Electronic Supplementary Material (ESI) for Sustainable Energy & Fuels.
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PAPER

Supplementary Information

Towards decarbonization of shipping: Direct emissions & life cycle impacts from a biofuel trial aboard an ocean-going dry bulk vessel

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Supplementary Note 1 | Recorded Engine, Navigation & Environmental Data

The recorded data for the biofuel blend and the LSMGO for each engine operating mode are presented in Fig. S1-S7 and Fig. S8-S12 respectively.

Vessel Performance Solutions

Ship details	Input	Unit	Input	Unit
Ship name and IMO number	KIRA OLDENDORFF	Text	9867566	Integer
Draught fore, draught aft	13.84	m	15.16	m
Maximum roll angle during run	7	Deg.		
Navigational Data				
Position run start, latitude	S	N/S	17.39.104	Deg. Min Decimal minutes, eg. 55.37.763
Position run start, longitude	E	E/W	063.44.848	Deg. Min Decimal minutes, eg. 12.42.763
Position run end, latitude	S	N/S	17.40.756	Deg. Min Decimal minutes, eg. 55.37.763
Position run end, longitude	E	E/W	063.42.360	Deg. Min Decimal minutes, eg. 12.42.763
Distance covered GPS, speed log	5.9	NM	5.68	NM
Date and time run start UTC, run duration	2021/04/17 03:45	YYYY:MM:DD HR:MM UT	01.00.00	Hours, Minutes,seconds, eg. 02.30.45
Average rudder angle, maximum rudder angle	6	Degrees	12	Degrees
Engine information				
RPM	37	RPM		
Fuel consumed for propulsion (ME), total	280	kg		
Indicator power	1986	kW		
Fuel pump index in percentage	25	%		
Turbo charger 1 RPM, Turbo charger 2 RPM	2700	RPM		RPM
Environmental conditions				
True wind speed and direction	7.3	m/s	45	Degrees, compass, coming from
Ship heading	234	Degrees, compass		
Wind driven waves, Douglas sea state and direction	4	Douglas sea state (0-9)	250	Degrees, compass. Going to
Swell height and direction	2	m	280	Degrees, compass. Going to
Temperature of water and Air	31	Celsius, water	27	Celsius, Air
Water depth, minimum, average	3000		3648	m

Fig. S1 Biofuel Blend Mode 1 – Dead Slow Ahead.

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Vessel Performance Solutions

Ship details	Input	Unit	Input	Unit
Ship name and IMO number	KIRA OLDENDOEFF	Text	9867566	Integer
Draught fore, draught aft	13.85	m	15.15	m
Maximum roll angle during run	7	Deg.		
Navigational Data				
Position run start, latitude	S	N/S	12.15.328	Deg. Min Decimal minutes, eg. 55.37.763
Position run start, longitude	E	E/W	071.39.006	Deg. Min Decimal minutes, eg. 12.42.763
Position run end, latitude	S	N/S	12.21.393	Deg. Min Decimal minutes, eg. 55.37.763
Position run end, longitude	E	E/W	071.30.831	Deg. Min Decimal minutes, eg. 12.42.763
Distance covered GPS, speed log	10.02	NM	10.19	NM
Date and time run start UTC, run duration	2021.04.15 04:50	YYYY:MM:DD HR:MM UT	01.00.00	Hours, Minutes,seconds, eg. 02.30.45
Average rudder angle, maximum rudder angle	6	Degrees		Degrees
Engine information				
RPM	66	RPM		
Fuel consumed for propulsion, total	825	kg		
Indicator power	3675	kW		
Fuel pump index in percentage	53	%		
Turbo charger 1 RPM, Turbo charger 2 RPM	7820	RPM		RPM
Environmental conditions				
True wind speed and direction	9.4	m/s	110	Degrees, compass, coming from
Ship heading	227	Degrees, compass		
Wind driven waves, Douglas sea state and direction	4	Douglas sea state (0-9)	310	Degrees, compass. Going to
Swell height and direction	2	m	320	Degrees, compass. Going to
Temperature of water and Air	32	Celsius, water	29	Celsius, Air
Water depth, minimum, average	4000		4000	m

Fig. S2 Biofuel Blend Mode 2 – Slow Ahead (A).

