A Life Cycle Approach for Sustainable Aviation Biofuels Production: The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

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- GHG emissions from land use change (i.e., land conversion into biofuel feedstock) can negate GHG savings of alternative aviation biofuels
- Uncertainty derived from data variability and methodological choices hinder consideration of LUC emissions within CORSIA

H2020 project #875538

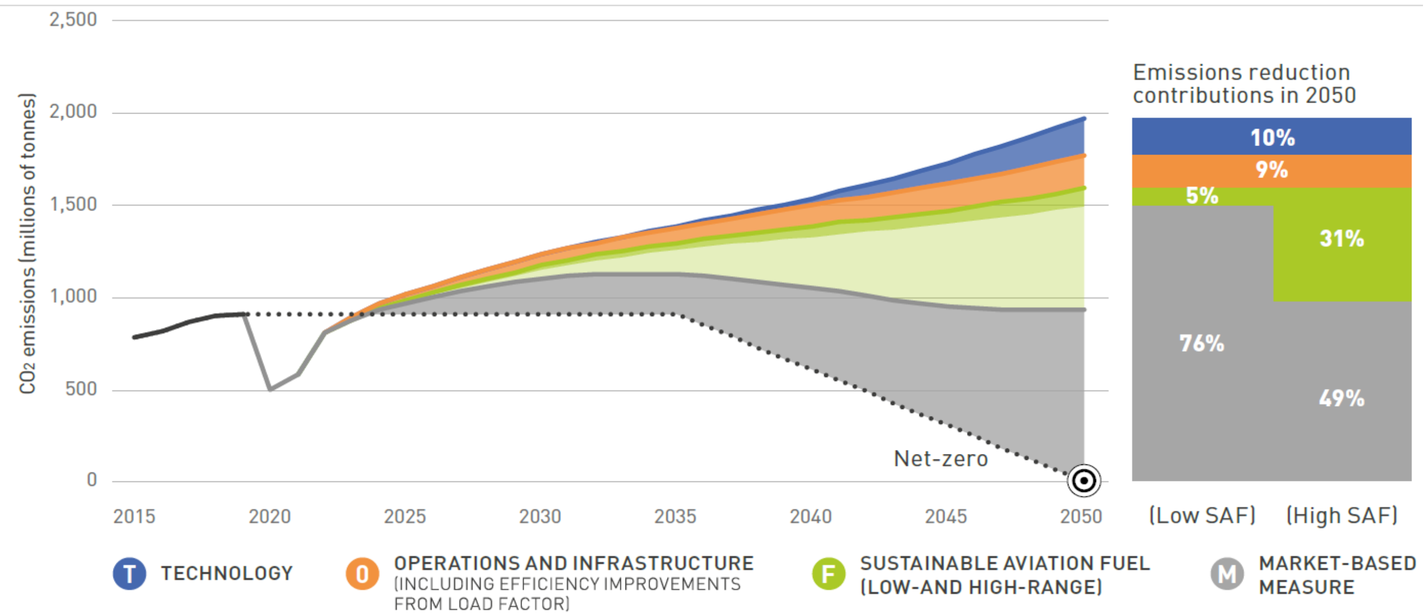
1. Background

Background

- Aviation: 2.1% of global GHG emissions in 2019, 1.3% from international aviation (ATAG, 2020)
  - Growing by 4% per annum, pre-pandemic (ICAO 2019)
- COVID-19-adjusted forecasts: aviation traffic will grow between 2.3% to 3.3% per annum between 2019 and 2050 (ATAG, 2021) vs. 2.9% and 4.2% (ATAG, 2020)
- UNFCCC Paris Agreement
  - Quantifies emissions from domestic aviation
    - Incl. emissions from ground service, equipment and road vehicles; terminals, maintenance, and facilities; air traffic control, and from fuel combustion from gate-to-gate
- ICAO (International Civil Aviation Organization)
  - Quantifies emissions from international civil aviation from fuel combustion from gate-to-gate
  - Sets technology standards e.g., increased fuel efficiency
  - Aspirational goals
    - Short-term: 1.5% annual fuel efficiency improvement in 2009-2019
    - Medium-term: Carbon neutral growth from 2020
    - Long-term: Reduce net emissions to 50% by 2050 w.r.t. 2005

Background

Air Transport Action Group (ATAG)
Waypoint 2050 Report, 2021



Comparison with industry -50% long-term goal set in 2009
In order to meet the industry long-term goal of -50% by 2050 compared to 2005 levels, Technology would contribute 12% of emissions reductions. Operations and infrastructure improvements 11%. Sustainable Aviation Fuels would show a low- to high-range continuation of current investment curve delivering between 30 - 195 Mt (40 - 240 billion litres) of SAF with a 100% emissions reduction factor by 2050 (between 6 and 37% of 2050 emissions reductions). The remainder required to meet goal would need to be met with out-of-sector carbon removals or offsets, in the order of 650 – 1,200 Mt in 2050.

