Task 39
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Comparison of GHG Emissions Assessment Models

Phase II

BioGrace — GHGenius — GREET — JRC — VSB

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Objectives

To identify the main differences and commonalities in methodological structures, calculation procedures, and assumptions, providing a detailed understanding of how models estimate GHG emissions.

Phase II, Part 1 focuses on understanding the particularities of GHG emissions of FAME and HVO/HEFA production systems from vegetable oils in different parts of the world: soybean oil, palm oil, and used cooking oil (UCO).

Phase II, Part 2 will focus on the LCA of industrial processes under development for the conversion of biomass to advanced biofuels.

Models

BIOGRACE + JRC

Harmonised Calculation of Biofuel Greenhouse Gas Emissions in Europe

GHGenius

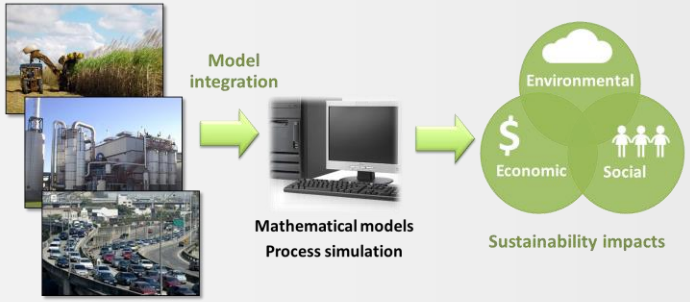
(S&T)² Consultants Inc

GHGenius

GREET LIFE-CYCLE MODEL

Argonne NATIONAL LABORATORY

The Greenhouse Gases, Regulated Emissions and Energy in Transportation



Virtual Sugarcane Biorefinery (VSB)

Models: main characteristics

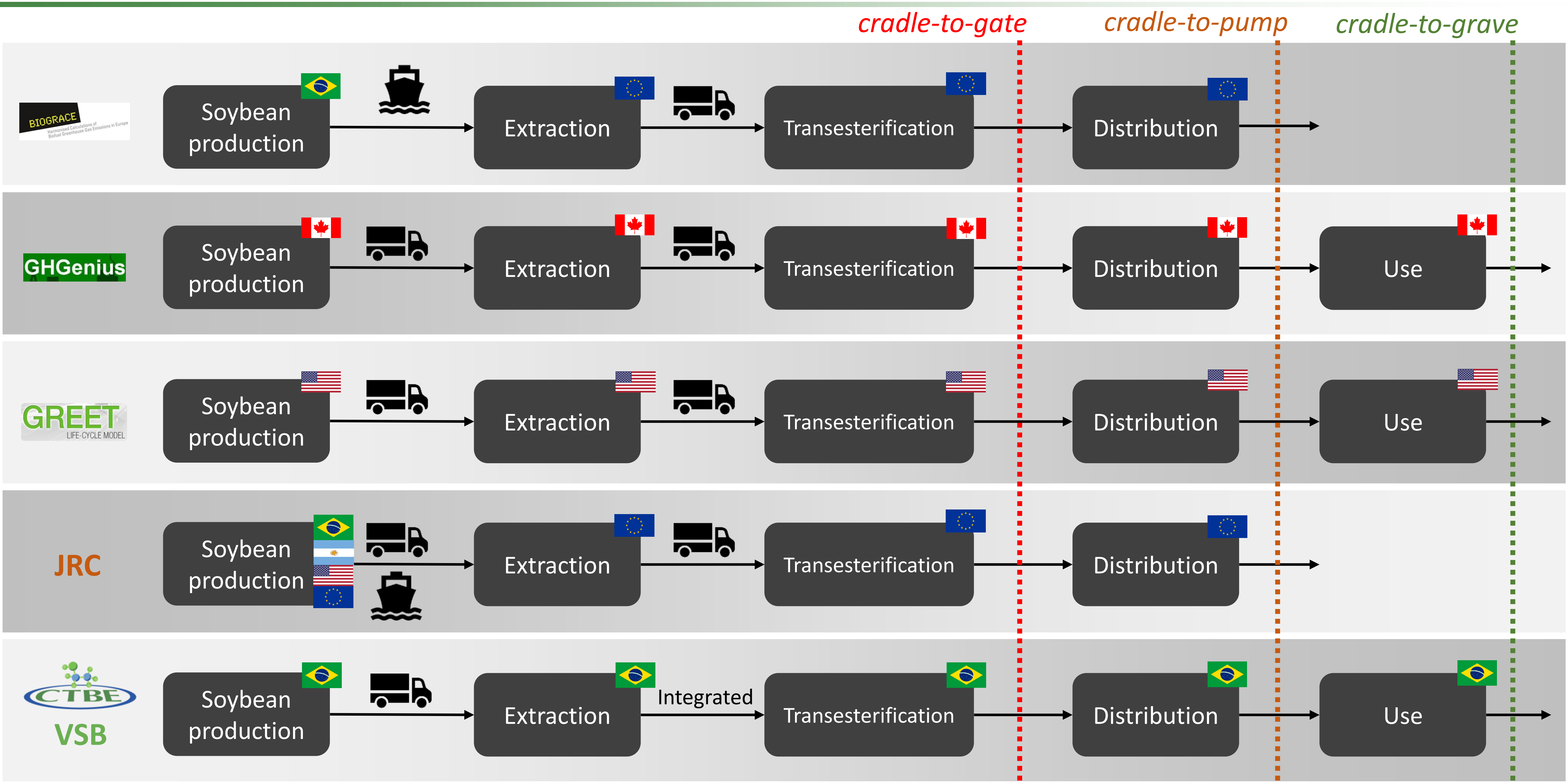
	BioGrace	GHGenius	GREET	JRC	VSB
Model version	4d (2015)	5.0a (2018)	2017	2017	2018
Developed for regulatory use	Yes	No	No	Yes	No
IPCC GWP method	2001	1995, 2001, 2007, 2013	2013	2013	2013
Lifecycle data	JRC	Internal	Internal	JRC	Ecoinvent
Functional unit	MJ	km MJ	km, mile Btu, MJ	MJ	km MJ
Default allocation	Energy	Mostly substitution[1]	Variable[2]	Energy	Economic
Land use change	C stocks	Internal model	CCLUB/GTAP	C stocks	-
Possible boundaries	Well-to-pump	Well-to-wheel	Well-to-wheel	Well-to-pump	Well-to-wheel