Vessel Performance Solutions

Ship details	Input	Unit	Input	Unit
Ship name and IMO number	KIRA OLDENDORFF	Text	9867566	Integer
Draught fore, draught aft	13.84	m	15.16	m
Maximum roll angle during run	6	Deg.		
Navigational Data				
Position run start, latitude	S	N/S	17.41.693	Deg. Min Decimal minutes, eg. 55.37.763
Position run start, longitude	E	E/W	063.40.843	Deg. Min Decimal minutes, eg. 12.42.763
Position run end, latitude	S	N/S	17.46.268	Deg. Min Decimal minutes, eg. 55.37.763
Position run end, longitude	E	E/W	063.33.811	Deg. Min Decimal minutes, eg. 12.42.763
Distance covered GPS, speed log	8.12	NM	8.42	NM
Date and time run start UTC, run duration	2021/04/17 04:45	YYYY:MM:DD HR:MM UT	01.00.00	Hours, Minutes,seconds, eg. 02.30.45
Average rudder angle, maximum rudder angle	4	Degrees	8	Degrees
Engine information				
RPM	55	RPM		
Fuel consumed for propulsion (ME), total	561	kg		
Indicator power	3178	kW		
Fuel pump index in percentage	40	%		
Turbo charger 1 RPM, Turbo charger 2 RPM	5080	RPM		RPM
Environmental conditions				
True wind speed and direction	7.5	m/s	45	Degrees, compass, coming from
Ship heading	235	Degrees, compass		
Wind driven waves, Douglas sea state and direction	4	Douglas sea state (0-9)	250	Degrees, compass. Going to
Swell height and direction	2	m	290	Degrees, compass. Going to
Temperature of water and Air	31	Celsius, water	27	Celsius, Air
Water depth, minimum, average	3000		3420	m

Fig. S3 Biofuel Blend Mode 2 – Slow Ahead (B).

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Vessel Performance Solutions

Ship details	Input	Unit	Input	Unit
Ship name and IMO number	KIRA OLDENDORFF	Text	9867566	Integer
Draught fore, draught aft	13.84	m	15.16	m
Maximum roll angle during run	6	Deg.		
Navigational Data				
Position run start, latitude	S	N/S	17.47.790	Deg. Min Decimal minutes, eg. 55.37.763
Position run start, longitude	E	E/W	063.31.291	Deg. Min Decimal minutes, eg. 12.42.763
Position run end, latitude	S	N/S	17.53.286	Deg. Min Decimal minutes, eg. 55.37.763
Position run end, longitude	E	E/W	063.23.020	Deg. Min Decimal minutes, eg. 12.42.763
Distance covered GPS, speed log	9.6	NM	9.8	NM
Date and time run start UTC, run duration	2021/04/17 05:45	YYYY:MM:DD HR:MM UT	01.00.00	Hours, Minutes,seconds, eg. 02.30.45
Average rudder angle, maximum rudder angle	3	Degrees	6	Degrees
Engine information				
RPM	63	RPM		
Fuel consumed for propulsion (ME), total	736	kg		
Indicator power	4072	kW		
Fuel pump index in percentage	48	%		
Turbo charger 1 RPM, Turbo charger 2 RPM	7095	RPM		RPM
Environmental conditions				
True wind speed and direction	7.5	m/s	45	Degrees, compass, coming from
Ship heading	234	Degrees, compass		
Wind driven waves, Douglas sea state and direction	4	Douglas sea state (0-9)	230	Degrees, compass. Going to
Swell height and direction	2	m	290	Degrees, compass. Going to
Temperature of water and Air	31	Celsius, water	30	Celsius, Air
Water depth, minimum, average	3000		3288	m

Fig. S4 Biofuel Blend Mode 3 – Half Ahead.

Vessel Performance Solutions

Ship details	Input	Unit	Input	Unit
Ship name and IMO number	KIRA OLDENDORFF	Text	9867566	Integer
Draught fore, draught aft	13.85	m	15.15	m
Maximum roll angle during run	6	Deg.		
Navigational Data				
Position run start, latitude	S	N/S	11.59.155	Deg. Min Decimal minutes, eg. 55.37.763
Position run start, longitude	E	E/W	072.02.606	Deg. Min Decimal minutes, eg. 12.42.763
Position run end, latitude	S	N/S	12.06.004	Deg. Min Decimal minutes, eg. 55.37.763
Position run end, longitude	E	E/W	071.52.171	Deg. Min Decimal minutes, eg. 12.42.763
Distance covered GPS, speed log	12.29	NM	13	NM
Date and time run start UTC, run duration	2021.04.15 02:30	YYYY:MM:DD HR:MM UT	1:00:00	Hours, Minutes,seconds, eg. 02.30.45
Average rudder angle, maximum rudder angle	4	Degrees	6	Degrees
Engine information				
RPM	79	RPM		
Fuel consumed for propulsion, total	1215	kg		
Indicator power	6257	kW		
Fuel pump index in percentage	74	%		
Turbo charger 1 RPM, Turbo charger 2 RPM	10845	RPM		RPM
Environmental conditions				
True wind speed and direction	10.8	m/s	135	Degrees, compass, coming from
Ship heading	233	Degrees, compass		
Wind driven waves, Douglas sea state and direction	4	Douglas sea state (0-9)	315	Degrees, compass. Going to
Swell height and direction	2	m	320	Degrees, compass. Going to
Temperature of water and Air	32	Celsius, water	27	Celsius, Air
Water depth, minimum, average	3884		4000	m