- October 2021: the International Air Transport Association (IATA) member airlines pledged to achieve net-zero carbon emissions from their operations by 2050
- Despite GHG savings from fuel efficiency gains since 1960s, additional efforts needed to meet the 2050 goal
- **Sustainable aviation fuels (SAF)** identified as the preferred short-term option to reduce GHG and the need for carbon offsets
  - Up to 31% GHG reductions
- SAF: bio-based aviation fuels that reduce GHG emissions relative to conventional kerosene

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

- Adopted in 2016 by ICAO country members
- Starting in 2021, the scheme is voluntary for all countries until 2027
- To offset any growth in GHG emissions from international aviation (not covered by the Paris Agreement)
- Airlines must offset any GHG emission increases **above 2019 levels** either by:
  - Buying carbon offsets: credits generated by projects/programs reducing emissions
  - Using SAFs: drop-in jet fuels derived from biomass or waste resources that can be used without modifications of the aircraft
- Eligible SAFs to be certified that deliver **GHG savings relative to fossil kerosene**
- Current share of SAFs in jet kerosene for aviation is still very small (<0.1%)
  - In the EU: 0.05% of total jet fuel consumption, most of it imported

*ICAO 2019 Environmental Report

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

CORSIA

Sustainability criteria:

- SAF should achieve life cycle emission reductions of at least 10% w.r.t. fossil fuel reference from well to wake, incl. emissions from **indirect land use change (ILUC)**
- SAF should not be produced at the cost of land converted after 1 January 2008 that was **primary forest, wetlands or peatland**
- In the event of land use conversion after 1 January 2008, emissions from carbon stocks changes due to **direct land use change (DLUC)** should be estimated under the IPCC approach
- If **DLUC > default ILUC value**, the DLUC value shall replace the default ILUC value when estimating the SAF's net carbon intensity

CORSIA SUSTAINABILITY CRITERIA FOR CORSIA ELIGIBLE FUELS

Theme	Principle	Criteria
1. Greenhouse Gases (GHG)	Principle: CORSIA eligible fuel should generate lower carbon emissions on a life cycle basis.	Criterion 1: CORSIA eligible fuel shall achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values for aviation fuel on a life cycle basis.
2. Carbon stock	Principle: CORSIA eligible fuel should not be made from biomass obtained from land with high carbon stock.	Criterion 1: CORSIA eligible fuel shall not be made from biomass obtained from land converted after 1 January 2008 that was primary forest, wetlands, or peat lands and/or contributes to degradation of the carbon stock in primary forests, wetlands, or peat lands as these lands all have high carbon stocks.
		Criterion 2: In the event of land use conversion after 1 January 2008, as defined based on IPCC land categories, direct land use change (DLUC) emissions shall be calculated. If DLUC greenhouse gas emissions exceed the default induced land use change (ILUC) value, the DLUC value shall replace the default ILUC value.

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

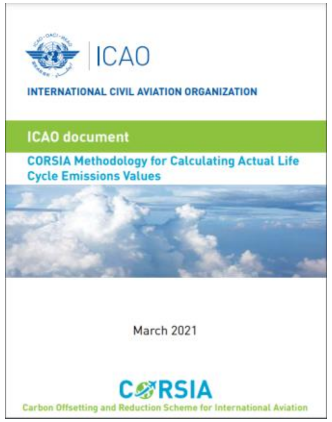
- CORSIA Eligible Fuel needs to come from a fuel producer that is certified by the ICAO Council, according to the CORSIA Sustainability Criteria (a) as certified by the Sustainability Certification Scheme (SCS)
- Two methods to determine life cycle GHG emissions value for CORSIA Eligible Fuel:

(b) Actual life cycle emissions values using CORSIA Methodology in ICAO documents: attributional LCA with energy allocation

(c) CORSIA default life cycle emissions values: developed by international team, approved by ICAO Council

a)

b)



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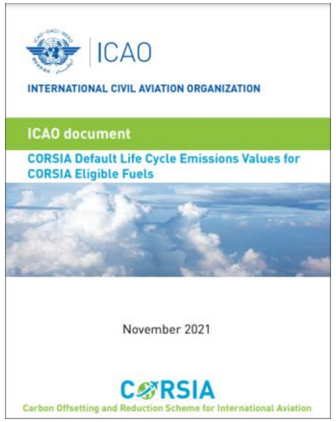


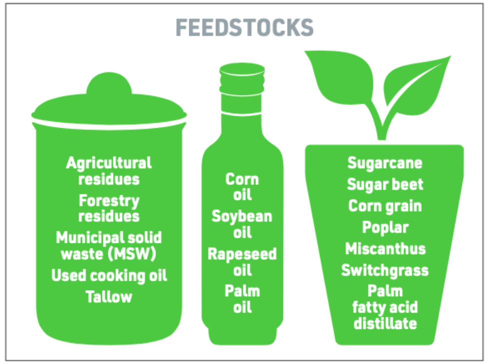
https://www.icao.int/environmental-protection/CORSIA/Documents/

New feedstocks within the H2020 ALTERNATE project

Feedstock Type	Feedstock Name	CORSIA	ALTERNATE
Oilseed crops	Camelina	■	
	Carinata	■	
	Castor bean		•
	Corn oil (from DDGS)	■	
	Jatropha	■	•
	Palm	■	
	Palm fatty acid distillate	■	
	Pennycress		•
	Rapeseed	■	
	Salicornia		•
	Soybean	■	
	Tobacco		•
Lignocellulosic biomass	Agricultural residues	■	
	Forest residues	■	
	Giantreed		•
	Miscanthus	■	
	Reed canary grass		•
	Short rotation woody crops	■	
	Switchgrass	■	
Carbohydrate crops	Sweet sorghum		•
	Sugar beet	■	
	Sugar cane	■	
	Wheat		•
Wastes	Municipal Solid Waste (MSW)	■	
	Used cooking oil	■	
	Tallow	■	

- **DLUC:** on-site conversion of land from previous uses into SAF feedstock, e.g., forest to cropland
- **ILUC:** market-mediated land conversion among global land uses in response to an increased demand for biomass for non-food uses
- Estimation of ILUC emissions is ongoing, based on two economic equilibrium models (**GTAP-BIO and GLOBIOM**) according to CORSIA protocol
- No specifications for DLUC estimation besides IPCC