[1] For soybean meal, mass allocation is also used

[2] For FAME and HVO/HEFA, mainly energy/mass/economic allocations are used


FAME from soybean oil

System boundaries: Soybean FAME



Particularities: Soybean FAME

	BioGrace	GHGenius	GREET	JRC	VSB
Main product	FAME	FAME	FAME	FAME	FAME
Co-products	• Glycerin	• Glycerin	• Glycerin • Heavy distillate (FFA)*	• Glycerin	• Glycerin

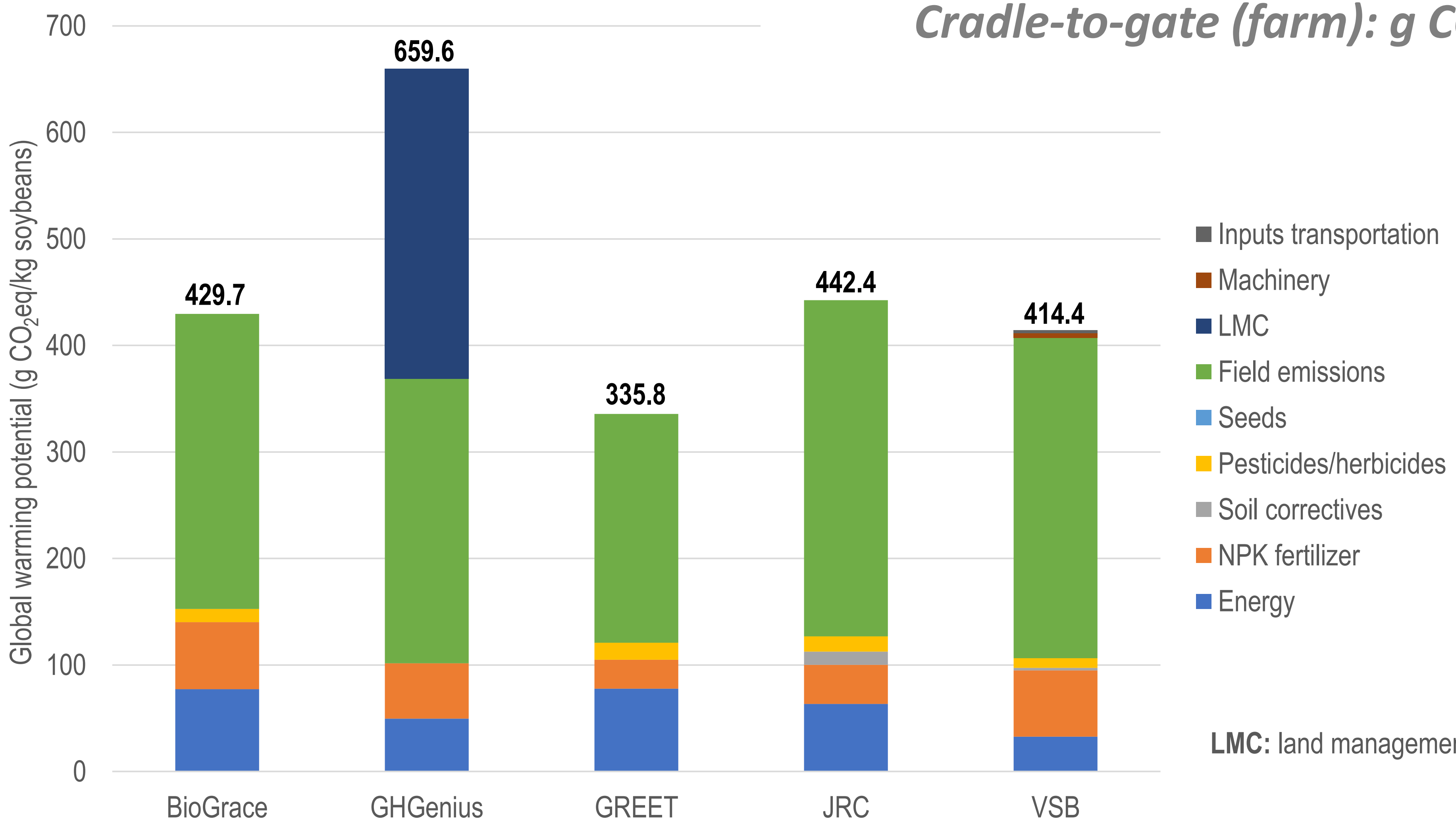
- All models also consider soybean meal as a co-product from the extraction of oil from soybeans

* Probably a mistake in process "Vegetable oil transesterification (Biodiesel)"

Soybean FAME

Soybean agricultural emissions

Cradle-to-gate (farm): g CO_2eq/kg soybeans



LMC: land management change

Major differences

Soybean agricultural emissions

Cradle-to-gate (farm)

- Each model considers soybean production in a different region
  - **BioGrace:** production in Brazil
  - **GHGenius:** production in Central Canada
  - **GREET:** production in USA
  - **JRC:** weighted average production in Argentina, Brazil, USA, and EU
  - **VSB:** production in Brazil

- GHGenius is the only model to consider land management change (LMC) emissions as a default input

Soybean FAME

Agricultural inputs per tonne of soybeans (unallocated)

	BioGrace	GHGenius	GREET	JRC	VSB	
Soybean productivity	2,798	2,980	-	2,788	3,240	kg/ha.yr
			Total energy			
Energy input	883	481	822	724	391	MJ
Diesel	24.6	8.4	16.2	20.2	10.7	L
Natural gas	-	-	1,134.7	-	-	L
Electricity	-	11.6	11.0	-	-	kWh
Gasoline	-	2.5	4.0	-	-	L
LPG	-	1.1	1.4	-	-	
			Inputs			
N	3.4	1.7	2.0	1.9	2.4	kg N
K_2O	26.1	10.1	12.6	15.8	31.6	kg K_2O
P_2O_5	27.8	5.9	7.9	16.4	25.9	kg P_2O_5
Soil correctives[1]	-	1.0	-	170.6	230.0	kg inputs
Pesticides/herbicides	1.1	0.5	0.8	1.3	0.8	kg inputs
Seeds[2]	-	41.7	-	-	-	kg
			Field emissions[3]			
N_2O	0.9	0.9	0.8	1.0	0.7	kg N_2O
CO_2	-	-	-	21.0	79.9	kg CO_2
LMC	-	292.4	-	-	-	kg CO_2eq

