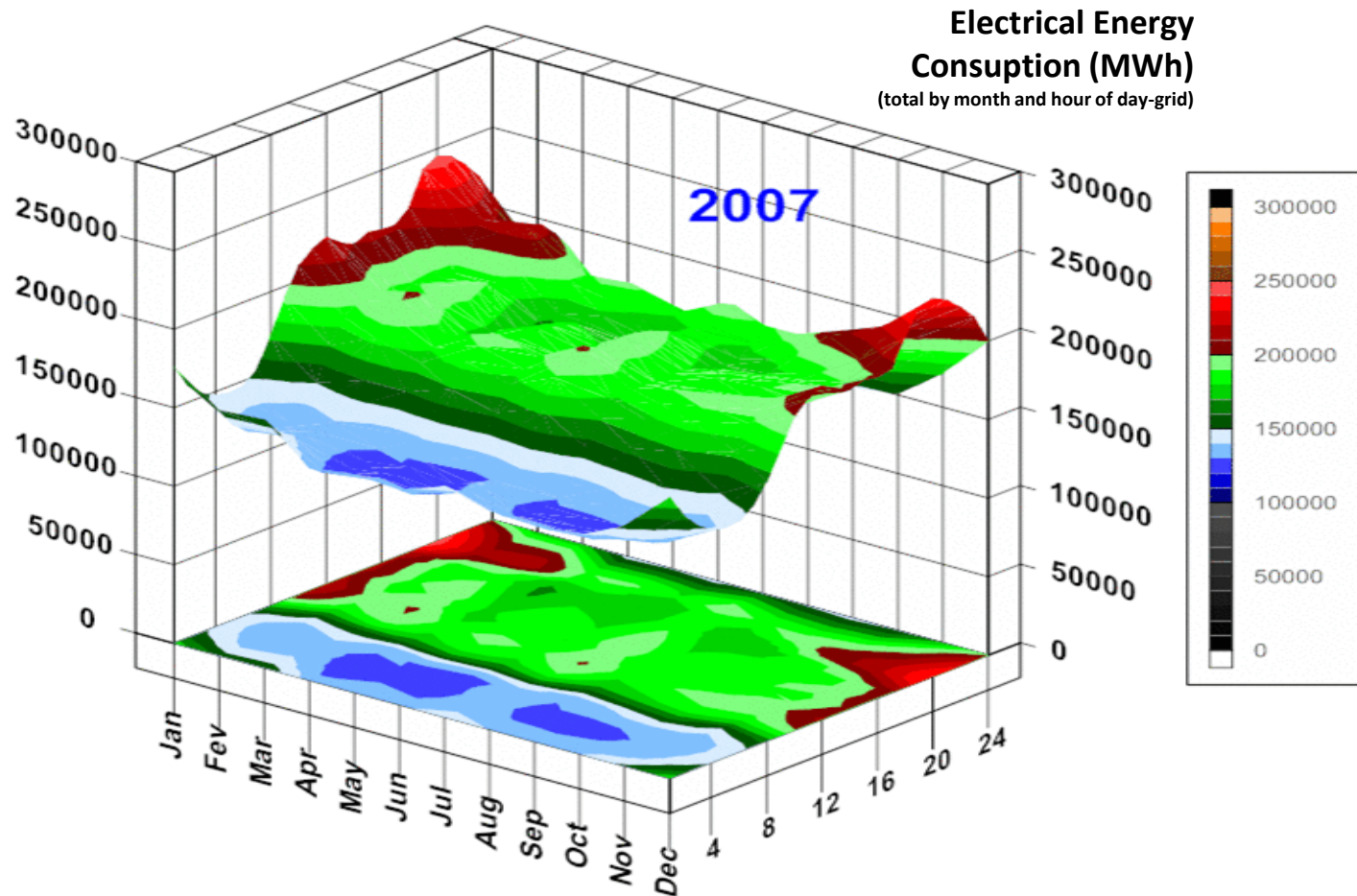
Hourly variability by month in Portugal (2012-2014)