CORSIA feedstocks:



Objective

- Estimate life cycle GHG emissions from alternative feedstocks for SAF production considering uncertainty in DLUC estimation
- Assess how uncertainty in DLUC emissions of alternative feedstocks affects GHG savings and eligibility for CORSIA

Jatropha

Pennycress

Castor bean

Tobacco

Salicornia

Switchgrass

Giant reed

Red canary grass

Wheat

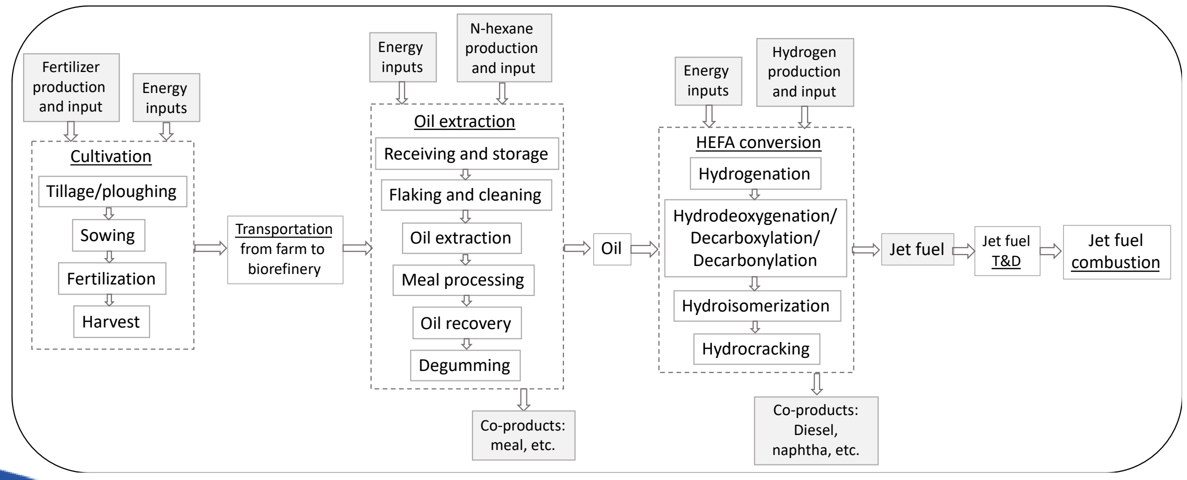
Miscanthus

2. Methodological aspects

Goal and scope definition

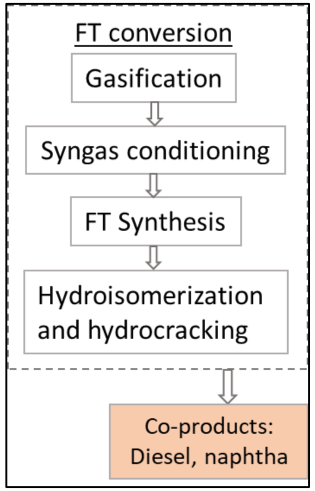
- Pathways certified by the American Society for Testing and Materials (ASTM)
- Core-LCA emissions as **gCO_2eq per 1 MJ of jet fuel** (functional unit) from well-to-wake
- **Attributional LCA** with **energy allocation,** based on primary and secondary LCI data and assumptions on co-products' applications, mainly
  - Additional naphtha and diesel obtained (from ethanol-to-jet or refined oil-to-jet conversion)
  - Protein cakes from hydro-processing of esters and fatty acids (HEFA) pathways and DDGS from alcohol-to-jet (ATJ) pathways → animal feed
  - Straw from both HEFA and ATJ → energy production

Oilseeds

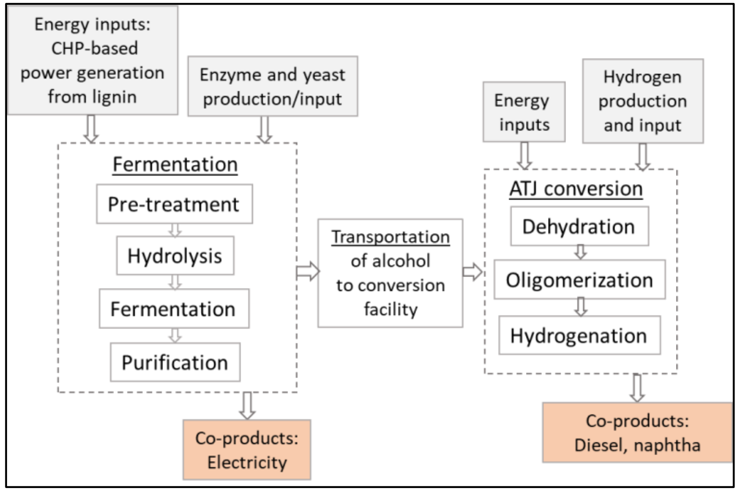


Lignocellulosic and starch-based crops

Fischer-Tropsch



Alcohol-to-jet



Methods for DLUC calculation

- Tier 1 approach of IPCC guidelines (2006): land conversion into cropland
- GHG sources from changes in C pools → Equation 2.1 (IPCC 2006)
  - Above-ground biomass (AGB) and below-ground biomass (BGB)
  - Dead organic matter in dead wood (DW) and litter (LI)
  - Soil organic carbon (SOC)
  - Harvested wood products (HWP) = 0 under Tier 1 approach

$$DLUC = \frac{(\Delta C_{AGB} + \Delta C_{BGB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SOC} + \Delta C_{HWP})}{25} \times \frac{44}{12}$$

- Additional GHG flows → Equations 11.2; 11.8; 11.10 (IPCC 2006)
  - N_2O emissions from mineralized N as a result of SOC changes (direct & indirect)