[1] $CaCO_3$, $CaSO_4$ and sulphur

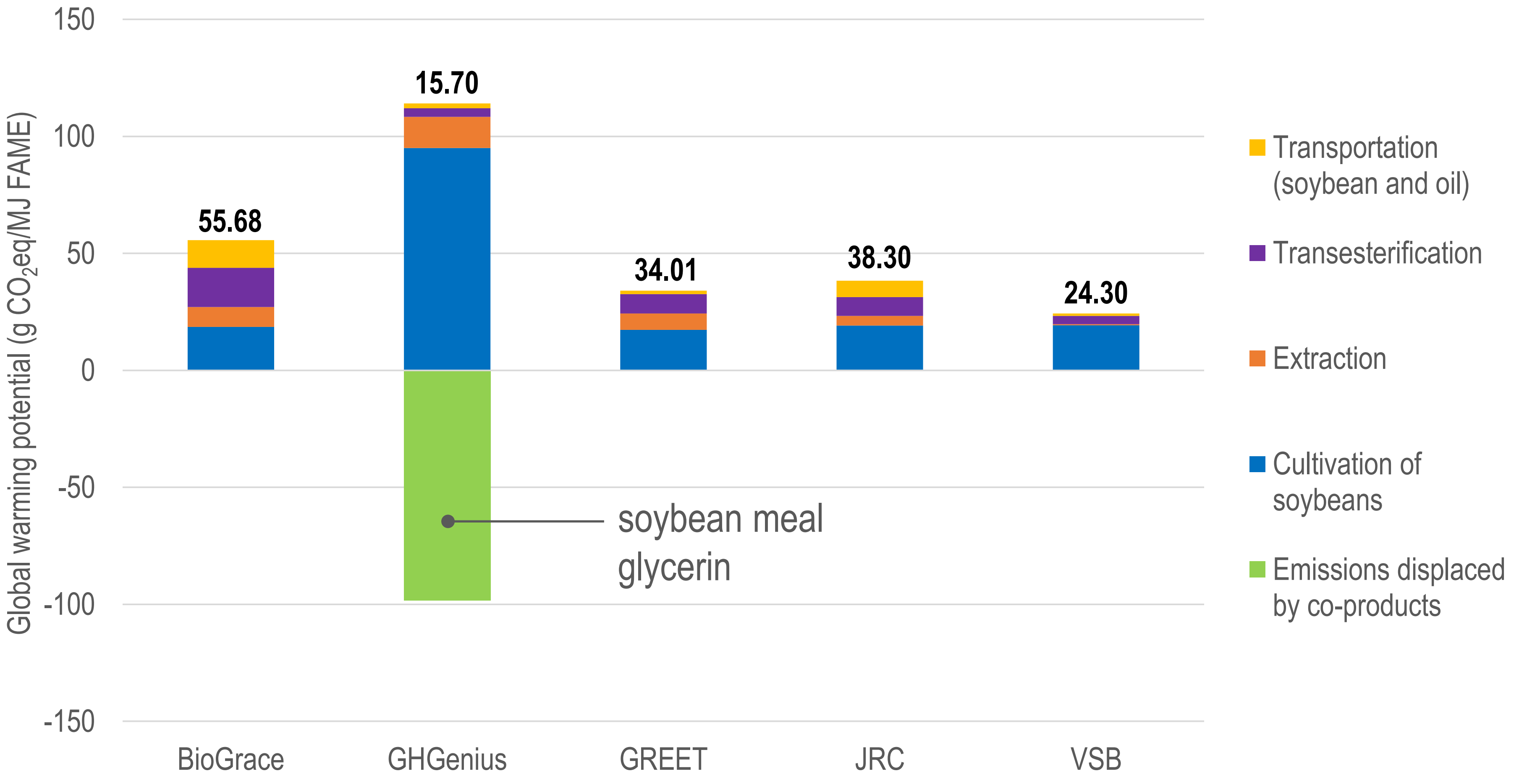
[2] Only GHGenius considers seeds as an input (low emission factor)

[3] Emissions from agricultural residues, from limestone and N fertilizer, and N fixation

Soybean FAME: Cradle-to-gate

FAME production emissions (allocated)

g CO_2eq/MJ FAME



Major differences

FAME production emissions

Cradle-to-gate

- BioGrace: considers a 1.4 factor for converting input values from typical to default in industrial processes (oil extraction and oil transesterification)

- BioGrace: soybean transportation emissions are high since the model considers overseas transportation of soybeans from Brazil to the EU

- JRC: soybean transportation emissions are high since the model considers 90% of the soybeans coming from overseas (Argentina, Brazil, and USA)

- JRC: determined value of 38.30 g CO_2eq/MJ FAME was calculated with the BioGrace model using JRC input data
  - JRC original value: 42.4 g CO_2eq/MJ FAME

Major differences

FAME production emissions

Cradle-to-gate

- GHGenius: does not allocate emissions, but rather considers co-products credits (substitutions)
  - In view of this, soybean cultivation presents higher emissions that in other models.
- VSB: considers the consumption of high amounts of renewable energy in the industrial phase (oil extraction and transesterification)
- Calculation of emissions among models: BioGrace, GREET, and JRC (energy allocation); GHGenius (substitution); VSB (economic allocation)

