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CNPEM

Workshop on
Quantifying and Managing Land Use Effects of Bioenergy

GHG LCA of soybean-based biodiesel

The implications of alternative LUC scenarios

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Motivation

- The increase in soybean production is being stimulated by the growing demand for animal feed and biodiesel.
- Soybean biodiesel production is creating environmental concerns, namely in terms of GHG emissions.
- Several life cycle (LC) studies have been performed for soybean biodiesel. However, some aspects remain controversial:
  - addressed alternative cultivation systems
  - accounted for land use change (LUC)
  - analyzed different methods for handling co-products

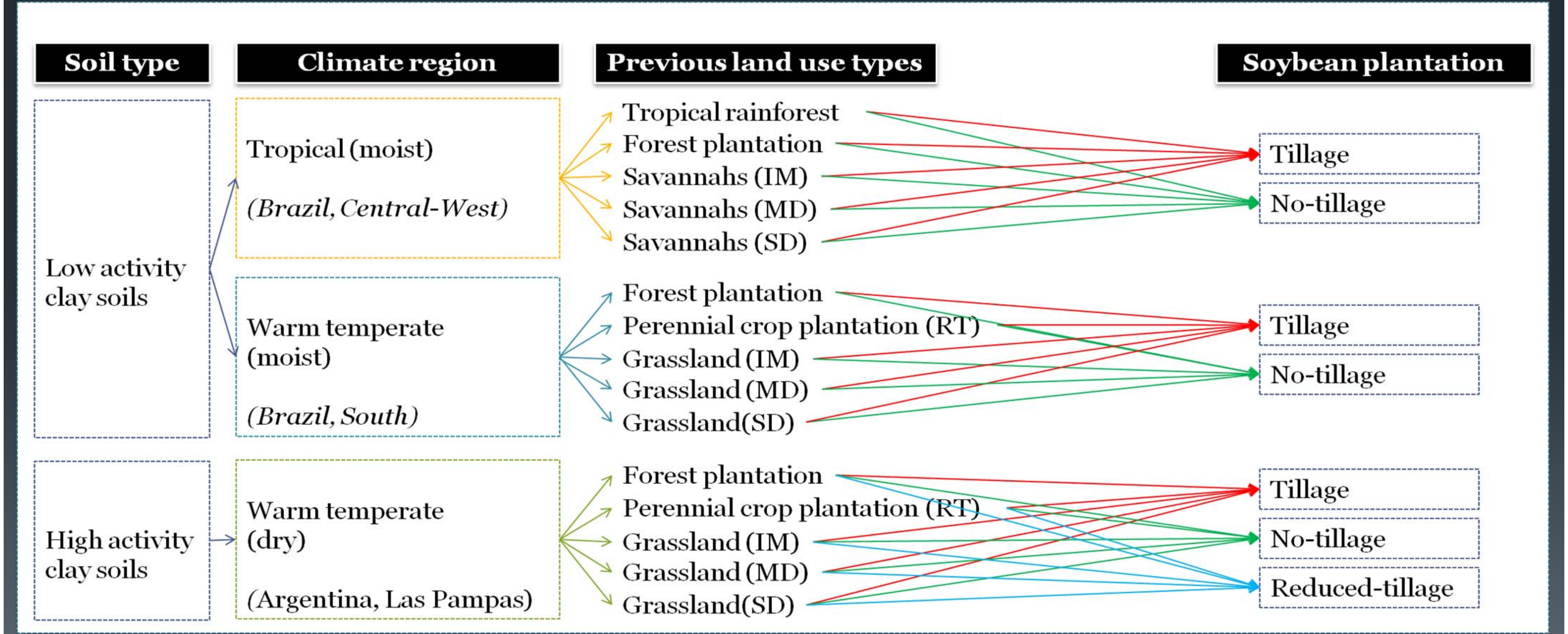
Main Goals

- To develop a LC model and present a GHG assessment of biodiesel produced in Portugal from Latin-America (LA) soybeans.
- To perform a comprehensive evaluation of the implications of 35 alternative LUC scenarios and various soybean production systems (tillage, no(reduced)-tillage) in 3 climate regions in LA.
- To evaluate the influence of alternative methods for handling co-products in the GHG assessment results for soybean biodiesel.
- Indirect LUC emissions have not been addressed.
- **Functional unit:** 1 MJ soybean biodiesel (37,2 MJ/kg biodiesel).