→ Forgone carbon sequestration is excluded: discussion ongoing

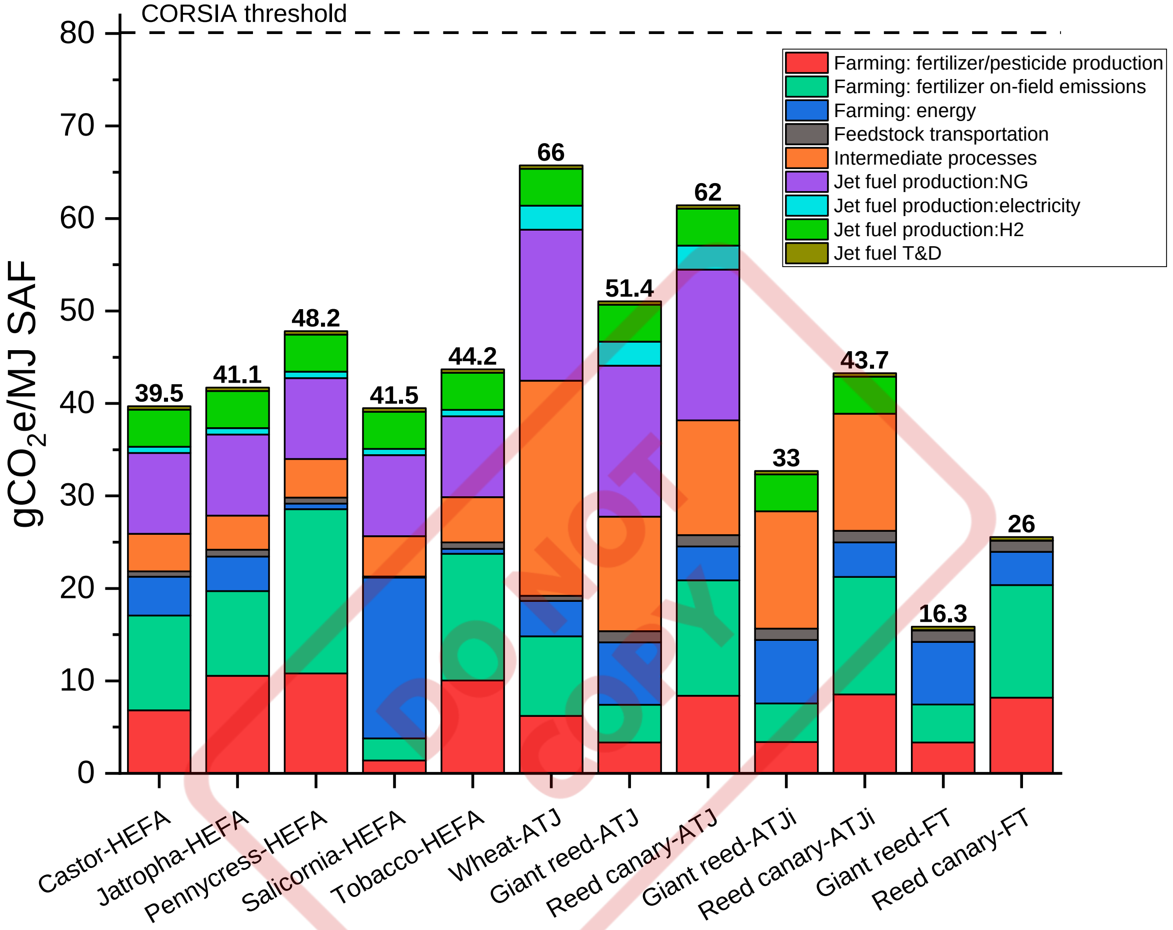
Methods for DLUC calculation

- Additional assumptions on yields and crop biomass (in line input application intensity in IPCC)

			Crop biomass (AGB, BGB) at harvest (t C/ha)			Yields (t/ha)			References	
			Low input	Medium input	High input	Low input	Medium input	High input	Crop biomass[1]	Yields
Oilseed crops	C	Camelina	1.8	2.0	2.2	1.9	2.3	2.7	Angelini et al. (2020)	Angelini et al. (2020); Li et al. (2014)
	N	Castor bean	1.3	1.4	1.6	1.1	1.3	1.6	De Souza David et al. (2013)	Carrino et al. (2020); Alexopoulou et al. (2015)
	C	Jatropha	12.0	13.2	14.5	2.5	3.0	3.6	Bailis and Batka (2010); Achten et al. (2013)	Bailis and Batka (2010); Achten et al. (2013); Van Eijck et al. (2014)
	C	Oil palm	37.5	37.5	37.5	17.1	18.0	18.9	IPCC (2019); Khasanah et al (2015)	FAOSTAT (2021): Yields in 2015-2019 in Malaysia and Indonesia
	N	Pennycress	0.9	1.0	1.1	0.7	1.0	1.2	Moore et al. (2020); Fan et al. (2013)	Rukavina et al. (2011); Cubins et al. (2019)
	C	Rapeseed	1.3	1.5	1.6	3.0	3.4	4.0	IPCC (2019); Williams et al. (2013)	FAOSTAT (2021): Yields in 2015-2019 in France and Germany
	N	Salicornia	3.8	4.2	4.6	1.5	2.0	2.5	Bresdin et al. (2016); Garza-Torres et al. (2019)	Stratton et al. (2010)
	C	Soybean	1.2	1.4	1.5	3.0	3.2	3.5	IPCC (2019); Ordonez et al. (2020)	FAOSTAT (2021): Yields in 2015-2019 in Brazil and USA
	N	Tobacco	1.8	2.0	2.2	2.1	2.5	3.0	Fatica et al. (2019)	Fatica et al. (2019); Grisan et al. (2016)
Lignocellulosic or starch-based crops	C	Maize	2.2	2.4	2.6	9.9	11.0	12.1	FAOSTAT (2021): Yields in 2015-2019 in US and China	Puntel et al. (2016)
	N	Wheat	1.3	1.4	1.5	5.3	5.9	6.5	FAOSTAT (2021): Yields in 2015-2019 in France and Germany	Puntel et al. (2016)
	C	Miscanthus	12.4	14.9	17.9	17.3	20.8	25.0	Bilandzija et al. (2016)	Same as switchgrass
	C	Switchgrass	5.8	6.9	8.3	8.0	9.6	11.5	Bilandzija et al. (2016)	Hong et al. (2014); Kering (2012)
	N	Gian reed	6.5	7.5	8.6	14.6	16.8	19.3	Dragoni et al. (2015)	Scordia et al. (2019, 2021)
	N	Reed canary grass	4.9	5.6	6.5	8.5	9.8	11.3	Lindh et al. (2009)	Scordia et al. (2019, 2021)