Soybean FAME

Industrial inputs per MJ of oil

	BioGrace	GHGenius	GREET	JRC[1]	VSB	
			Extraction			
Electricity	48.08	24.97	23.25	16.23	19.04	10^{-3} MJ
Natural gas	226.07	140.89	107.78	90.96	-	10^{-3} MJ
n-Hexane	6.42	21.25	3.07	3.66	7.59	10^{-3} MJ
Coal	-	-	53.05	-	-	10^{-3} MJ
Residual oil	-	-	1.67	-	-	10^{-3} MJ
Forest residue	-	-	1.67	-	154.66	10^{-3} MJ
Diesel	-	-	0.83	-	0.63	10^{-3} MJ
Renewable natural gas	-	-	0.83	-	-	10^{-3} MJ
			Refining			
Electricity	1.07	-	-	2.42	-	10^{-3} MJ
Natural gas	12.80	-	-	6.47	-	10^{-3} MJ
Fuller's earth	0.23	-	-	-	-	g
NaOH	-	-	-	0.07	-	g
H_3PO_4	-	-	-	0.01	-	g

[1] JRC considers two drying steps before the industrial phase (one prior to soybean transportation and one prior to oil extraction), consuming around 9.3 10^{-3} MJ/MJ Oil

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Soybean FAME

Industrial inputs per MJ of FAME

	BioGrace	GHGenius	GREET	JRC	VSB	
			Transesterification			
Electricity	6.07	3.25	3.90	4.71	4.16	10^{-3} MJ
Natural gas	111.76	21.60	31.39	36.70	-	10^{-3} MJ
Forest residue	-	-	1.67	-	35.03	10^{-3} MJ
Diesel	-	-	0.63	-	0.01	10^{-3} MJ
H_3PO_4	0.06	0.02	0.01	-	0.01	g
HCl	0.75	0.33	0.07	0.10	0.37	g
Na_2CO_3	0.09	-	-	-	-	g
NaOH	0.25	0.01	0.01	-	0.04	g
Citric Acid	-	0.02	-	-	-	g
Nitrogen	-	0.70	0.06	-	-	g
Sodium methylate	-	0.18	-	0.11	0.62	g
Methanol	81.84	51.80	58.09	51.10	58.04	10^{-3} MJ

Soybean FAME

Transportation of soybean (grains and oil) parameters

	BioGrace	GHGenius	GREET	JRC	VSB	
			Soybean transportation			
Truck	700	100	16 (MHD)	517	324	km
Truck	-	-	64 (HHD)	-	-	km
Train	-	-	-	179	-	km
Inland ship	-	-	-	614	-	km
Ocean	10,186	-	-	9,381	-	km
			Soybean oil transportation			
Barge	-	-	837	-	-	km
Train	-	-	1,126	-	-	km
Truck	-	50	129 (HHD)	-	116	km

MHD: medium-heavy-duty truck
HHD: heavy-heavy-duty truck

Harmonization: remarks

Harmonization of FAME production emissions

Cradle-to-gate

- Harmonization of inputs: insertion of VSB agricultural inputs
  - Agricultural inputs and industrial inputs (oil extraction and oil transesterification)
  - Soybean productivity and industrial yields

- Harmonization of transportation: insertion of transportation modals and distances considered in the VSB model
  - Removal of overseas soybean transportation in the BioGrace model

Harmonization: remarks

Harmonization of FAME production emissions

Cradle-to-gate

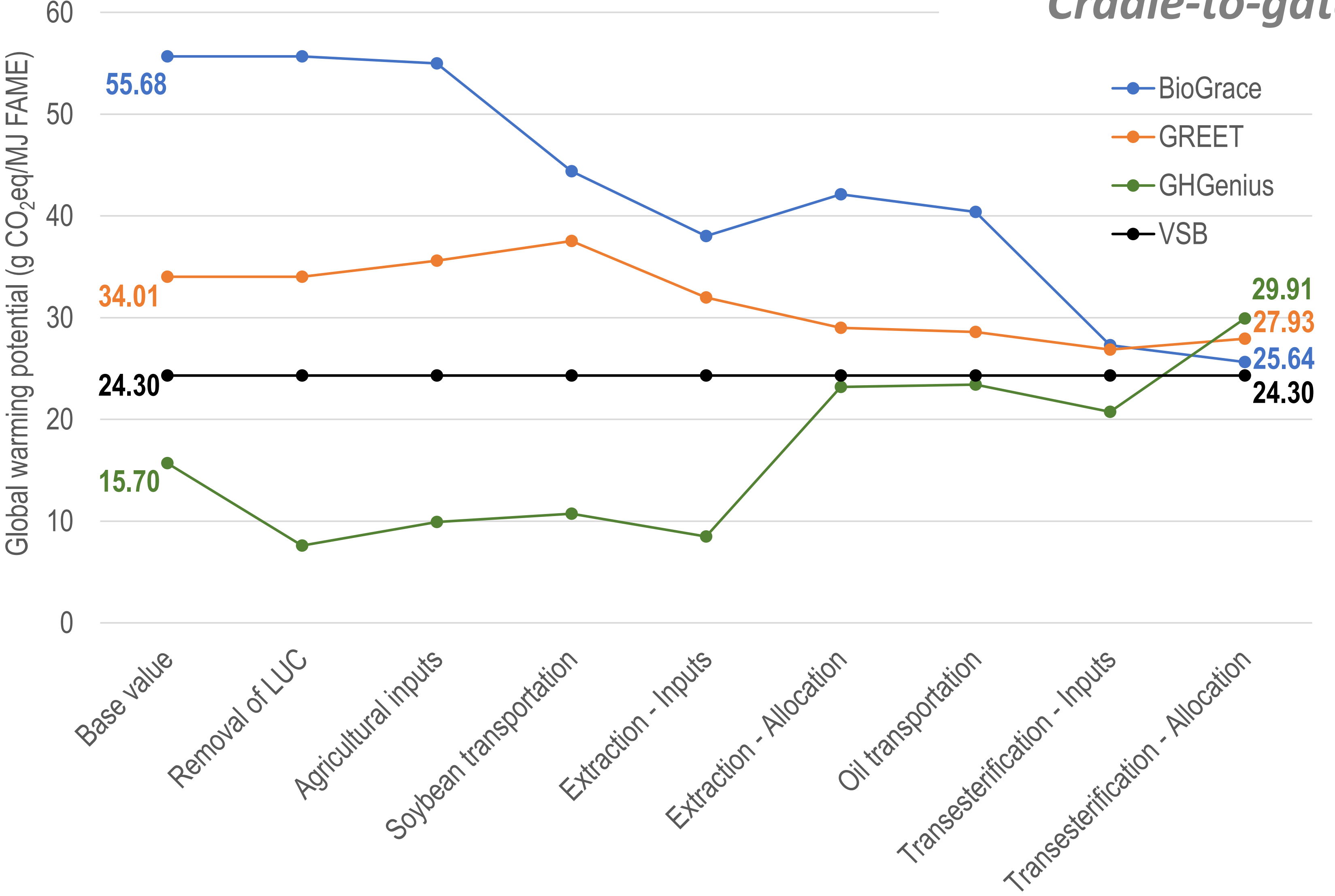
- Harmonization of allocation procedure: modification of default methods to consider full economic allocation as in the VSB model
- Harmonization of emission factors: insertion of VSB emission factors for selected inputs with discrepant values
  - NPK fertilizer, diesel, and methanol (such inputs have the highest influence over the final result)
- BioGrace: the 1.4 factor for converting input values from typical to default in industrial processes (oil extraction and oil transesterification) was removed in the harmonization procedure

