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SUPPLEMENTARY INFORMATION
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Contribution of jet fuel from forest residues to multiple Sustainable Development Goals

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Supplementary Information for “Contribution of jet fuel from forest residues to multiple Sustainable Development Goals”

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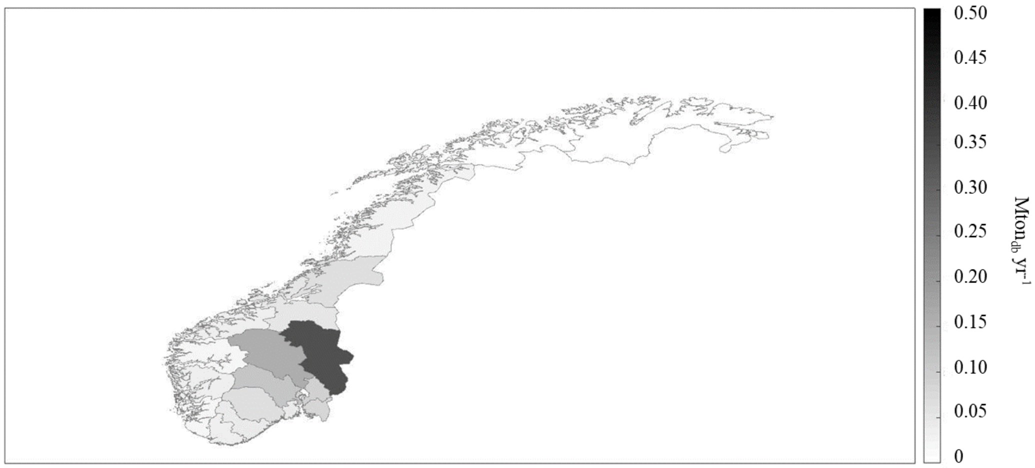
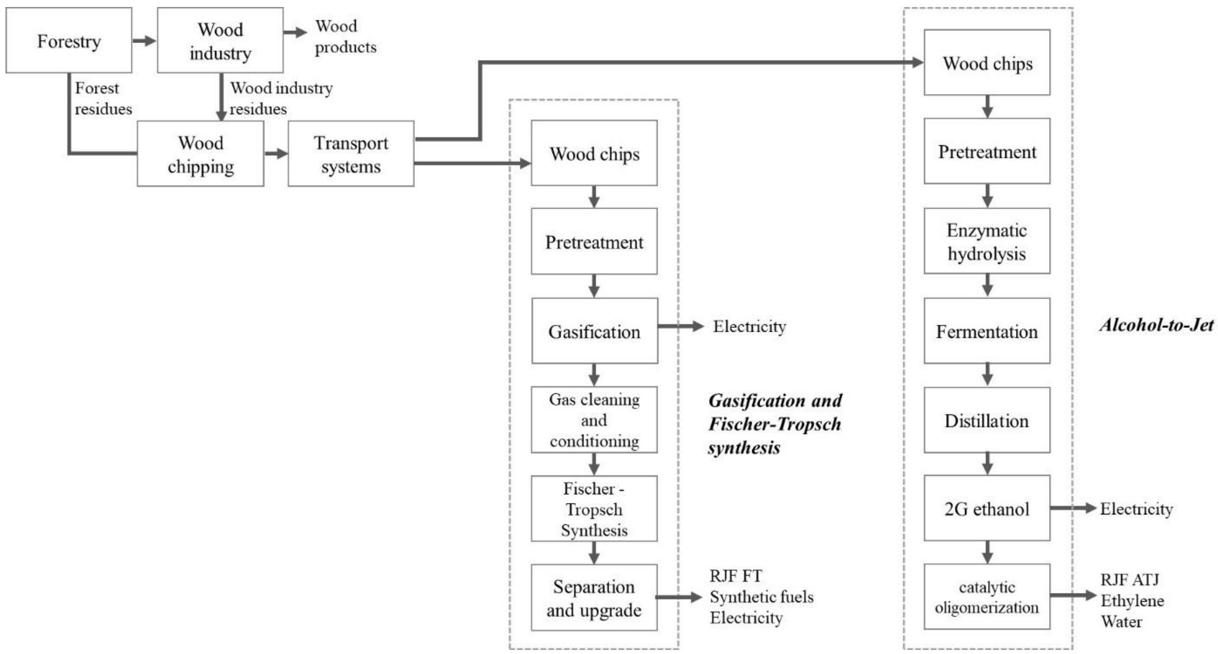
This supplementary information file includes:

- Supplementary Figures 1-4
- Supplementary Tables 1-13
- Supplementary References 1-35

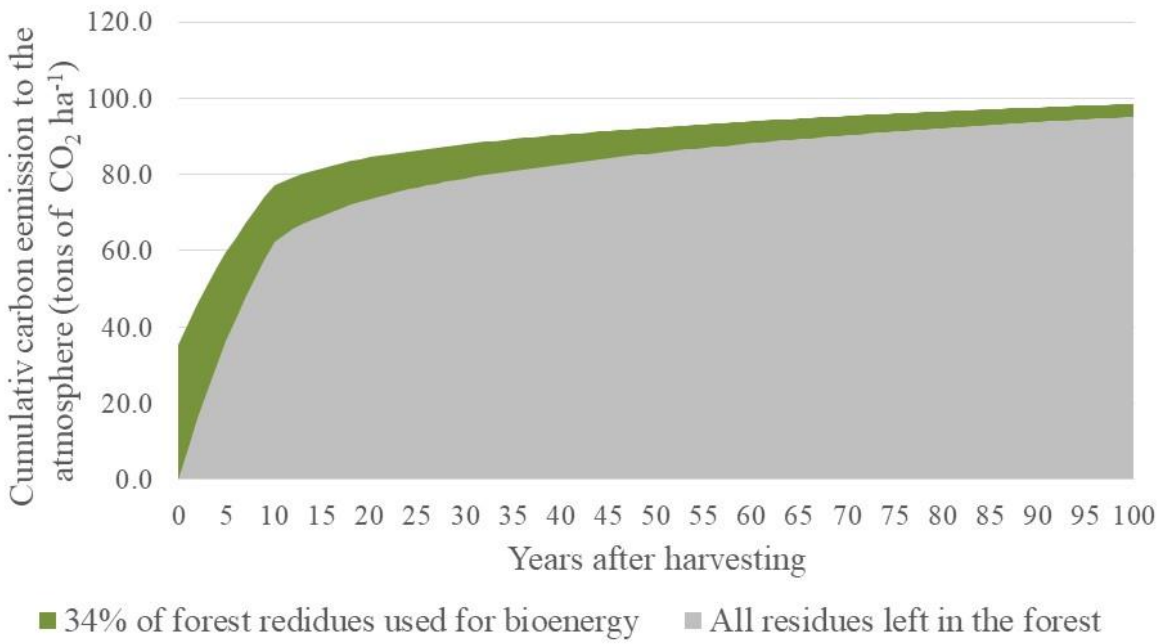
Supplementary Figures



Supplementary Figure 1. Forest residues extraction volumes for RJF deployment per county in Norway (based on 34% harvesting of total residues available at harvesting).



Supplementary Figure 2. Simplified process flow diagram of alcohol-to-jet (RJF ATJ) and gasification followed by Ficher-Tropsch synthesis (RJF FT) conversion technologies.



Supplementary Figure 3. Cumulative biogenic carbon emissions (national average, considering trends in each county and tree species) for the scenario where part of forest residues are used for bioenergy and the scenario where all the residues are left in the forest floor to naturally decompose. The use of forest residues for bioenergy essentially anticipate carbon oxidation to the atmosphere.