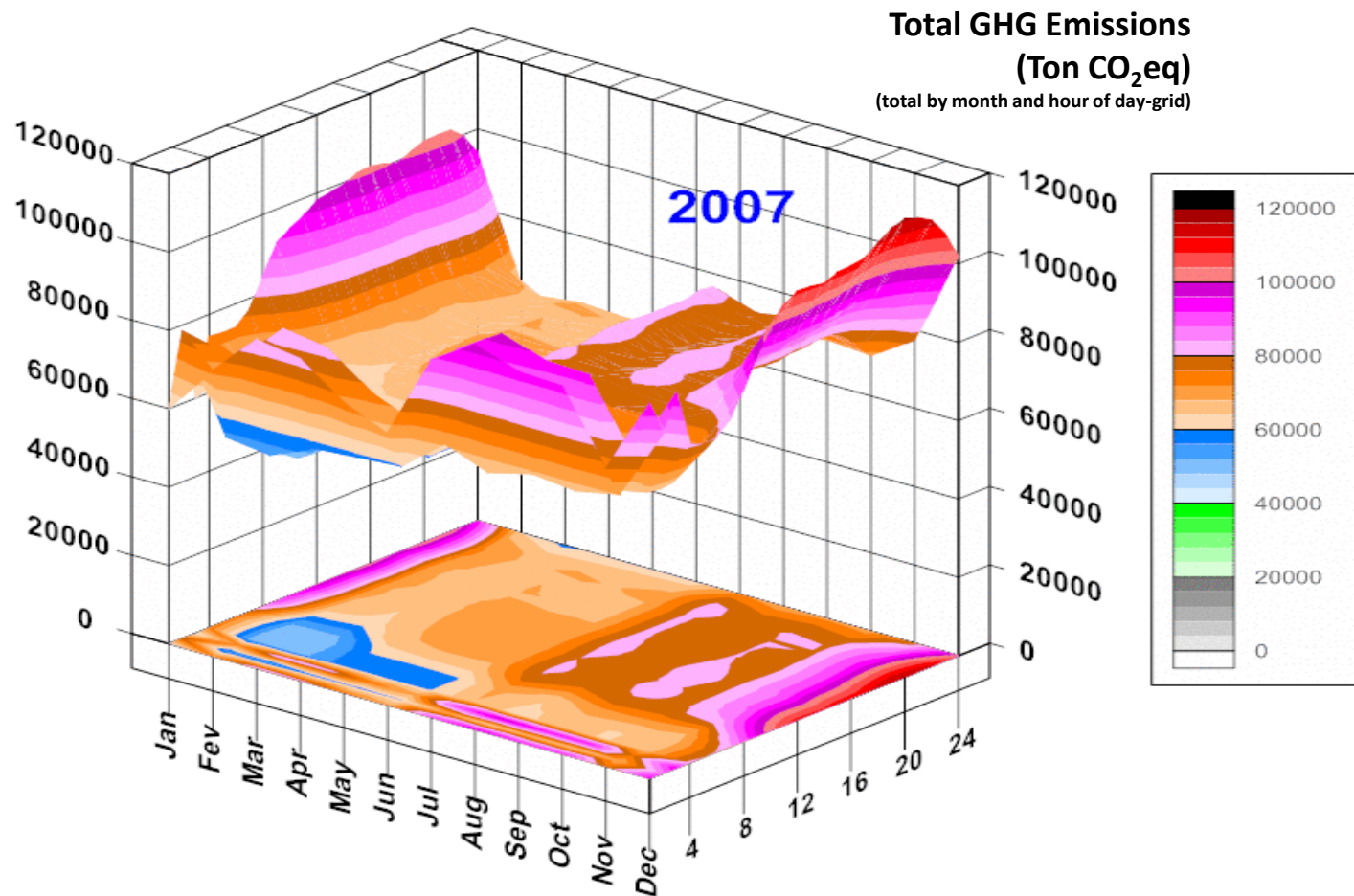
- **High variability** in GHG emissions between hours, months and years
- Higher in the **first semester** (due to variability in hydro generation)