OBS: JRC was not included in the harmonization since the calculation procedures are proprietary – and, therefore, not publicly available

Harmonization: Soybean FAME

Harmonization of FAME production emissions

Cradle-to-gate: g CO_2eq/MJ FAME



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Harmonization: Remaining major differences

Harmonization of FAME production emissions

Cradle-to-gate

- Particularities of each model
  - **BioGrace:** the default emission factor for methanol includes burning (this is usually only considered in the use phase of the lifecycle analysis)
  - **GHGenius:** the model calculates low emissions for the industrial phase and higher emissions for transportation in comparison with other models
  - **GREET:** the model presents several differences along the production chain that ultimately accumulate and affect the final result, such as transportation efficiencies and emission factors of minor inputs
  - **VSB:** in an overall analysis, it preferentially considers energy sources with low emissions (such as forest residues) to power industrial processes

Harmonization: Remaining major differences

Harmonization of FAME production emissions

Cradle-to-gate

- Characterization factors differ among models

	BioGrace	GREET	GHGenius[1]	JRC[2]	VSB
CO_2	1	1	1	1	1
CH_4	23	30	25	23 (25)	25
N_2O	296	265	298	296 (298)	298

[1] GHGenius also takes into account several characterization factors to convert several other compounds (such as VOC, NO_x, fluorides, etc.) into CO_2eq using 2007 IPCC GWP data

[2] The same characterization factors as those in BioGrace were maintained (proprietary model, and, therefore, not publicly available)

- Calculation procedures also differ from one model to another
- Remaining steps that were not harmonized can cumulatively account for the differences found in the final result

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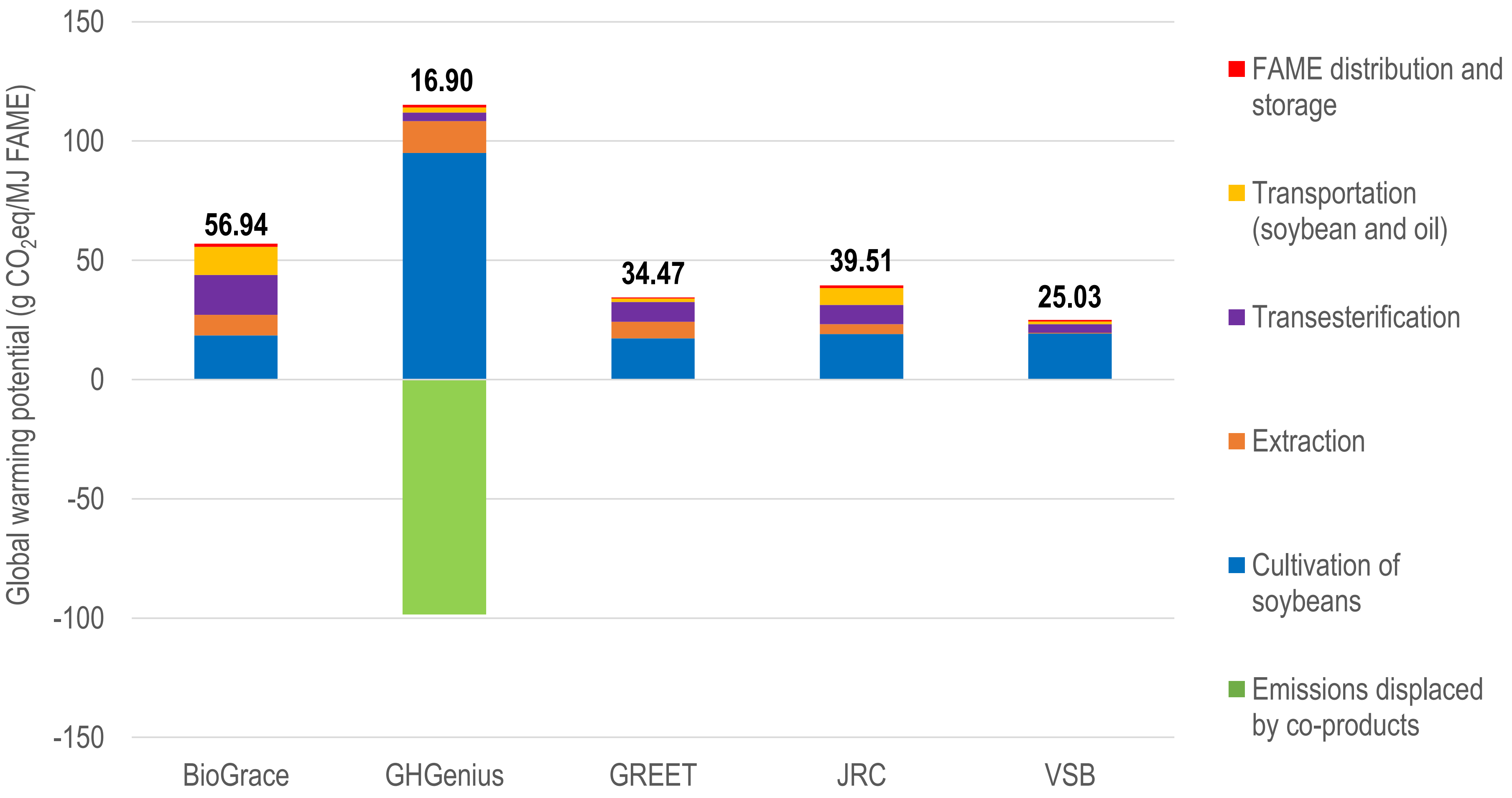
Harmonization: Partial conclusions