	Baseline			Improved FT			Improved ATJ			Improved supply-chain			All improvements		
	FJF	RJF ATJ	RJF FT	FJF	RJF ATJ	RJF FT	FJF	RJF ATJ	RJF FT	FJF	RJF ATJ	RJF FT	FJF	RJF ATJ	RJF FT
Goal 2: Zero Hunger															
Terrestrial acidification	0.87	1.00	0.55	0.87	1.00	0.54	0.87	0.72	0.55	0.87	0.83	0.54	0.87	0.69	0.54
Terrestrial ecotoxicity	0.25	1.00	0.09	0.25	1.00	0.08	0.25	0.38	0.09	0.25	-0.04	0.08	0.25	0.07	0.08
Terrestrial eutrophication	0.73	1.00	0.67	0.73	1.00	0.67	0.73	0.84	0.67	0.73	0.92	0.67	0.73	0.82	0.67
Goal 3: Good Health and Well-Being															
Human toxicity, cancer	0.35	1.00	0.36	0.35	1.00	0.27	0.35	0.43	0.36	0.35	0.69	0.36	0.35	0.37	0.27
Human toxicity, non-cancer	0.09	1.00	0.07	0.09	1.00	0.06	0.09	0.38	0.07	0.09	0.26	0.07	0.09	0.16	0.06
Particulate matter formation	0.73	1.00	0.53	0.73	1.00	0.52	0.73	0.69	0.53	0.73	0.75	0.53	0.73	0.63	0.52
Goal 6: Clean Water and Sanitation															
WDI	0.18	1.00	0.06	0.18	1.00	0.05	0.18	0.23	0.06	0.18	0.44	0.05	0.18	0.12	0.04
Freshwater eutrophication	0.24	1.00	0.13	0.24	1.00	0.11	0.24	0.28	0.13	0.24	0.59	0.13	0.24	0.21	0.10
Freshwater ecotoxicity	0.20	1.00	0.20	0.20	1.00	0.17	0.20	0.35	0.20	0.20	0.71	0.20	0.20	0.29	0.16
Goal 7: Affordable and Clean Energy															
Non-renewable energy	1.00	0.31	0.07	1.00	0.31	0.07	1.00	0.12	0.07	1.00	0.21	0.07	1.00	0.10	0.07
Fossil depletion	1.00	0.25	0.07	1.00	0.25	0.07	1.00	0.10	0.07	1.00	0.19	0.07	1.00	0.10	0.07
Coal use	0.32	1.00	0.15	0.32	1.00	0.12	0.32	0.29	0.15	0.32	0.44	0.14	0.32	0.20	0.11
Goal 11: Sustainable Cities and Communities															
Photochemical oxidant formation	0.78	1.00	0.67	0.78	1.00	0.67	0.78	0.81	0.67	0.78	0.82	0.67	0.78	0.76	0.67
Ozone formation (Human)	0.75	1.00	0.66	0.75	1.00	0.66	0.75	0.82	0.66	0.75	0.84	0.66	0.75	0.77	0.66
Bulk waste	0.12	0.87	0.34	0.12	0.87	0.31	0.12	0.47	0.34	0.12	1.00	0.34	0.12	0.53	0.31
Goal 12: Responsible Consumption and Production															
Ecological footprint	1.00	0.36	0.08	1.00	0.36	0.07	1.00	0.16	0.08	1.00	0.23	0.08	1.00	0.13	0.07
Metal depletion	0.26	1.00	0.25	0.26	1.00	0.22	0.26	0.39	0.25	0.26	0.99	0.25	0.26	0.37	0.22
Hazardous waste	0.70	1.00	0.16	0.70	1.00	0.13	0.70	0.28	0.16	0.70	0.53	0.15	0.70	0.21	0.12
Goal 13: Climate Action															
GWP100	1.00	0.38	0.08	1.00	0.38	0.07	1.00	0.19	0.08	1.00	0.26	0.08	1.00	0.16	0.07
Goal 14: Life Below Water															
Marine eutrophication	0.33	0.88	0.30	0.33	0.88	0.29	0.33	0.49	0.30	0.33	1.00	0.29	0.33	0.53	0.29
Marine aquatic ecotox. 100a	0.32	1.00	0.24	0.32	1.00	0.19	0.32	0.37	0.24	0.32	0.69	0.24	0.32	0.32	0.19
Aquatic acidification	0.89	1.00	0.60	0.89	1.00	0.59	0.89	0.75	0.60	0.89	0.85	0.59	0.89	0.73	0.59
Goal 15: Life on Land															
Ecosystems	1.00	0.44	0.08	1.00	0.44	0.07	1.00	0.20	0.08	1.00	0.26	0.08	1.00	0.16	0.07
Ecosystem damage potential	0.35	1.00	0.12	0.35	1.00	0.11	0.35	0.37	0.12	0.35	0.44	0.12	0.35	0.23	0.11
Natural land transformation	1.00	0.24	0.07	1.00	0.24	0.07	1.00	0.10	0.07	1.00	0.19	0.07	1.00	0.10	0.07