LC model and scenario analysis

Addressing:

1. 35 alternative LUC scenarios to establish soybean plantations
2. 3 Plantation systems: tillage, no(reduced)-tillage



IM-Improved management; MD-Moderately degraded; SD-Severely degraded; RT-Reduced-tillage

Multifunctionality

Allocation factors				
Process phase	**Products**	**Mass allocation**	**Energy allocation**	**Economic allocation**
Extraction	*Soybean meal*	80,3%	64,4%	59,3%
	Soybean oil	19,7%	35,6%	40,7%
Biodiesel production	*Soybean biodiesel*	89,3%	95,3%	98,8%
	Glycerine	10,7%	4,7%	1,2%

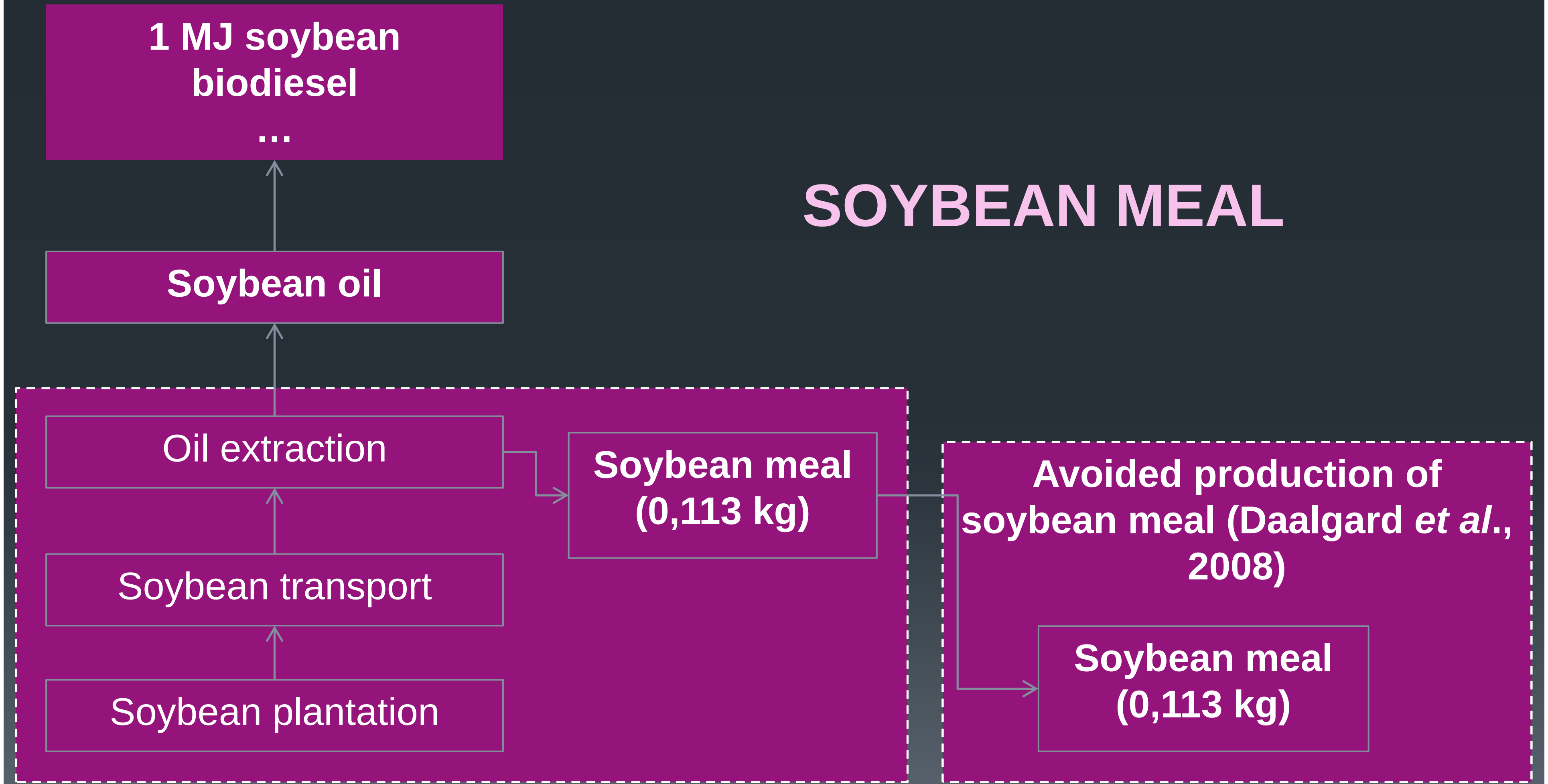
LHV:

- 16,3 MJ/kg soybean meal (13% H_2O)
- 36,6 MJ/kg soybean oil
- 37,2 MJ/kg soybean biodiesel (EC, 2009)
- 15,2 MJ/kg glycerine (9% H_2O)

Prices:

- 331 US $/t soybean meal - average 2010 (IMF, 2011)
- 925 US $/t soybean oil - average 2010 (IMF, 2011)
- 951,6 €/t soybean biodiesel – 2010 (DGEG, 2011)
- 100 €/t glycerine (personal information)

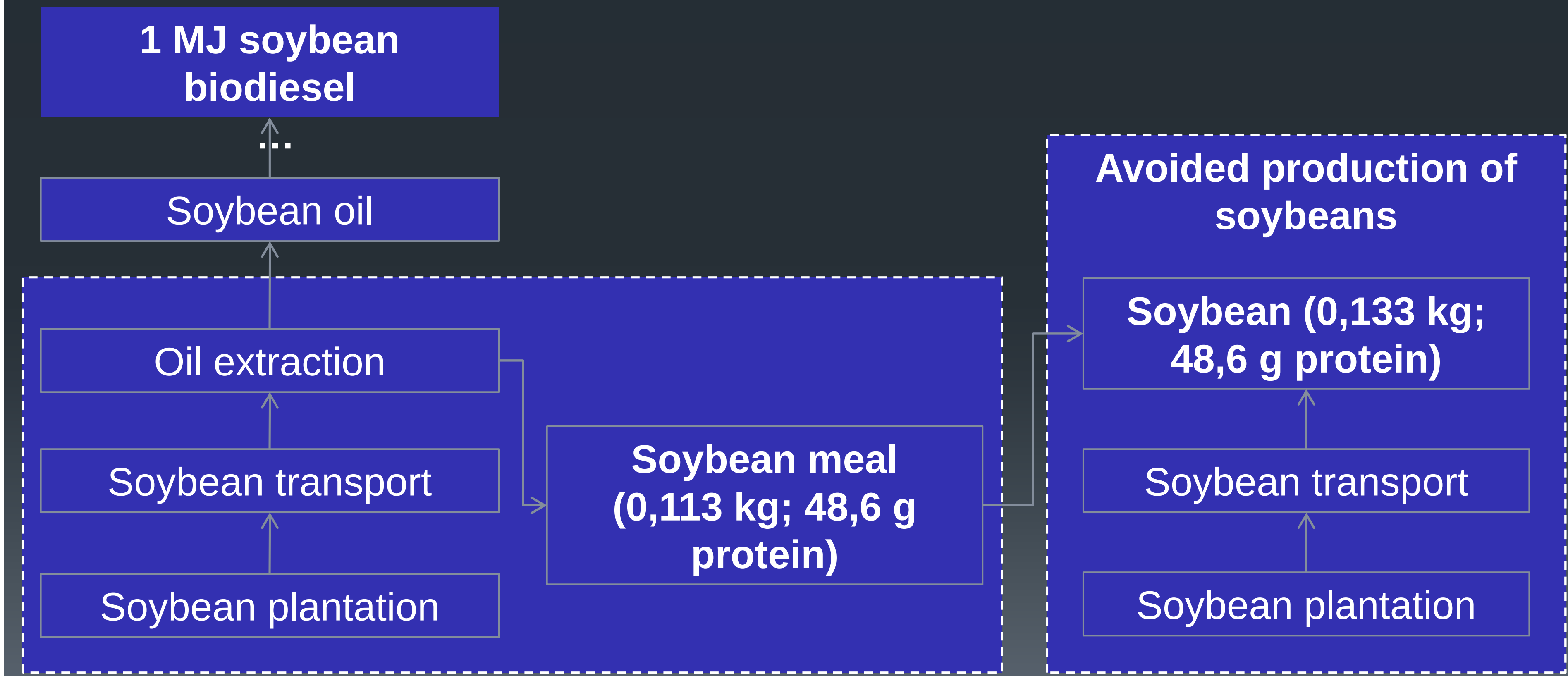
Substitution method



SOYBEAN MEAL

Substitution method

Soybean (grain)



CO_2 emissions from LUC

Annualized emissions from carbon stock changes caused by LUC have been calculated following IPCC Tier 1 and Renewable Energy Directive:

$$e_l = (CS_R - CS_A) \times 44/12 \times 1/20 \times 1/P$$

- **e_l** - GHG emissions from carbon stock change due to LUC (g CO_2eq/MJ soybean biodiesel)
- **CS_R** - carbon stock associated with the **R**eference (previous) land use (t C/ha)
- **CS_A** - carbon stock associated with the **A**ctual land use (soybean plantation) (t C/ha)
- **P** - productivity of the crop (MJ soybean biodiesel/ha per year)

$$CS_i = SOC_i + C_{veg} = (SOC_{ST} \times F_{LU} \times F_{MG} \times F_I) + C_{veg}$$

- **SOC -** soil organic carbon
- **SOC_{ST}** - Standard soil organic carbon
- **F_{LU}, F_{MG}, F_I** - factors reflecting the difference in SOC associated with type of land use, principle management practice and different levels of carbon input to soil compared to SOC_{ST}