The harmonization procedure shows that, once the production chains are harmonized, the models are able to reach similar final values regarding the carbon intensity of soybean FAME

Soybean FAME: Cradle-to-pump

FAME emissions including distribution

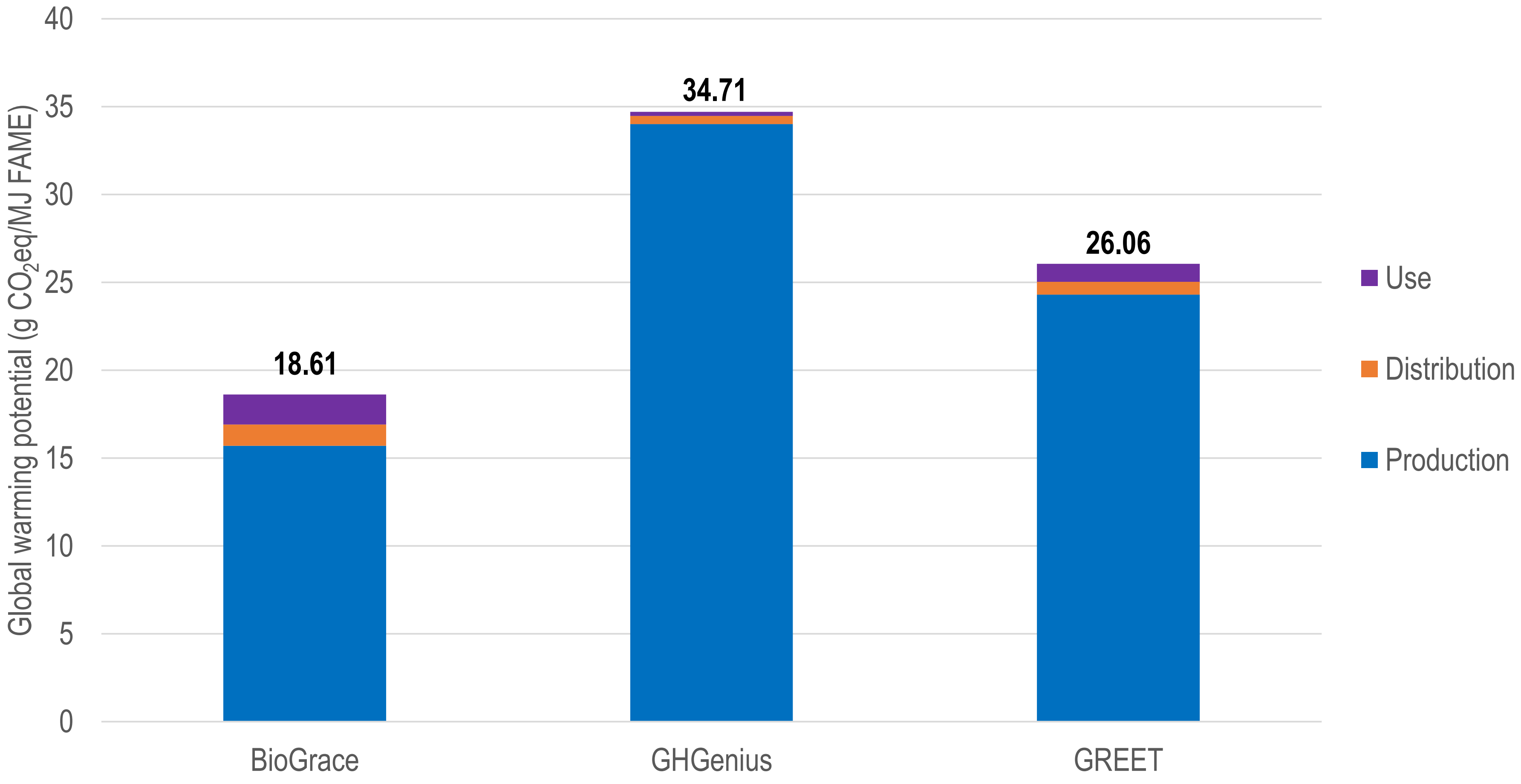
g CO_2eq/MJ FAME



Soybean FAME: Cradle-to-grave

FAME emissions including distribution and use

g CO_2eq/MJ FAME

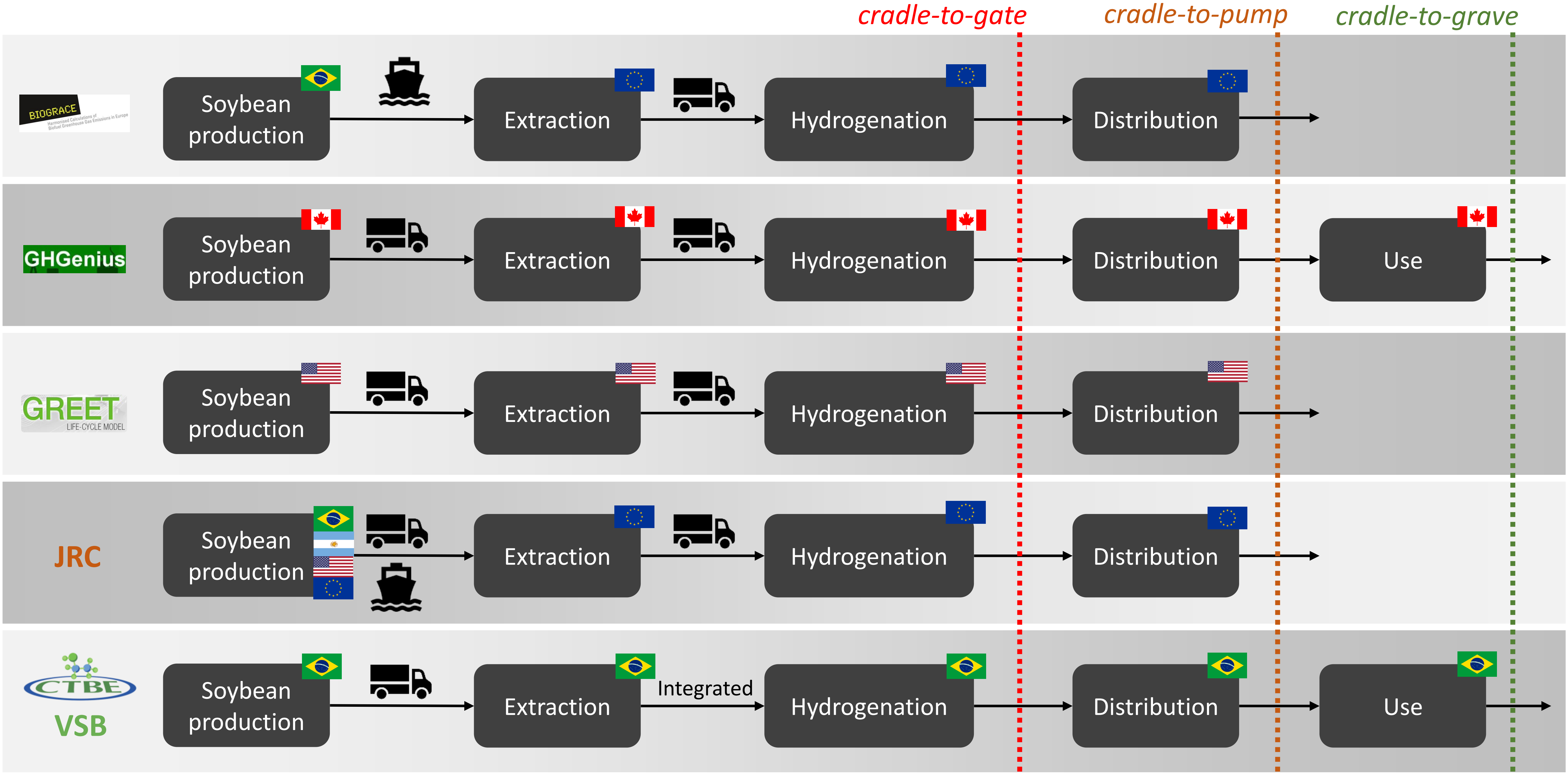


Final remarks: Soybean FAME

	BioGrace	GHGenius	GREET	JRC	VSB
Agricultural phase	High energy input	High amount of LMC emissions	High consumption of natural gas	High N_2O field emissions	High consumption of K_2O and $CaCO_3$; high CO_2 field emissions
Industrial phase	Only model to consider oil refining. High consumption of natural gas, high use of methanol and electricity.	High emissions associated with oil extraction. High n-hexane consumption.	Emission factors for natural gas, electricity, coal and n-hexane are high. Considers coal consumption.	Only model to consider pre-drying steps for soybean conditioning	Low emissions due to low fossil fuel consumption and to electricity from Brazil being largely of renewable origin.
Transportation (soybeans and oil)	High emissions due to large transportation distances	Low emissions	Low emissions	High emissions due to large transportation distances	Low emissions
Distribution and use	High emissions associated with distribution	High emissions associated with vehicle operation	Low emissions	High emissions associated with distribution	Low emissions
Global warming potential	High emissions	Low emissions due to high co-product's credits (soybean meal and glycerin)	Intermediate emissions compared to the other models	Intermediate emissions compared to the other models	Low emissions due to low fossil energy consumption