Supplementary Figure 4. Heat map showing normalized impacts of the RJF pathways on the SDGs under default conditions (baseline) and after implementation of improvement options in technology and in supply-chain processes. Results are shown as normalized to the highest environmental impact indicator across the set of simulations (deep red, down to deep green).

Supplementary Tables

Supplementary Table 1. Climate impacts of jet fuel pathways presented in Figure 1. Values given in g CO_2eq. $MJ_{jet\ fuel}^{-1}$ for results based on GHG only, with NTCFs and considering Europe as emission region.

	RJF ATJ (GWP20)	RJF FT (GWP20)	FJF (GWP20)	RJF ATJ (GWP100)	RJF FT (GWP100)	FJF (GWP10)	RJF ATJ (GTP100)	RJF FT (GTP100)	FJF (GTP100)
Results considering GHG only									
CO_2	24.1	6.2	84.3	23.1	6.2	84.3	23.1	6.2	84.3
CH_4	7.8	0.7	4.5	3.1	0.3	1.9	1.1	0.1	0.7
N_2O	1.9	0.2	0.2	2.1	0.3	0.3	2.1	0.3	0.3
Total	33.9	7.2	89.1	28.4	6.8	86.5	26.3	6.6	85.3
Results considering both GHGs and NTCFs									
CO_2	24.1	6.2	84.3	23.1	6.2	84.3	23.1	6.2	84.3
CH_4	7.8	0.7	4.5	3.1	0.3	1.9	1.1	0.1	0.7
N_2O	1.9	0.2	0.2	2.1	0.3	0.3	2.1	0.3	0.3
CO	11.7	0.7	0.8	3.1	0.2	0.2	-0.3	0.0	0.0
NMVOC	0.5	0.4	0.8	0.1	0.1	0.2	0.0	0.0	0.0
NO_x	40.4	44.0	47.2	7.2	8.1	8.7	0.9	1.0	1.0
SO_x	-14.8	-1.9	-23.3	-4.0	-0.5	-6.3	-0.5	-0.1	-0.8
OC	-3.3	-0.2	-0.1	-0.9	-0.1	0.0	-0.1	0.0	0.0
BC	17.1	1.5	2.3	4.5	0.4	0.6	0.6	0.1	0.1
Contrails	232.3	232.3	224.5	62.9	62.9	60.8	9.0	9.0	8.7
Total	317.7	283.9	341.3	101.4	78.0	150.7	35.9	16.6	94.2
Results considering regional metrics (Europe) for NTCFs									
CO_2	24.1	6.2	84.3	23.1	6.2	84.3	23.1	6.2	84.3
CH_4	7.8	0.7	4.5	3.1	0.3	1.9	1.1	0.1	0.7
N_2O	1.9	0.2	0.2	2.1	0.3	0.3	2.1	0.3	0.3
CO	7.5	0.6	0.8	2.4	0.2	0.2	-0.4	0.0	0.0
NMVOC	0.5	0.4	0.8	0.1	0.1	0.2	0.0	0.0	0.0
NO_x	57.8	61.3	65.9	9.1	10.5	11.2	0.9	1.1	1.2
SO_x	-14.8	-1.9	-20.0	-4.0	-0.5	-5.4	-0.5	-0.1	-0.7
OC	-3.6	-0.2	0.0	-1.0	-0.1	0.0	-0.2	0.0	0.0
BC	8.0	0.8	1.2	2.3	0.2	0.4	0.4	0.0	0.1
Contrails	187.3	187.3	181.0	50.2	50.2	48.5	7.5	7.5	7.2
Total	276.6	255.4	318.8	87.6	67.4	141.7	34.0	15.2	93.0