- **C_{veg}** - above and below ground vegetation carbon stock in living biomass and in dead organic matter

Previous land use: SOC_R and C_{vegR}

Climate region, soil type	R: Reference land use		SOC: SOC_{ST} (t C/ha)	SOC: F_{LU}	SOC: F_{MG}	SOC: F_I	SOC: SOC_R (t C/ha)	C_{vegR} (t C/ha)
Tropical (moist), low activity clay soils	*Tropical rainforest*		47	1	-	-	47	198
	Forest plantation				1	1	47	58
	Savannah	IM			1,17	1,11	61	53
		MD			0,97	1	46	
		SD			0,7	1	33	
Warm temperate (moist), low activity clay soils	*Forest plantation*		63	1	1	1	63	31
	Perennial crop (RT)				1,08	1	68	43
	Grassland	IM			1,14	1,11	80	7
		MD			0,95	1	60	
		SD			0,7	1	44	
Warm temperate (dry), high activity clay soils	*Forest plantation*		38	1	1	1	38	31
	Perennial crop (RT)				1,02	1	39	43
	Grassland	IM			1,14	1,11	48	3
		MD			0,95	1	36	
		SD			0,7	1	27	

IM-Improved management; MD-Moderately degraded; SD-Severely degraded; RT-Reduced-tillage

Soybean plantation (Actual LU): SOC_A & C_{vegA}

Climate region, soil type	A: Actual land use		SOC: SOC_{ST} (t C/ha)	F_{LU}	F_{MG}	F_I	SOC_A (t C/ha)	C_{vegA} (t C/ha)
Tropical (moist), low activity clay soils	*Soybean plantation*	T	47	0,48	1	1	23	0
		NT		0,48	1,22	1	28	0
Warm temperate (moist), low activity clay soils		T	63	0,69	1	1	43	0
		NT		0,69	1,15	1	50	0
Warm temperate (dry), high activity clay soils		T	38	0,8	1	1	30	0
		RT		0,8	1,02	1	31	0
		NT		0,8	1,1	1	33	0
T – Tillage; NT-No-tillage; RT-Reduced-tillage								