HVO/HEFA from soybean oil

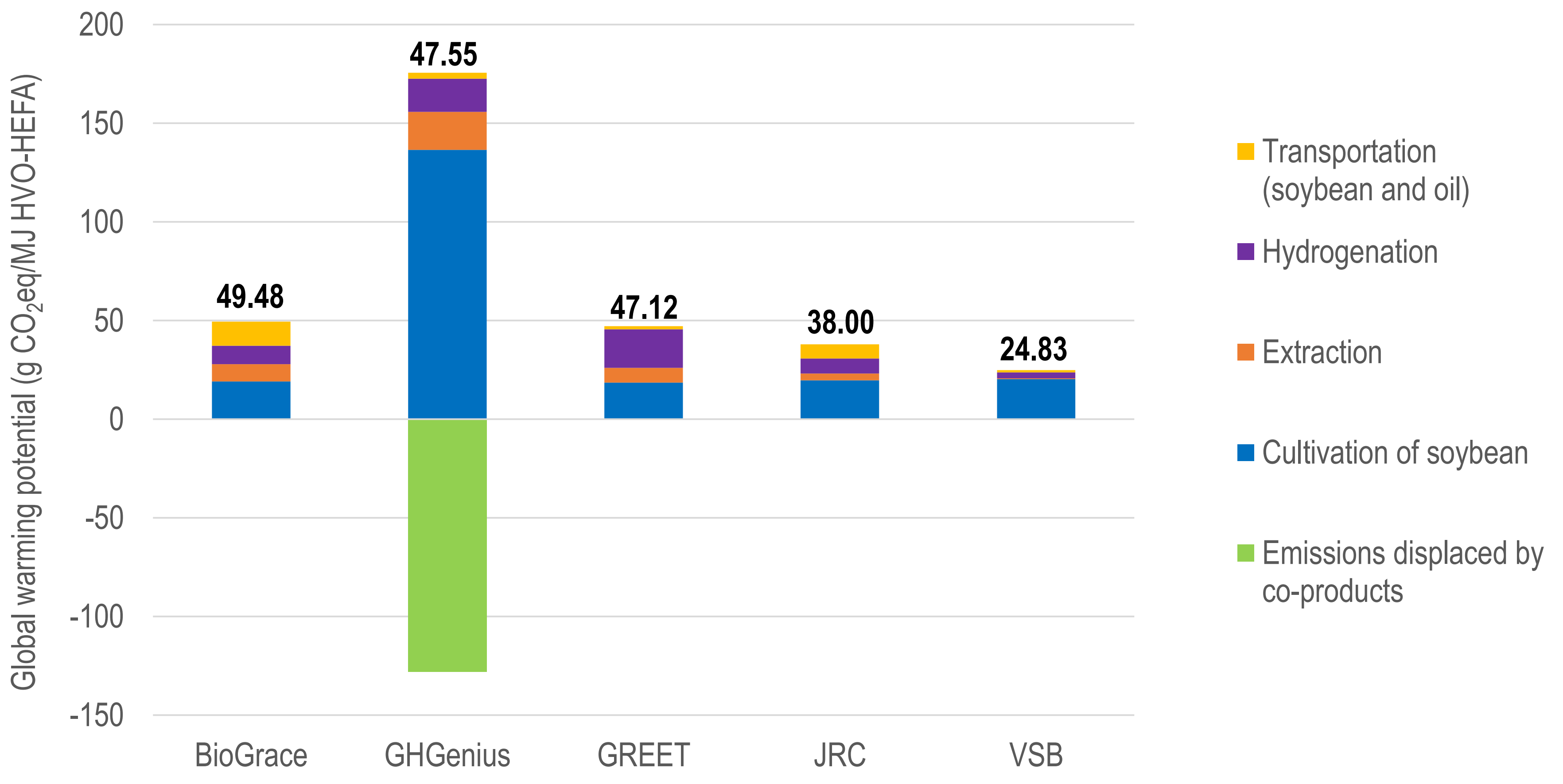
System boundaries: Soybean HVO/HEFA



Soybean HVO/HEFA: Cradle-to-gate

HVO/HEFA production emissions

g CO_2eq/MJ HVO-HEFA



Final remarks: Soybean HVO/HEFA

	BioGrace	GHGenius	GREET	JRC	VSB
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Industrial phase	Only model to consider oil refining. High consumption of natural gas, high use of methanol and electricity.	High emissions associated with oil extraction. High n-hexane consumption.	Emission factors for natural gas, electricity, coal and n-hexane are high. Considers coal consumption.	Only model to consider pre-drying steps for soybean conditioning	Low emissions due to low fossil fuel consumption (e.g. H_2 production through water electrolysis using LCM when required)
Transportation (soybeans and oil)	High emissions due to large transportation distances	Low emissions	Low emissions	High emissions due to large transportation distances	Low emissions
Distribution and use	High emissions associated with distribution	High emissions associated with vehicle operation	Low emissions	High emissions associated with distribution	Low emissions
Global warming potential	High emissions	High emissions	High emissions	Intermediate emissions compared to the other models	Low emissions due to low fossil energy consumption

Conclusions and next steps

- The assessment was able to identify the main parameters impacting the determination of the emissions associated to the production and use of biofuels.

- The harmonization procedure shows it is possible to align the results issued by the models through a series of steps.

Next steps

- **Phase II.1:** carrying out the assessment for the same fuels (FAME and HVO/HEFA) from different feedstocks: palm oil and used cooking oil (UCO). Incorporation of comments from the Steering Committee and elaboration of the technical report.

- **Phase II.2:** prospective LCA of industrial processes under development for the conversion of biomass to advanced biofuels.

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Auxiliary slides

Main used general emission factors

Agricultural phase

	BioGrace	GHGenius	GREET	JRC	VSB	
Diesel	88	111	95	88	84	g CO_2eq/MJ
Natural gas	68	-	78	68	-	g CO_2eq/MJ
Electricity	129	61	188	129	40	g CO_2eq/MJ
Gasoline	-	103	80	-	-	g CO_2eq/MJ
LPG	-	71	88	-	-	g CO_2eq/MJ
N	5,881	3,104	4,548	5,881	2,799	g CO_2eq/kg
K_2O	576	426	686	576	545	g CO_2eq/kg
P_2O_5	1,011	2,016	1,807	1,011	1,468	g CO_2eq/kg
CaO	130	-	-	130	-	g CO_2eq/kg
$CaCO_3$	-	-	-	-	13	g CO_2eq/kg
Gypsum	-	-	-	-	2	g CO_2eq/kg
Sulphur	-	113	-	-	-	g CO_2eq/kg
Pesticides	10,971	21,791	24,733	10,971	10,076	g CO_2eq/kg
Herbicides	-	-	21,854	-	10,448	g CO_2eq/kg

Main used general emission factors

Industrial phase

	BioGrace	GHGenius	GREET	JRC	VSB	
n-Hexane	81	78	87	81	-	g CO_2eq/MJ
Coal	-	-	101	-	-	g CO_2eq/MJ
Residual oil	-	-	95	-	-	g CO_2eq/MJ
Forest residue	-	-	3	-	2	g CO_2eq/MJ
Natural Gas	-	60	69	-	-	g CO_2eq/MJ
Diesel	-	-	95	-	-	g CO_2eq/MJ
Renewable natural gas	-	-	24	-	-	g CO_2eq/MJ
Fuller's Earth	200	-	-	200	-	g CO_2eq/kg
H_3PO_4	3,012	1,543	853	3,012	1,676	g CO_2eq/kg
HCl	751	756	1,980	751	1,836	g CO_2eq/kg
Na_2CO_3	1,190	-	-	1,190	-	g CO_2eq/kg
NaOH	469	888	2208	469	1513	g CO_2eq/kg
Citric acid	-	1,476	-	-	-	g CO_2eq/kg
Nitrogen	-	132	-	-	-	g CO_2eq/kg
Sodium methylate	-	1,981	-	-	1,836	g CO_2eq/kg
Methanol	100	22	30	100	28	g CO_2eq/MJ
Hydrogen	88	-	87	88	20	g CO_2eq/MJ

Phase 1 publication

- May/2017: *Biotechnology for Biofuels*
- Oct/2017: *Renewable and Sustainable Energy Reviews*
- Sep/2018: response to reviewers of RSER