Fig. S5 Biofuel Blend Mode 4 – Full Ahead (A).

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Ship details	Input	Unit	Input	Unit
Ship name and IMO number	KIRA OLDENDORFF	Text	9867566	Integer
Draught fore, draught aft	13.84	m	15.16	m
Maximum roll angle during run	4	Deg.		
Navigational Data				
Position run start, latitude	S	N/S	18.07.624	Deg. Min Decimal minutes, eg. 55.37.763
Position run start, longitude	E	E/W	063.00.463	Deg. Min Decimal minutes, eg. 12.42.763
Position run end, latitude	S	N/S	18.14.550	Deg. Min Decimal minutes, eg. 55.37.763
Position run end, longitude	E	E/W	062.49.799	Deg. Min Decimal minutes, eg. 12.42.763
Distance covered GPS, speed log	12.27	NM	12.54	NM
Date and time run start UTC, run duration	2021/04/17 09:00	YYYY:MM:DD HR:MM UT	01.00.00	Hours, Minutes,seconds, eg. 02.30.45
Average rudder angle, maximum rudder angle	3	Degrees	6	Degrees
Engine information				
RPM	79	RPM		
Fuel consumed for propulsion (ME), total	1179	kg		
Indicator power	6058	kW		
Fuel pump index in percentage	74	%		
Turbo charger 1 RPM, Turbo charger 2 RPM	10870	RPM		RPM
Environmental conditions				
True wind speed and direction	6.7	m/s		Degrees, compass, coming from
Ship heading	236	Degrees, compass		
Wind driven waves, Douglas sea state and direction	4	Douglas sea state (0-9)	235	Degrees, compass. Going to
Swell height and direction	2	m	290	Degrees, compass. Going to
Temperature of water and Air	31	Celsius, water	31	Celsius, Air
Water depth, minimum, average	3215		3347	m

Fig. S6 Biofuel Blend Mode 4 – Full Ahead (B).

Ship details	Input	Unit	Input	Unit
Ship name and IMO number	KIRA OLDENDOEFF	Text	9867566	Integer
Draught fore, draught aft	13.85	m	15.15	m
Maximum roll angle during run	8	Deg.		
Navigational Data				
Position run start, latitude	S	N/S	12.39.238	Deg. Min Decimal minutes, eg. 55.37.763
Position run start, longitude	E	E/W	071.06.638	Deg. Min Decimal minutes, eg. 12.42.763
Position run end, latitude	S	N/S	12.54.816	Deg. Min Decimal minutes, eg. 55.37.763
Position run end, longitude	E	E/W	070.43.395	Deg. Min Decimal minutes, eg. 12.42.763
Distance covered GPS, speed log	13.8	NM	14.3	NM
Date and time run start UTC, run duration	2021.04.15 08:15	YYYY:MM:DD HR:MM UT	01.00.00	Hours, Minutes,seconds, eg. 02.30.45
Average rudder angle, maximum rudder angle	4	Degrees	10	Degrees
Engine information				
RPM	90	RPM		
Fuel consumed for propulsion, total	1780	kg		
Indicator power	8939	kW		
Fuel pump index in percentage	88	%		
Turbo charger 1 RPM, Turbo charger 2 RPM	13143	RPM		RPM
Environmental conditions				
True wind speed and direction	10.1	m/s	113	Degrees, compass, coming from
Ship heading	232	Degrees, compass		
Wind driven waves, Douglas sea state and direction	4	Douglas sea state (0-9)	310	Degrees, compass. Going to
Swell height and direction	2	m	315	Degrees, compass. Going to
Temperature of water and Air	32	Celsius, water	29	Celsius, Air
Water depth, minimum, average	3000		3729	m

Fig. S7 Biofuel Blend Mode 5 – Full Navigation Ahead.