Soybean plantations: main inputs & yields

Soybean plantation (values per ha and year)		Brazil		Argentina		
		NT[1]	T[2]	NT[3]	RT[4]	T[4]
Inputs	*Pesticides*	8,0 kg	1,47 kg	6,75 kg	3,26 kg	
	Limestone	375 kg	-	-	-	
	Fertilizers	33,8 kg P 65,4 kg K	30 kg P_2O_5 30 kg K_2O	16 kg P	5 kg MAP 10,5 kg TSP	
	Diesel	65 L	65 L	35 L	35,6 L	62,6 L
	Electricity	122 MJ	-	-	-	
Production	*Yield (kg soybeans)*	2830	2544	2630	2591	

[1] Cavalett and Ortega, 2009, [2] Jungbluth et al., 2007, [3]Dalgaard et al., 2008, [4]Panichelli et al., 2009

Soybean plantations: GHG emissions

- Direct GHG emissions from:
  - fertilizer application
  - biological nitrogen fixation (N_2O)
    - Direct and indirect N_2O emissions (IPCC Guidelines Tier 1, default and uncertainty range)
  - diesel combustion from agricultural operations

- Indirect GHG emissions associated with the production of agricultural and energy inputs.

Transportation of soybeans

- Transportation of soybeans from the plantations in LA to the mills in Europe (Portugal) encompass the transport by truck to the harbors in Brazil (Paranaguá) and Argentina (Buenos Aires), by transoceanic freight ship and train to the mills.

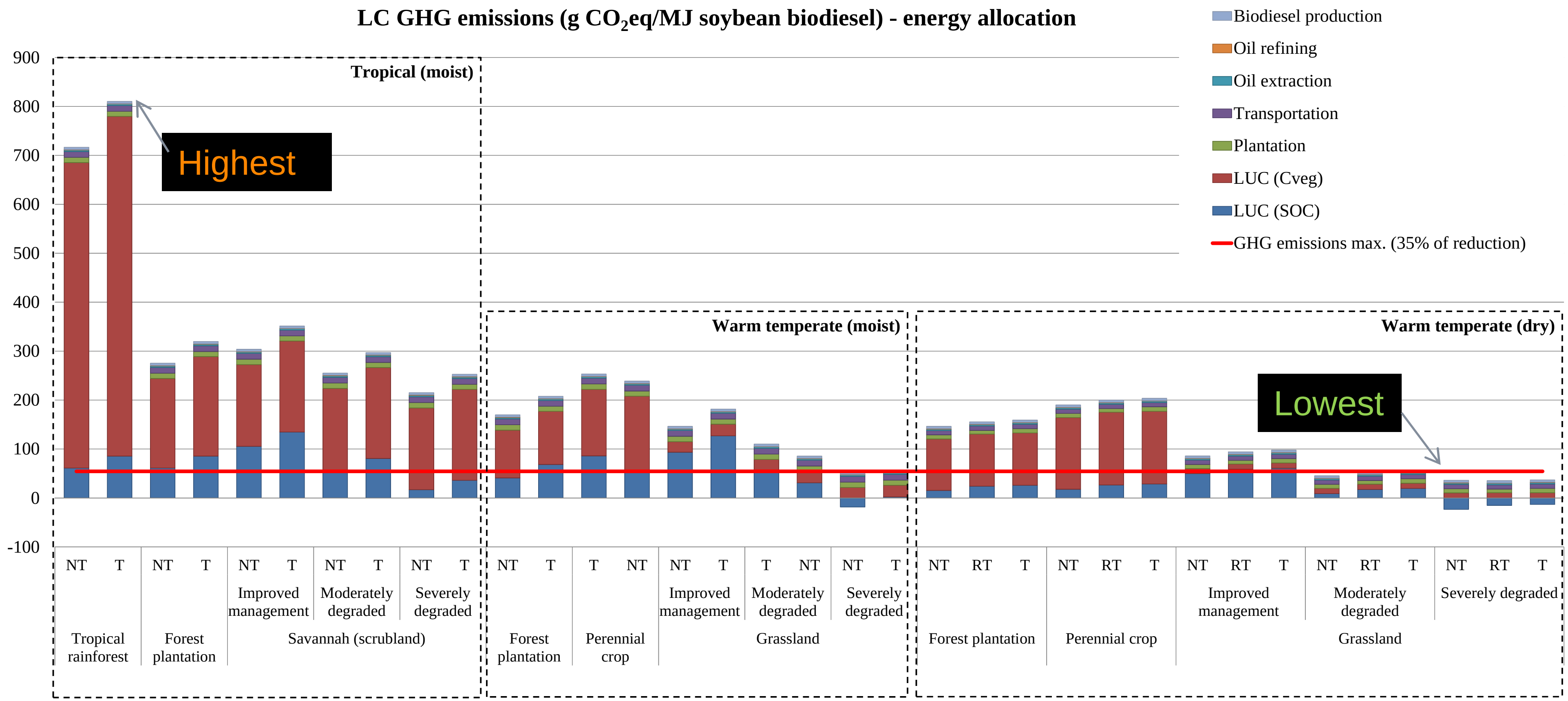
		Transoceanic ship (50000 t)	Trucks (20-28 t)	Train
Average distances (km)	***Brazil***	8146	790	60
	Argentina	9556	394	60
Emission factors (kg CO_2 eq/tkm)[1]		0,011	0,193	0,039