Supplementary Table 2. Summary of the selected environmentally-oriented SDGs and criteria for selection of corresponding indicators from environmental impact assessment models.

SDG Goals	Relevant SDG Target from ref.[1]	SDG Indicator from ref.[1]	Selected indicators
Goal 1: No Poverty	Not applicable	Not applicable	Not applicable
Goal 2: Zero Hunger	2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality	2.4.1 Proportion of agricultural area under productive and sustainable agriculture	Terrestrial acidification, measured in kg sulfur dioxide equivalents (SO_2eq.), form ref.[2] Terrestrial ecotoxicity, measured in kg triethylene glycol equivalents (TEGeq.) into soil, from ref.[3] Terrestrial eutrophication, measured in molecules of nitrogen equivalents (molc Neq.), from ref.[4]
Goal 3: Good Health and Well-Being	3.4 By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being 3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	3.4.1 Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease 3.9.1 Mortality rate attributed to household and ambient air pollution	Human toxicity, cancer, measured in comparative toxic units (CTU), from ref.[5] Human toxicity, non-cancer, measured in comparative toxic units (CTU), from ref.[5] Particulate matter formation, measured in kg of particulate matter with diameter smaller than 10µm equivalents (PM10eq.), form ref.[2]
Goal 4: Quality Education	Not applicable	Not applicable	Not applicable
Goal 5: Gender Equality	Not applicable	Not applicable	Not applicable
Goal 6: Clean Water and Sanitation	6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity 6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	6.4.1 Change in water-use efficiency over time 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources 6.6.1 Change in the extent of water-related ecosystems over time	Water depletion index (WDI), measured in m^3 of water, from ref.[6] Freshwater eutrophication, measured in kg phosphorous equivalents (Peq.), form ref.[2] Freshwater ecotoxicity, measured in comparative toxic units (CTU), from ref.[5]
Goal 7: Affordable and Clean Energy	7.2 By 2030, increase substantially the share of renewable energy in the global energy mix 7.3 By 2030, double the global rate of improvement in energy efficiency	7.2.1 Renewable energy share in the total final energy consumption 7.3.1 Energy intensity measured in terms of primary energy and GDP	Non-renewable energy, measured in MJ of non renewable energy use, from ref.[7] Fossil depletion, as surplus costs of future resource production, measured in United States dollars (USD) of 2013 form ref.[2] Coal use, measured in kg of brown and hard coal use, from ref.[8]
Goal 8: Decent Work and Economic Growth	Not applicable	Not applicable	Not applicable
Goal 9: Industry, Innovation and Infrastructure	Not applicable	Not applicable	Not applicable
Goal 10: Reduced Inequalities	Not applicable	Not applicable	Not applicable
Goal 11: Sustainable Cities and Communities	11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries	11.3.1 Ratio of land consumption rate to population growth rate 11.6.1 Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities	Photochemical oxidant formation, measured in kg of non-methane volatile organic compounds (NMVOC), form ref.[2] Ozone formation (human), measured in person.ppm.h, from ref.[9,10] Bulk waste, measured in kg, from ref.[9,10]