# Evolution of Consumption:

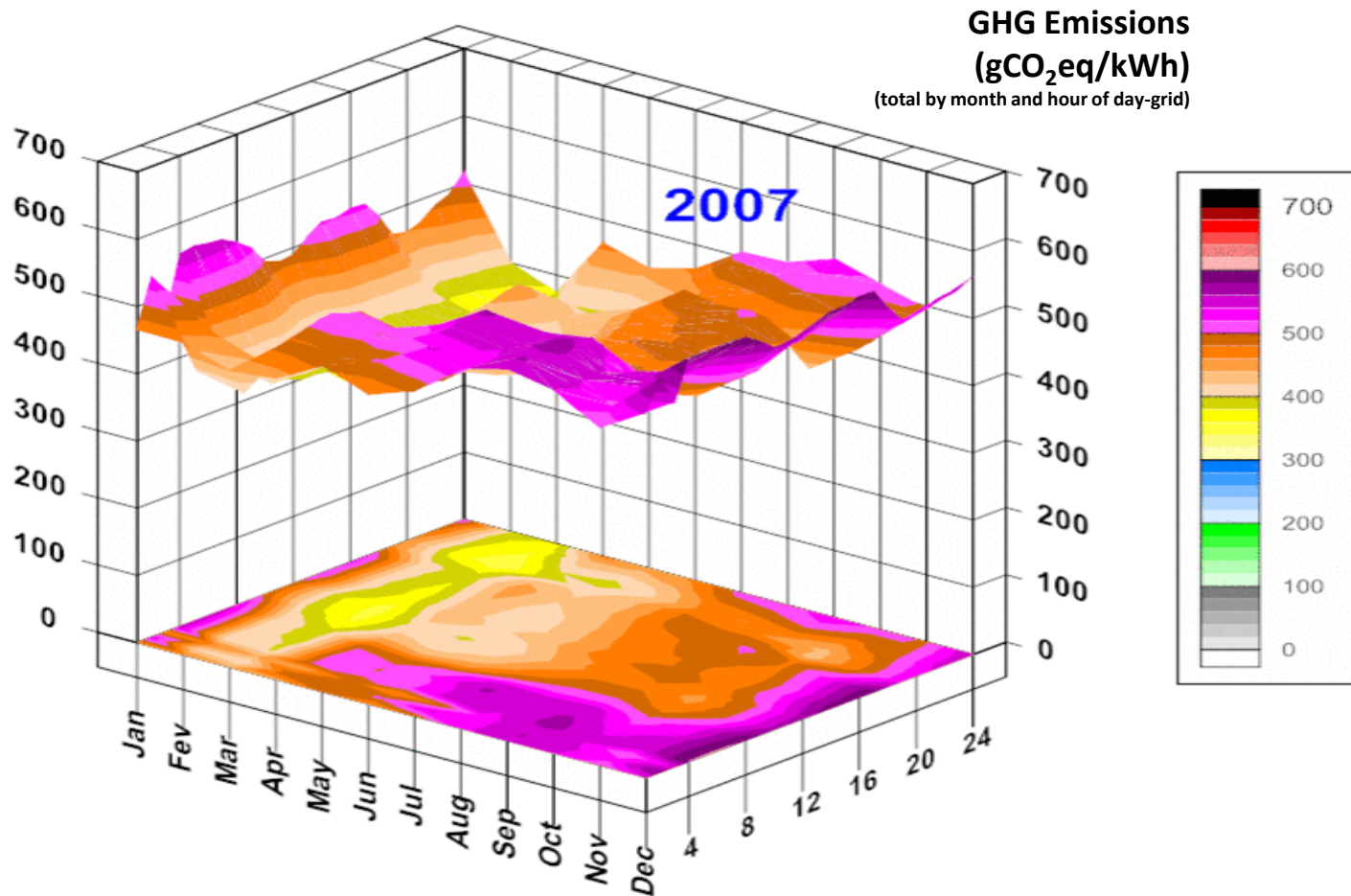
## Annual, month and hour variability (2007-2014)



# Evolution of Total GHG Emissions: Annual, month and hour variability (2007-2014)



# Evolution of GHG Emissions per kWh: Annual, month and hour variability (2007-2014)



BioEcon Workshop “BIOECONOMY IN AGRICULTURE”

Institute of Soil Science and Plant Cultivation, Pulawy , June 2016



Thank You!

Fausto Freire