3. Results

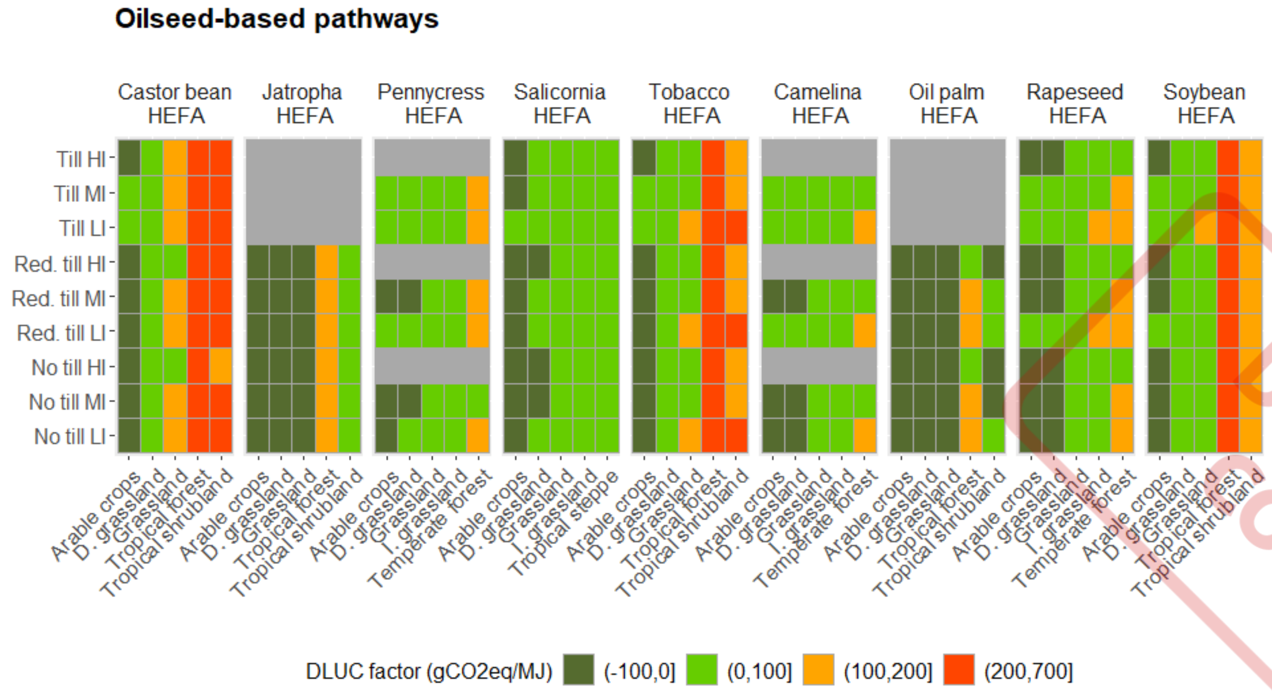
Life cycle GHG emissions without DLUC



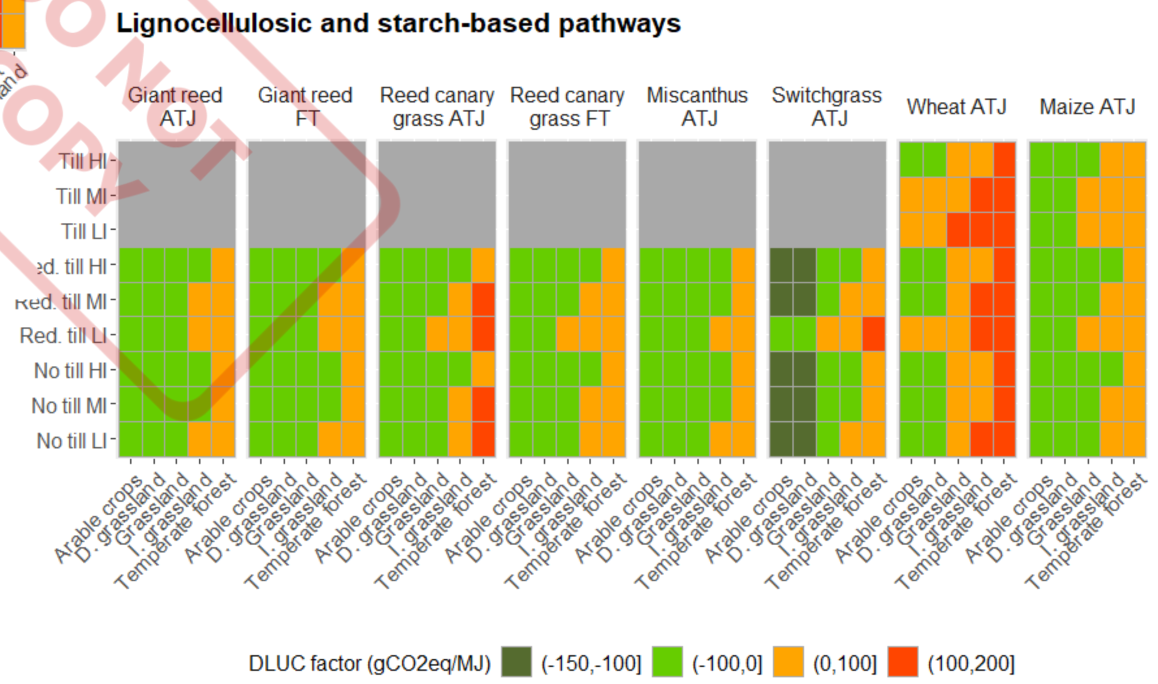
*Intermediate process: oil extraction step for HEFA; ethanol production step for ATJ;
ATJi: ATJ pathways with integrated energy production from straw.