Vessel Performance Solutions

Ship details	Input	Unit	Input	Unit
Ship name and IMO number	KIRA OLDENDOEFF	Text	9867566	Integer
Draught fore, draught aft	14	m	14.9	m
Maximum roll angle during run	3	Deg.		
Navigational Data				
Position run start, latitude	N	N/S	31.30.216	Deg. Min Decimal minutes, eg. 55.37.763
Position run start, longitude	W	E/W	014.03.971	Deg. Min Decimal minutes, eg. 12.42.763
Position run end, latitude	N	N/S	31.343406	Deg. Min Decimal minutes, eg. 55.37.763
Position run end, longitude	W	E/W	014.02.888	Deg. Min Decimal minutes, eg. 12.42.763
Distance covered GPS, speed log	4.3	NM	4.69	NM
Date and time run start UTC, run duration	2021.05.12 13:30	YYYY:MM:DD HR:MM UT	01.00.00	Hours, Minutes,seconds, eg. 02.30.45
Average rudder angle, maximum rudder angle	3	Degrees	6	Degrees
Engine information				
RPM	36	RPM		
Fuel consumed for propulsion, total	304	kg		
Indicator power	2284	kW		
Turbo charger 1 RPM, Turbo charger 2 RPM	1500	RPM		RPM
Environmental conditions				
True wind speed and direction	11	m/s	27	Degrees, compass, coming from
Ship heading	21	Degrees, compass		
Wind driven waves, Douglas sea state and direction	4	Douglas sea state (0-9)	225	Degrees, compass. Going to
Swell height and direction	2.5	m	180	Degrees, compass. Going to
Temperature of water and Air	22	Celsius, water	22	Celsius, Air
Water depth, minimum, average	3586		3800	m

Fig. S8 LSMGO Mode 1 - Dead Slow Ahead.

Vessel Performance Solutions

Ship details	Input	Unit	Input	Unit
Ship name and IMO number	KIRA OLDENDOEFF	Text	9867566	Integer
Draught fore, draught aft	14	m	14.9	m
Maximum roll angle during run	3	Deg.		
Navigational Data				
Position run start, latitude	N	N/S	31.23.525	Deg. Min Decimal minutes, eg. 55.37.763
Position run start, longitude	W	E/W	014.07.931	Deg. Min Decimal minutes, eg. 12.42.763
Position run end, latitude	N	N/S	31.30.216	Deg. Min Decimal minutes, eg. 55.37.763
Position run end, longitude	W	E/W	014.03.971	Deg. Min Decimal minutes, eg. 12.42.763
Distance covered GPS, speed log	6.95	NM	7.11	NM
Date and time run start UTC, run duration	2021.05.12 12:30	YYYY:MM:DD HR:MM UT	01.00.00	Hours, Minutes,seconds, eg. 02.30.45
Average rudder angle, maximum rudder angle	3	Degrees	5	Degrees
Engine information				
RPM	55	RPM		
Fuel consumed for propulsion, total	587	kg		
Indicator power	3675	kW		
Fuel pump index in percentage	40	%		
Turbo charger 1 RPM, Turbo charger 2 RPM	4500	RPM		RPM
Environmental conditions				
True wind speed and direction	12	m/s	33	Degrees, compass, coming from
Ship heading	19	Degrees, compass		
Wind driven waves, Douglas sea state and direction	5	Douglas sea state (0-9)	31	Degrees, compass. Going to
Swell height and direction	2.5	m	359	Degrees, compass. Going to
Temperature of water and Air	22	Celsius, water	22	Celsius, Air
Water depth, minimum, average	3961		4000	m

Fig. S9 LSMGO Mode 2 - Slow Ahead.

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Vessel Performance Solutions

Ship details	Input	Unit	Input	Unit
Ship name and IMO number	KIRA OLDENDOEFF	Text	9867566	Integer
Draught fore, draught aft	14	m	14.9	m
Maximum roll angle during run	3	Deg.		
Navigational Data				
Position run start, latitude	N	N/S	30.59.196	Deg. Min Decimal minutes, eg. 55.37.763
Position run start, longitude	W	E/W	014.14.656	Deg. Min Decimal minutes, eg. 12.42.763
Position run end, latitude	N	N/S	31.07.276	Deg. Min Decimal minutes, eg. 55.37.763
Position run end, longitude	W	E/W	014.11.852	Deg. Min Decimal minutes, eg. 12.42.763
Distance covered GPS, speed log	8.44	NM	8.93	NM
Date and time run start UTC, run duration	2021.05.12 09:50	YYYY:MM:DD HR:MM UT	01.00.00	Hours, Minutes,seconds, eg. 02.30.45
Average rudder angle, maximum rudder angle	4	Degrees	5	Degrees
Engine information				
RPM	63	RPM		
Fuel consumed for propulsion, total	762	kg		
Indicator power	4370	kW		
Fuel pump index in percentage	50	%		
Turbo charger 1 RPM, Turbo charger 2 RPM	7600	RPM		RPM
Environmental conditions				
True wind speed and direction	12	m/s	30	Degrees, compass, coming from
Ship heading	15	Degrees, compass		
Wind driven waves, Douglas sea state and direction	4	Douglas sea state (0-9)	220	Degrees, compass. Going to
Swell height and direction	2	m	180	Degrees, compass. Going to
Temperature of water and Air	22	Celsius, water	21	Celsius, Air
Water depth, minimum, average	2000		3000	m

