Supplementary Material

1 Indirect land use change values

Table 1 below presents the iLUC values shown in Figure 1 in the main text, along with the sources from where they were obtained.

Table 1. Indirect land use change values used in the fuel standards

	iLUC value (gCO_2e/MJ fuel)		
	Rapeseed biodiesel	**Soybean biodiesel**	**Sugarcane ethanol**
RED (EC, 2018)	33 (low) 55 (mean) 66 (high)	33 (low) 55 (mean) 66 (high)	4 (low) 13 (mean) 17 (high)
RTFO (UKDfT, 2024a)	55	55	13
LCFS (CARB, 2014)	19.4	29.1	11.8
RFS (USEPA, 2023a)	11 (low) 35.8 (mean) 67.3 (high)	6 (low) 35.5 (mean) 71.1 (high)	-4.2 (low) 5.6 (mean) 14.1 (high)
CORSIA (ICAO, 2022a)	24.1 (Europe) 26 (global)	24.5 (USA) 27 (Brazil) 25.8 (global)	7.3 (Brazil) 9.1 (global)

2 Fuel carbon intensity scores

2.1 Data sources for default values

For the RED, RTFO and CORSIA, default values for the carbon intensity (CI) of the fuel pathways are provided in the fuel standards documents and appendices (EC, 2018; ICAO, 2022b; UKDfT, 2024a).

For the LCFS, the CI scores come from pathways and fuel production sites that have been approved by the California Air Resources Board (CARB), meaning that there can be multiple approved values for the same fuel and pathway (CARB, 2023). In these instances, the average of the values was taken and used for this study.

The RFS provides default values for pathways that have been approved by the US Environmental Protection Agency (USEPA, 2023a), as well as pathways that have been approved due to their similarity to other pathways (USEPA, 2023b). These sources were used for the default values in this study.

2.2 Method for calculation of scores

For RED and RTFO, calculation guidelines are detailed in the fuel standard documentation. These guidelines were followed to calculate the CI scores for e-hydrogen produced via renewable and grid electricity according to these rules.

The formula for calculating the CI of a fuel according to the RED and RTFO is:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} \quad \text{Eq. 1}$$

Where:

E =	The total emissions from the use of the fuel (i.e. the CI score)
e_{ec} =	The emissions from the extraction/cultivation of raw materials (e.g. fertilizer, diesel for harvesting, etc.)
e_l =	The emissions as a result of land use changes
e_p =	The emissions from fuel processing (e.g. electricity, heat, chemicals, etc.)
e_{td} =	The emissions from transporting the fuel and/or raw materials
e_u =	The emissions from combustion of the fuel
e_{sca} =	Emission savings from soil carbon accumulation due to improved agricultural practices
e_{ccs} =	Emission savings from capture and permanent storage of CO_2
e_{ccr} =	Emission savings from capture of biogenic CO_2 to replace fossil CO_2 in other production processes

For e-hydrogen, where no cultivation, land use changes, soil improvement, or carbon capture and storage/recycling is involved, and that emissions from the combustion of the fuel are considered zero (EC, 2023; UKDfT, 2024b), the relevant parameters in Equation 1 are e_p and e_{td}. In Table 2, the parameters included for e-hydrogen production and their corresponding emission factors are shown. For the calculations, a basis of 1 kg hydrogen was used, and the lower heating value of hydrogen was taken as 120 MJ/kg.

Table 2. Parameters and emission factors used for the calculation of e-hydrogen

Parameter	**Amount**	**E_f (RED)**	**E_f (RTFO)**
Transport, pipeline	100 km	0.087 $kgCO_2e$/t-km	0 $kgCO_2e$/t-km
Electricity	55 $kWh/kg_{hydrogen}$	Renewable: 0 $kgCO_2e$/kWh Grid: 0.383 $kgCO_2e$/kWh	Renewable: 0 $kgCO_2e$/kWh Grid: 136 $kgCO_2$/MJ (0.490 $kgCO_2e$/kWh)

Water, desalinated	9 $kg/kg_{hydrogen}$	0.00574 $kgCO_2e/kg$	0.00574 $kgCO_2e/kg$

3 References

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EC, 2018. DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources.

ICAO, 2022a. CORSIA Methodology For Calculating Actual Life Cycle Emissions Values.

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UKDfT, 2024a. Renewable Transport Fuel Obligation: Compliance Guidance.

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