- All feedstocks fall below the CORSIA threshold
- Differences mainly due to **different yields and fertilizer input intensities**
- Highest emissions for **wheat, giant reed and reed canary grass ATJ** pathways:
    - energy co-generation from lignin (straw) improves the GHG performance (in ATJi)
- Lowest emissions for **giant reed and reed canary grass FT pathways**
    - Energy from biomass gasification covers the need for energy in FT synthesis and hydrocracking
- **Emissions from fertilizers** (application and production) and **jet fuel production** (hydrogen and natural gas consumption) largest GHG sources – except FT pathways
    - Salicornia harvest is diesel intensive
    - Ethanol conversion into jet fuel is energy intensive

Scenario-based DLUC emission factors



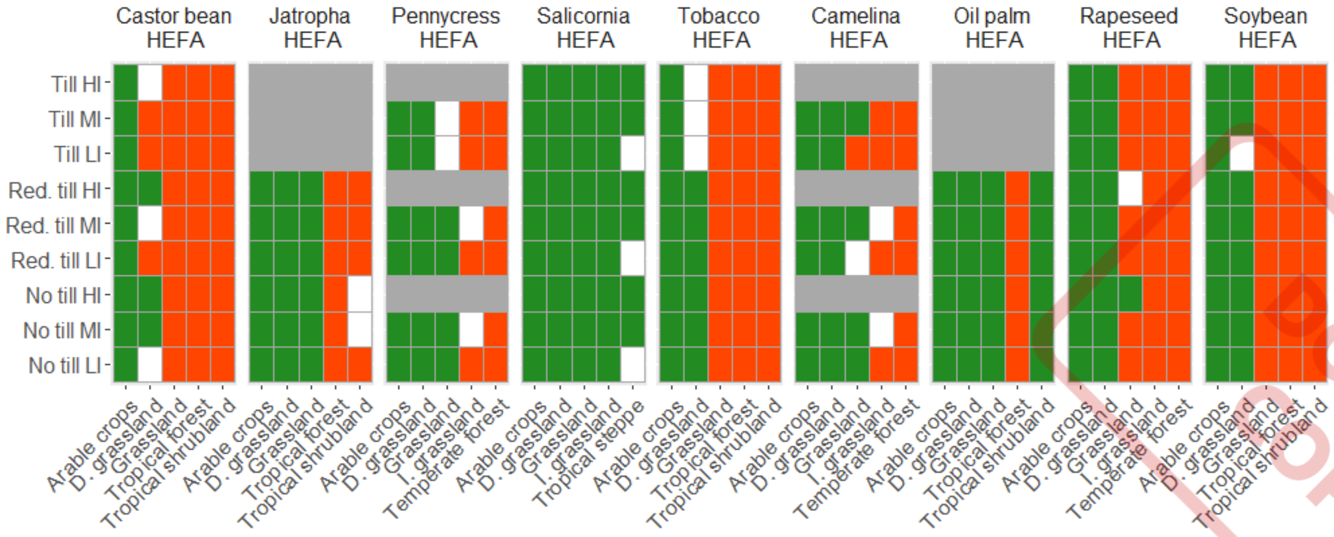
- High DLUC factors when secondary forests or shrublands are lost
- Perennial plants have lower DLUC factors due to SOC gains and carbon sequestration in crop biomass (jatropha, miscanthus, giant reed)



- Low-yielding crops have higher DLUC per MJ
- Co-products’ use reduces DLUC factors of camelina, pennycress, Salicornia, jatropha