Fig S10 LSMGO Mode 3 - Half Ahead.

Vessel Performance Solutions

Ship details	Input	Unit	Input	Unit
Ship name and IMO number	KIRA OLDENDORFF	Text	9867566	Integer
Draught fore, draught aft	14	m	14.9	m
Maximum roll angle during run	3	Deg.		
Navigational Data				
Position run start, latitude	N	N/S	30.40.389	Deg. Min Decimal minutes, eg. 55.37.763
Position run start, longitude	W 0.4	E/W	014.21.293	Deg. Min Decimal minutes, eg. 12.42.763
Position run end, latitude	N	N/S	30.50.605	Deg. Min Decimal minutes, eg. 55.37.763
Position run end, longitude	W	E/W	014.17.707	Deg. Min Decimal minutes, eg. 12.42.763
Distance covered GPS, speed log	10.62	NM	11.63	NM
Date and time run start UTC, run duration	2021.05.12 08:00	YYYY:MM:DD HR:MM UT	01.00.00	Hours, Minutes,seconds, eg. 02.30.45
Average rudder angle, maximum rudder angle	3	Degrees	5	Degrees
Engine information				
RPM	79	RPM		
Fuel consumed for propulsion, total	1245	kg		
Indicator power	6654	kW		
Fuel pump index in percentage	78	%		
Turbo charger 1 RPM, Turbo charger 2 RPM	11380	RPM		RPM
Environmental conditions				
True wind speed and direction	14	m/s	20	Degrees, compass, coming from
Ship heading	16	Degrees, compass		
Wind driven waves, Douglas sea state and direction	5	Douglas sea state (0-9)	210	Degrees, compass. Going to
Swell height and direction	2.5	m	165	Degrees, compass. Going to
Temperature of water and Air	22	Celsius, water	20	Celsius, Air
Water depth, minimum, average	2000		2713	m

Fig. S11 LSMGO Mode 4 - Full Ahead.

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Vessel Performance Solutions

Ship details	Input	Unit	Input	Unit
Ship name and IMO number	M/S Performance Run	Text	9200000	Integer
Draught fore, draught aft	10	m	11	m
Maximum roll angle during run	3	Deg.		
Navigational Data				
Position run start, latitude	N	N/S	55.12.560	Deg. Min Decimal minutes, eg. 55.37.763
Position run start, longitude	E	E/W	12.42.500	Deg. Min Decimal minutes, eg. 12.42.763
Position run end, latitude	N	N/S	55.12.560	Deg. Min Decimal minutes, eg. 55.37.763
Position run end, longitude	E	E/W	12.42.500	Deg. Min Decimal minutes, eg. 12.42.763
Distance covered GPS, speed log	15	NM	14.7	NM
Date and time run start, run duration	2015:09:08 02.22.00	YYYY:MM:DD HR:MM	01.00.00	Hours, Minutes,seconds, eg. 02.30.45
Average rudder angle, maximum rudder angle	2	Degrees	8	Degrees
Engine information				
RPM	87	RPM		
Fuel consumed for propulsion, total	1703	kg		
Indicator power	8939	kW		
Fuel pump index in percentage	70	%		
Turbo charger 1 RPM, Turbo charger 2 RPM	12000	RPM	NA	RPM
Environmental conditions				
True wind speed and direction	8	m/s	95	Degrees, compass, coming from
Ship heading	270	Degrees, compass		
Wind driven waves, Douglas sea state and direction	3	Douglas sea state (0-9)	275	Degrees, compass. Going to
Swell height and direction	1	m/s	180	Degrees, compass. Going to
Temperature of water and Air	14	Celsius, water	20	Celsius, Air
Water depth, minimum, average	120	m	250	m

Fig S12 LSMGO Mode 5 - Full Navigation Ahead.