[1] M. Spielmann *et al.*, 2007

Oil extraction, refining and biodiesel production: main inputs

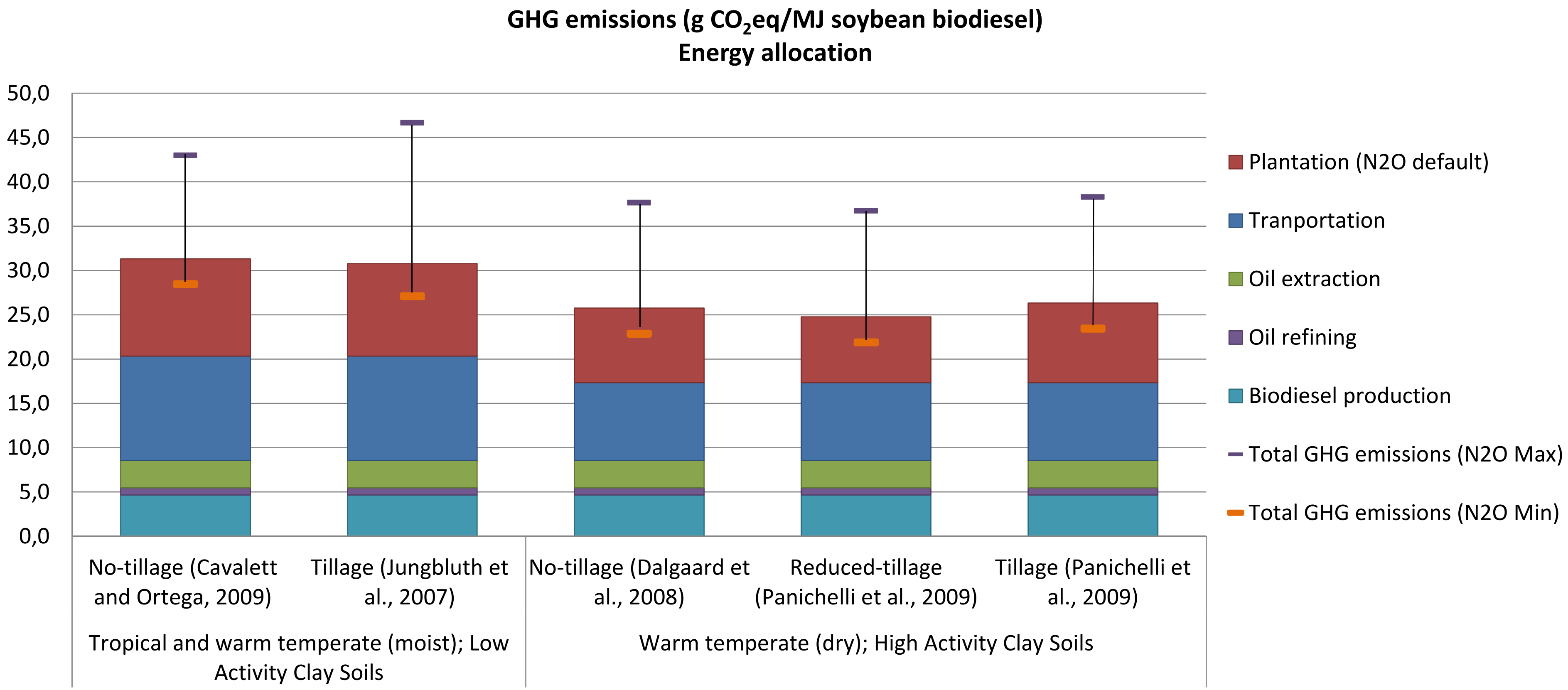
Portugal (average)		Oil extraction	Oil refining	Biodiesel production
Inputs	*Soybean*	5141 kg/t soybean oil	-	-
	Soybean oil	-	1032 kg/t ref. oil	-
	Soybean refined oil	-	-	1005 kg/t biodiesel
	Heat	3292 MJ/t soybean oil	271,2 MJ/t ref. oil	757 MJ/t biodiesel
	Electricity	0,2 MWh/t soybean oil	0,01 MWh/t ref.oil	0,04 MWh/t biodiesel
	Hexane	7,9 kg/t soybean oil	-	-
	Phosphoric acid (85% H_2O)	-	1,6 kg /t ref. oil	-
	Sodium hydroxide (50% H_2O)	-	4,6 kg /t refined oil	-
	Citric acid	-	0,4 kg /t refined oil	0,8/t biodiesel
	Fuller's earth	-	1,2 kg /t refined oil	-
	Hydrochloric acid (30% H_2O)	-	-	10,2/t biodiesel
	Sodium methoxide	-	-	5,2/t biodiesel
	Methanol	-	-	105,5/t biodiesel

Results: LC GHG balance (Energy allocation)