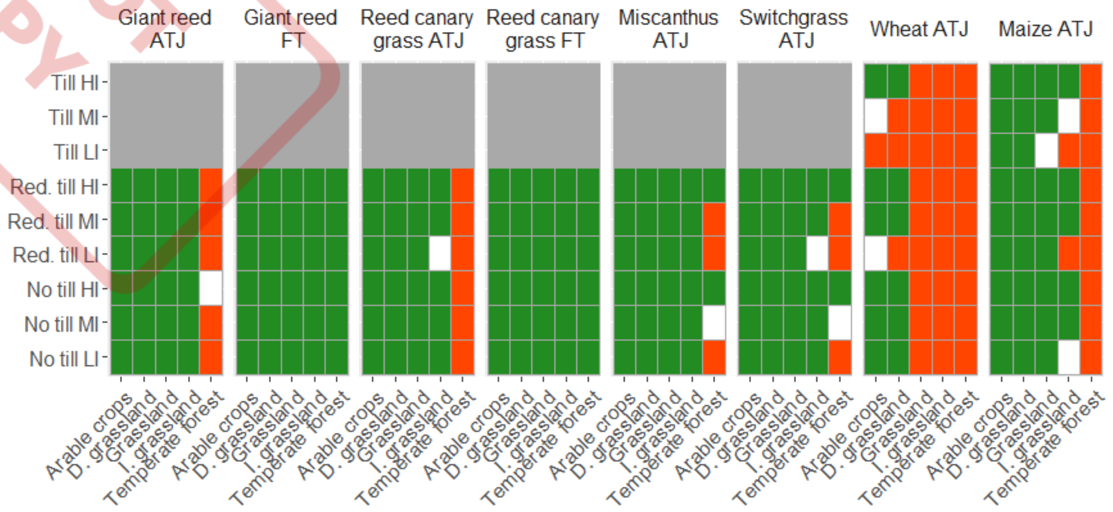
Scenario-based GHG savings

Oilseed-based pathways



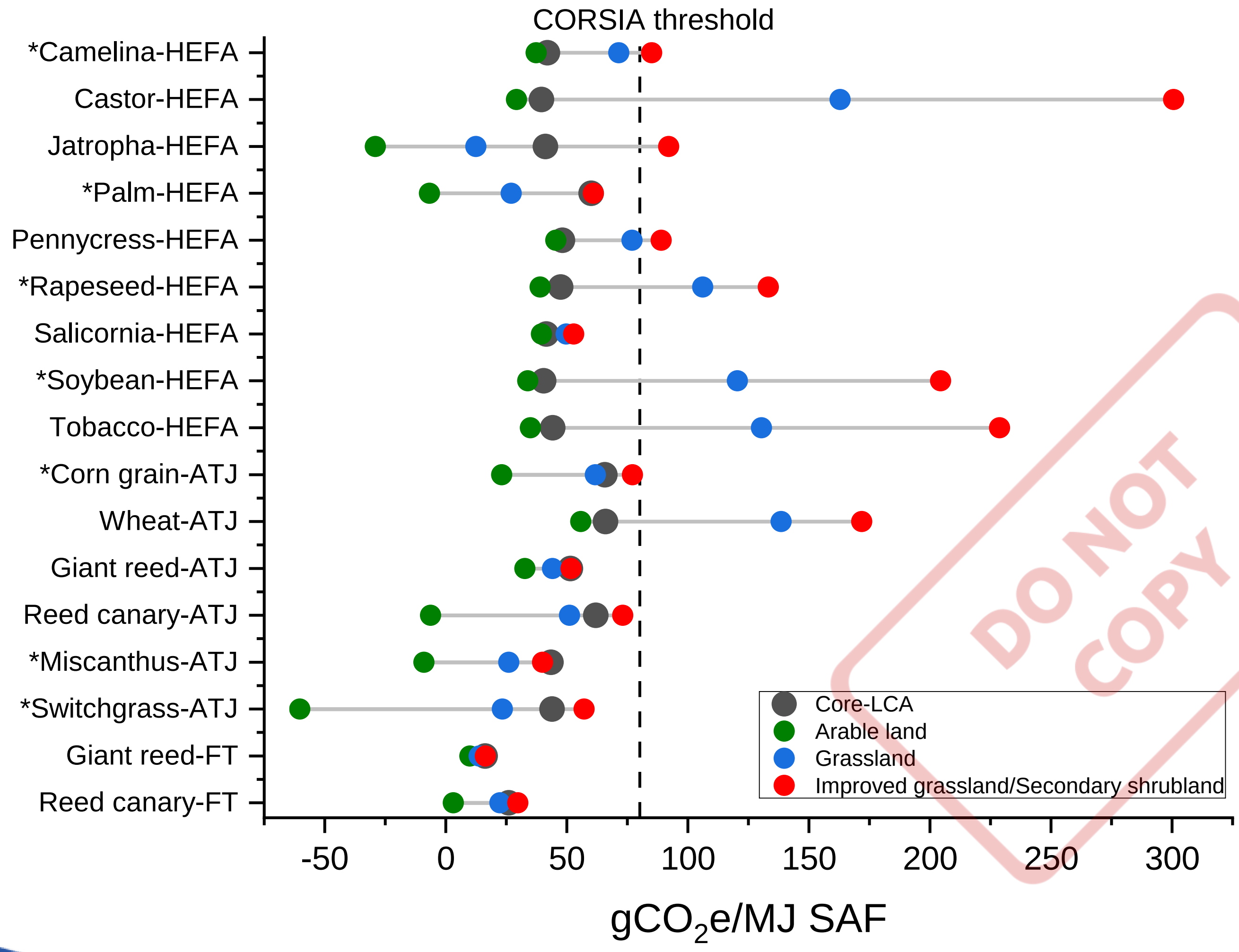
- Only FT from giant reed or reed canary grass and Salicornia HEFA yield GHG savings across all scenarios
- Remaining feedstocks do not meet CORSIA threshold if produced on carbon-rich land

Lignocellulosic and starch-based pathways



- Annual crops only to be produced at the cost of cropland or degraded grassland to meet CORSIA
  - Wheat ATJ only eligible if produced with reduced tillage or no tillage, or tillage with HI