Supplementary Note 2 | Chemical Analyses of the Biofuel Blend and the LSMGO

Results from the chemical testing of the biofuel blend and the LSMGO, including the test methods followed, are provided in Fig. S13-S14 and Fig. S15-S16 respectively. The cetane index of the biofuel blend is not provided below, as it was calculated taking into account the cetane index of the pure UCO biodiesel, equal to 55 (as provided by GoodFuels and measured following the ISO 4264 method), and the cetane index of the LSMGO, equal to 52 (Fig. S15). The C and N contents of the LSMGO were estimated based on European Commission, 2002[1].

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KIRA OLDENDORFF (9867566)

Test Results

	Unit	Test Results		Test Method
Density @ 15°C	kg/m3	856.8		ISO 12185
Viscosity @ 40°C	mm2/s	3.4		ASTM D7042
Water	%V/V	**0.06**		ASTM D6304-C
Micro Carbon Residue 10%	%m/m	0.28		ISO 10370
Sulfur	%m/m	0.048		ISO 8754
Ash	%m/m	< 0.010		LP2605
Vanadium	mg/kg	< 1		LP1105
Sodium	mg/kg	< 1		LP1105
Aluminium	mg/kg	< 1		LP1105
Silicon	mg/kg	2		LP1105
Iron	mg/kg	< 1		LP1105
Nickel	mg/kg	< 1		LP1105
Calcium	mg/kg	< 1		LP1105
Magnesium	mg/kg	< 1		LP1105
Zinc	mg/kg	< 1		LP1105
Phosphorus	mg/kg	2		LP1105
Potassium	mg/kg	2		LP1105
Pour Point	degC	-3		LP 1305
Flash Point	degC	> 70		LP1503
Visual Appearance	-	Pass		LP 1902
Aluminium + Silicon	mg/kg	< 3		
Temp.@ 10% recovery	degC	230		ISO 3405
Temp.@ 50% recovery	degC	316		ISO 3405
Temp.@ 90% recovery	degC	340		ISO 3405
Acid Number	mg KOH/g	0.23		ASTM D664
FTIR Screening	-	**See comment**		LP 2403
FAME content	%V/V	**45.88**		ASTM D7371
Gross Heat Combustion	MJ/kg	42.92		ASTM D240
Net Heat of Combustion[1]	MJ/kg	40.20		ASTM D240
Hydrogen	%m/m	12.8		ASTM D5291
Carbon	%m/m	82.8		ASTM D5291
Nitrogen	%m/m	< 0.10		ASTM D5291
Oxygen	%m/m	4.17		ASTM D5291 Ext
Steel Corrosion 20°C	-	1		LP 2902
Steel Corrosion 60°C	-	1		LP 2902
Steel Corrosion 80°C	-	1		LP 2902

[1] Calculated value

Fig. S13 Chemical composition and physical properties of the biofuel blend.

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Operational Advice

Water	This fuel category should not contain any water. The presence of water will increase the risk of microbial growth. In order to minimize the risk, it is important that any free water is removed from tank bottoms, tank drains and all filters in use
FAME	FAME may influence the cold flow properties and the affinity to water and thereby increasing the risk of microbial growth. Long term storage issues and material deposition on exposed surfaces may also be affected. In order to minimize the risk, it is important that the fuel is kept free from water, that any free water is removed from the tank bottoms and that tank drains and all filters in use are checked daily. When the fuel is stored for a prolonged period of time, e.g. more than 4-6 months, it is recommended to frequently monitor the fuel quality in the storage tanks
FTIR Analysis	FTIR screening indicates the presence of unidentified compounds. Further GCMS analysis would be required to possibly determine the type of compounds.

Fig. S14 Operational advice provided after the chemical analyses of the biofuel blend.

VPS KIRA OLDENDORFF (9867566)