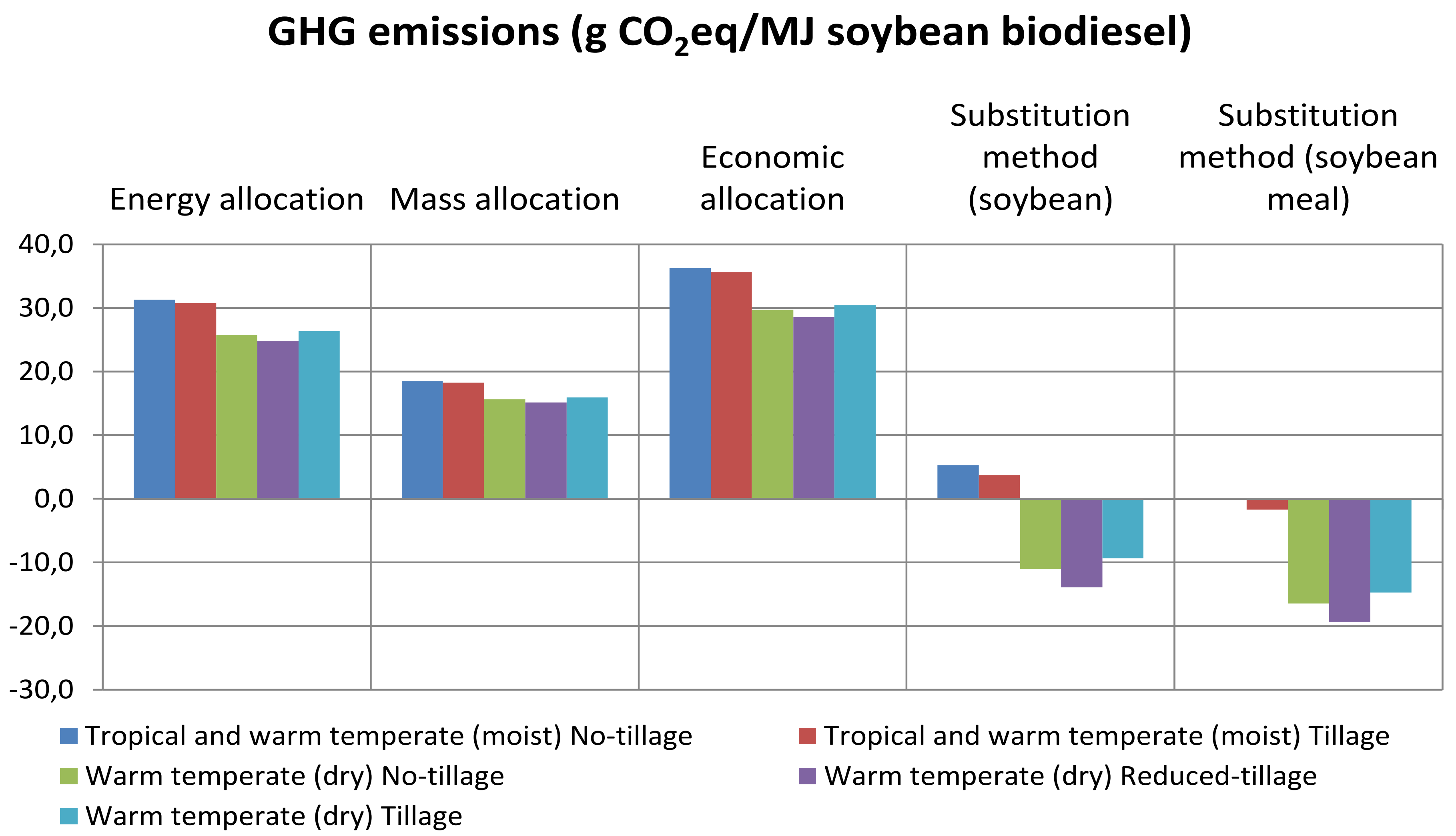
- Huge differences between the various LUC scenarios:
  severely degraded grassland: 13 g CO_2eq/MJ; tropical rainforest: 811 g CO_2eq/MJ
- GHG emissions due to LUC represent more than 64% in 27 scenarios and less than 46% in 5 scenarios.
- Tillage has higher GHG emissions than the corresponding no(reduced)-tillage LUC scenario.

LC GHG emissions (no LUC)



- **Very high uncertainty of N_2O emission calculation**. N_2O dominates GHG.
- **Contributions to the LC GHG emissions** (calculations with N_2O default parameters and emission factors):
  - 33-38% transport,
  - 30-35% plantation and
  - 27-35% process (extraction, refining and transesterification)

Multifuntionality:
LC GHG emissions (no LUC)



Conclusions

- LUC dominates the GHG balance of soybean biodiesel, but significant differences has been observed for the previous (alternative) LU types:
  - The original land choice is a critical issue to assure the sustainability of soybean biodiesel and degraded grassland should be preferably used.
- It is important to reduce uncertainty in the calculation of N_2O emissions from cultivation.
- Transport, plantation and processing have similar GHG emissions (calculated with N_2O default values).
- Tillage has higher GHG emissions than the corresponding no(reduced)-tillage LUC scenario.
- Further studies are needed (transparent agricultural inventories) to improve conclusions concerning cultivation systems.
- The co-product treatment method has an important influence in biodiesel GHG emissions

Thank you!

Questions and Comments

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