Total life cycle GHG emissions with DLUC



- **Core-LCA + DLUC** with reduced tillage and medium input intensity after conversion
- Conversion of **secondary shrubland** (in tropical climates) or **improved grassland** (in temperate climates) crosses the CORSIA threshold in oilseed pathways (exc. Salicornia and oil palm) plus wheat ATJ
- All **lignocellulosic ATJ and FT pathways are below** the CORSIA threshold, regardless the DLUC scenario
- **Biomass carbon loss** are the major contributor to the highest DLUC factors
- **Arable crops** yield **SOC losses**; while **perennial crops increase SOC**
- **Low seed/crop yields and no energy** applications of co-products contribute to high DLUC factors

4. Discussion and conclusions

Discussion and conclusions

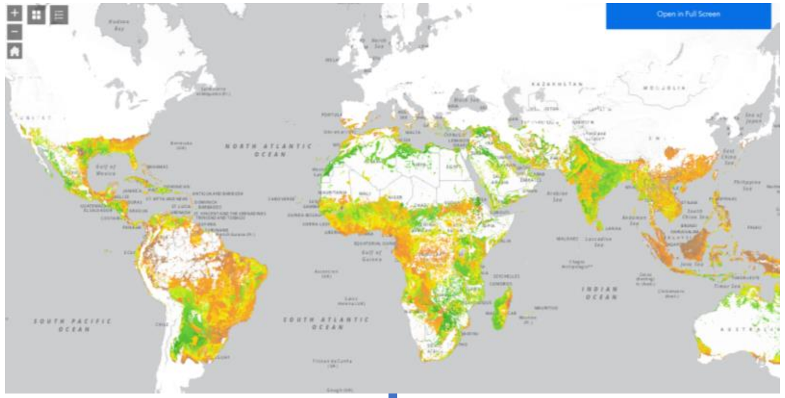
- All pathways-feedstocks assessed show **core-LCA emissions below CORSIA** threshold
- **DLUC emissions negate potential GHG savings** of both HEFA and ATJ when secondary forests, natural shrublands, grasslands are lost → need for the CORSIA sustainability criteria
    - Jatropha, Salicornia, and palm; lignocellulosic biomass (giant reed, miscanthus, switchgrass, and reed canary grass) deliver the largest GHG savings
    - Annual crops (wheat, soybean, castor, maize) only to be produced at the cost of arable land or (degraded) grassland, unless multi-cropping
- Uncertainty in DLUC emissions associated with **methodological choices** (producing region and major land uses) but also with **spatial variability in yields and carbon stocks**
- Carbon stocks in IPCC Tier 1 at the continent level, too coarse resolution
- Further **harmonization for DLUC estimation is desirable** for determining the GHG savings of SAFs under CORSIA LCA approach
- Other impacts to be addressed to better understand the sustainability implications of SAFs: water scarcity, food-feed-fuel competition, etc.

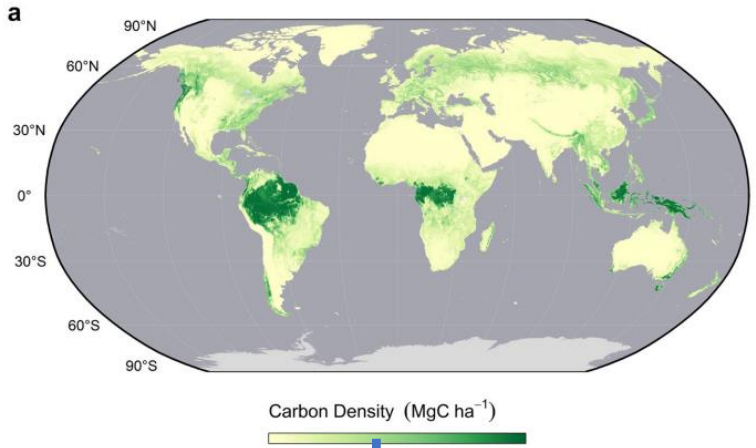
Work in progress: spatially-explicit DLUC factors

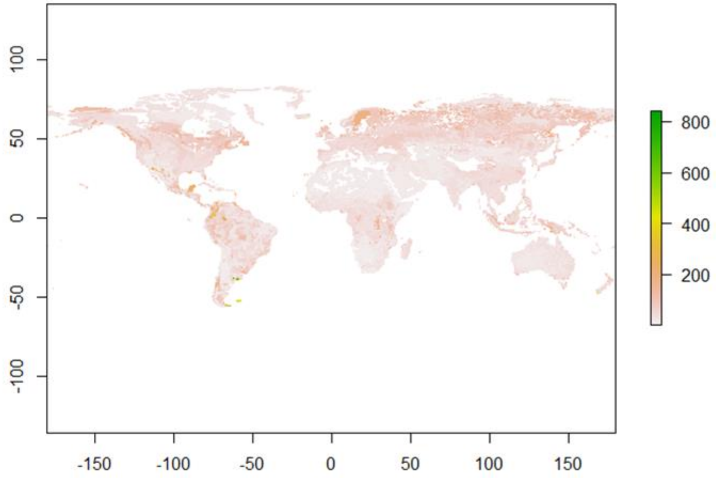
Average attainable yields in current cropland areas in 1981-2010 (without CO_2 fertilization), from GAEZ https://gaez.fao.org/

AGB and BGB stocks from Jung et al. (2021), based on biomass carbon density (Spawn et al. 2020) plus IPCC root-to-shoot ratios

SOC in mineral soils based on Harmonized World Soil Database (HWSD v 1.2) plus assumptions from IIASA's EPIC team







0.5 degree resolution (30 arc minute)

Integrated into GLOBIOM framework

Thanks for your attention!

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H2020 ALTERNATE project – Grant agreement #875538

https://www.alternateproject.com/

https://iiasa.ac.at/projects/assessment-of-alternative-aviation-fuels-development-alternate