Test Results

	Unit	Test Results	DMA	Test Method
Density @ 15°C	kg/m3	847.8	890.0	ISO 12185
Viscosity @ 40°C	mm2/s	3.364	2.000\6.000	ASTM D7042
Micro Carbon Residue 10%	%m/m	< 0.10	0.30	ISO 10370
Sulfur	%m/m	0.089	0.10	ISO 8754
Ash	%m/m	< 0.01	0.01	LP 1001
Pour Point	degC	**0**	-6\0	ISO 3016
Flash Point	degC	> 70.0	60.0	LP1503
Visual Appearance	-	Pass	Bright&Clear	LP 1902
Calculated Cetane Index[1]	-	52	40	ISO 4264
Acid Number	mg KOH/g	< 0.1	0.5	ASTM D664
FAME content	%V/V	< 0.1	0.1	EN 14078
Water	%V/V	< 0.01		ASTM D6304-C
Vanadium	mg/kg	< 1		IP 501
Sodium	mg/kg	< 1		IP 501
Aluminium	mg/kg	< 1		IP 501
Silicon	mg/kg	< 1		IP 501
Iron	mg/kg	< 1		IP 501
Nickel	mg/kg	< 1		IP 501
Calcium	mg/kg	< 1		IP 501
Magnesium	mg/kg	< 1		LP 1101
Zinc	mg/kg	< 1		IP 501
Phosphorus	mg/kg	< 1		IP 501
Potassium	mg/kg	< 1		LP 1101
Cloud Point	degC	**3**		LP 1305
Net Specific Energy[1]	MJ/kg	42.76		ISO 8217
Aluminium + Silicon	mg/kg	< 2		
Temp.@ 10% recovery	degC	224		ISO 3405
Temp.@ 50% recovery	degC	285		ISO 3405
Temp.@ 90% recovery	degC	350		ISO 3405
Cold Filter Plugging Point	degC	4		IP 309

[1] Calculated value

Fig. S15 Chemical composition and physical properties of the LSMGO.

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Operational Advice

Pour Point	Although pour point exceeds the -6°C winter limit, the summer limit of 0°C is met. Transfer may be difficult if the fuel temperature drops below 10°C. Maintaining a fuel temperature about 10°C above the pour point is recommended for satisfactory storage and transfer.
Cloud Point	Cloud point result indicates that at- or below the measured temperature, paraffin wax crystals will start to form. For satisfactory storage, transfer and treatment the fuel temperature should be maintained well above the cloud point.

Fig. S16 Operational advice provided after the chemical analyses of the LSMGO.

Supplementary Note 3 | Life Cycle Impact Assessment Methods of the Considered Literature Sources

The Well-To-Tank (WTT) / indirect CO_2 emissions of the considered fuels were estimated based on literature sources. An overview of the LCA methods followed in the selected literature sources that were taken into account in the present study is provided below.

A typical UCO-to-biodiesel production system was considered by Foteinis et al., 2020[2], including UCO collection from commercial or domestic sources, such as fast-food restaurants, and drop-off collection tanks, its transportation to the biodiesel production plant, its processing and biodiesel refining. UCO processing entailed pre-treatment and a two-step acid-base catalyzed transesterification process, *i.e.,* acid-catalyzed esterification and alkaline catalyst transesterification. Finally, the produced biodiesel was refined, *i.e.,* washed, to improve its quality. Energy, water and land used for the biodiesel production, as well as chemical reagents consumed during the process were included in the analysis. The system boundaries and the main input and output flows considered in the study are presented in Fig. S17. The production of 1 ton of biodiesel from UCO was considered as the functional unit. The physicochemical characteristics of the biodiesel considered in the study are very similar to those of the biodiesel used in our biofuel trial. The ReCiPe method was used for the impact assessment and more specifically, the hierarchist perspective which is ReCiPe's default model. The reported data refer to the period 2019 – 2020.

Regarding the WTT emissions of conventional, petroleum-based marine fuels, *i.e.,* MGO, LSMGO and HFO, the results of ICCT, 2021[3] study were used in our analysis. This study used the default system boundaries and flows of the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model[4] for the assessment of the CO_2 emissions of conventional marine fuels, accounting for emissions from crude oil recovery, transportation, refining, desulfurization (if applicable), and fuel transportation. Energy and water consumption for the petroleum-based fuel production were the main inputs considered. The system boundaries and the main input and output flows considered by the GREET model are presented in Fig. S18. The generation of 1 MJ of energy was considered as the functional unit of the analysis. The reported data refer to 2021.

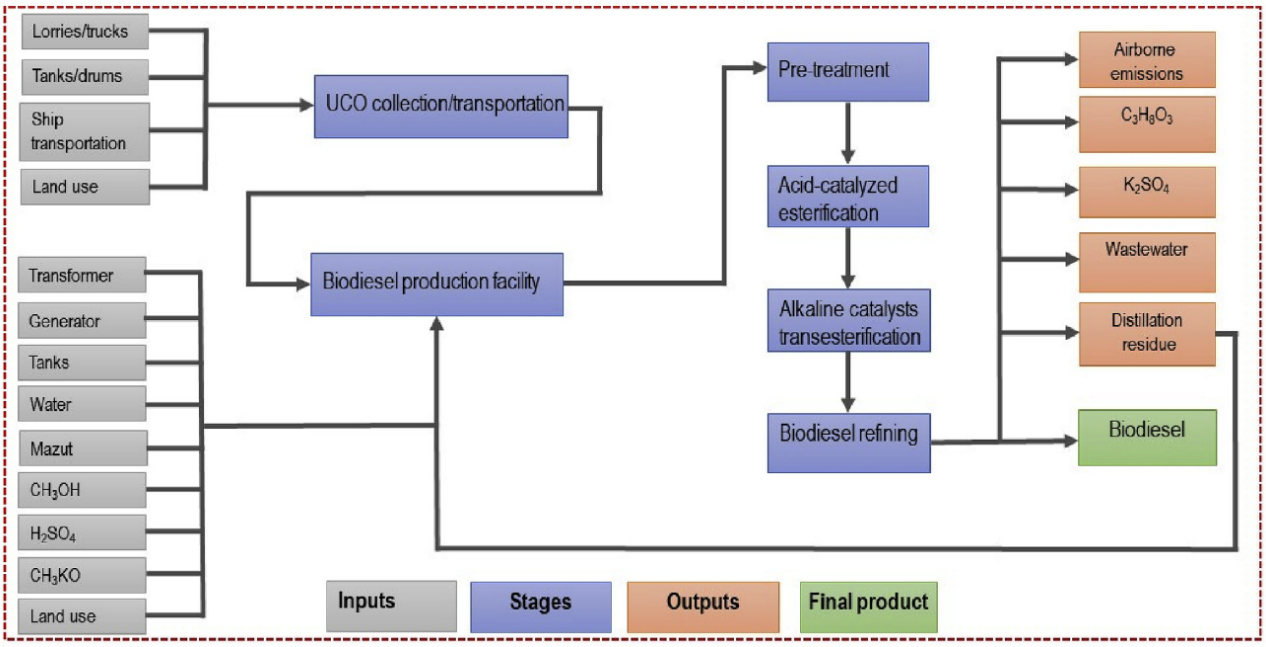

Fig.S17 The system boundaries of the UCO biodiesel production.[2]

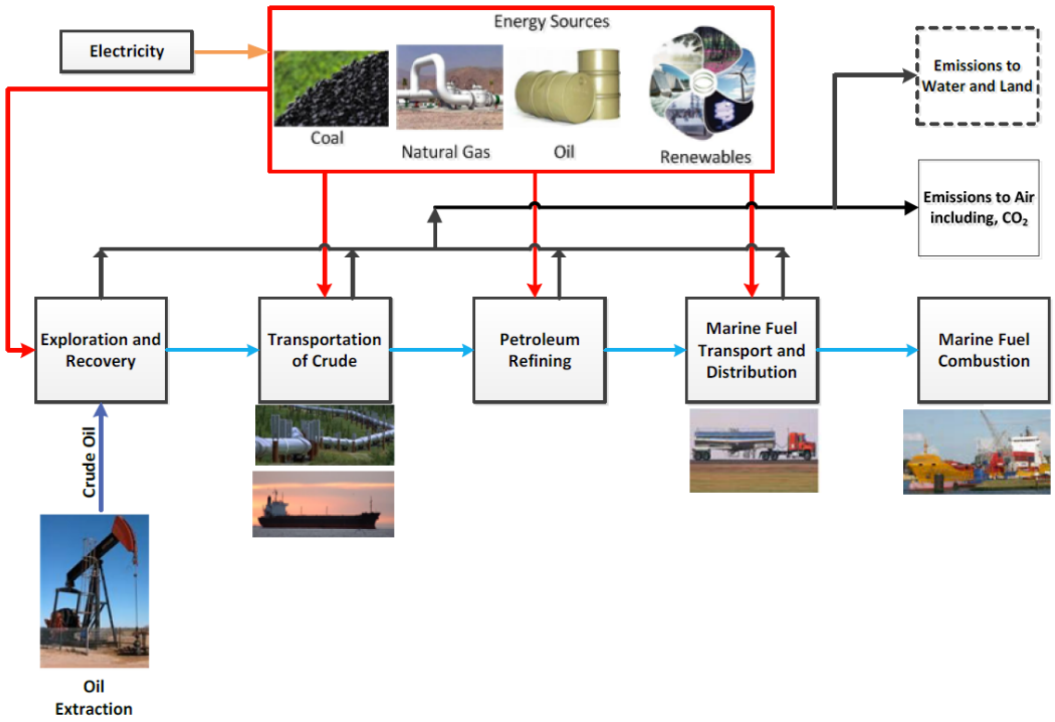

Fig.S18 The system boundaries of the conventional marine fuels production.[3,4]

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