	11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)	
Goal 12: Responsible Consumption and Production	12.2 By 2030, achieve the sustainable management and efficient use of natural resources 12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment 12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse	12.2.1 Material footprint, material footprint per capita, and material footprint per GDP 12.2.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP 12.4.2 Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment 12.5.1 National recycling rate, tons of material recycled	Ecological footprint, measured in points (Pt, adimensional), after normalization and weighting, from ref.[11] Metal depletion, measured in kg of iron equivalents (Feeq.), form ref.[2] Hazardous waste, measured in kg, from ref.[9,10]
Goal 13: Climate Action	13.2 Integrate climate change measures into national policies, strategies and planning	13.2.1 Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other)	Global warming potential (GWP100), measured in kg of carbon dioxide equivalents (CO_2eq.), from ref.[12]
Goal 14: Life Below Water	14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution 14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels	14.1.1 Index of coastal eutrophication and floating plastic debris density 14.3.1 Average marine acidity (pH) measured at agreed suite of representative sampling stations	Marine eutrophication, measured in kg of nitrogen equivalents (Neq.), form ref.[2] Marine aquatic ecotoxicity, cumulative impacts for 100 years, measured in kg of 1,4-dichlorobenzene equivalents (kg1,4-DBeq.), form ref.[13] Aquatic acidification, measured in kg sulfur dioxide equivalents (SO_2eq.)**,** from ref.[3]
Goal 15: Life on Land	15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line 15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase	15.1.1 Forest area as a proportion of total land area 15.2.1 Progress towards sustainable forest management with obligations under international agreements 15.3.1 Proportion of land that is degraded over total land area 15.4.1 Coverage by protected areas of important sites for mountain biodiversity 15.4.2 Mountain Green Cover Index 15.5.1 Red List Index	Ecosystems, considered as the impact of climate change, acidification, eutrophication and ecotoxicity on ecosystems quality, measured as temporary loss of species in a certain area (species.yr), form ref.[2] Ecosystem damage potential, measured point scores of land occupation and transformation (Pt, adimensional), from ref.[14] Natural land transformation, measured in m^2, form ref.[2]

	afforestation and reforestation globally 15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world 15.4 By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development 15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species 15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts	15.9.1 Progress towards national targets established in accordance with Aichi Biodiversity Target 2 of the Strategic Plan for Biodiversity 2011-2020	
Goal 16: Peace, Justice and Strong Institutions	Not applicable	Not applicable	Not applicable
Goal 17: Partnerships for the Goals	Not applicable	Not applicable	Not applicable

Supplementary Table 3. Summary of the technological advancements and improvements in supply-chain processes considered in the RJF pathways

Scenario	**Implemented technological advancements and improvements in supply-chain processes**
Improvements on the FT conversion process	The overall process efficiency is increased to the highest value assumed in the uncertainty analysis[15]. We assume that 50% reduction in the consumption of gasification bed material and catalyst for FT process is possible due to measures for improved materials selection, recovery and recycling[16].
Improvements on the ATJ conversion process	The overall process efficiency is increased to the highest value assumed in the uncertainty analysis[17]. We assume the following measures are feasible due the use of alternative biomass pretreatment options[18-20]: (a) no use of sulphuric acid and ammonia in the pretreatment unit operation; (b) 80% reduction in the use of sodium hydroxide to neutralize the lignocellulosic material after pretreatment; (c) no use of corn step liquor in the fermentation, and (d) no lime use for wastewater treatment. We also assume 50% reduction in enzyme use due to increasing enzymatic activity[21].
Improvement in supply-chain processes	After identifying the processes in the biofuels supply-chain with most important contributions to the sustainability impacts[8], we selected substitute processes with overall lower environmental sustainability impacts. The following changes are implemented: (a) the sugar used for enzyme production and for fermentation supplement is changed from sugar from Brazilian sugarcane to sugar from European sugar beet; (b) sodium hydroxide production (e.g. used in pretreatment of biomass in the ATJ process and in the gasification) was changed from the average global market mix to the specific technology using membrane cell in Europe and 100% of electricity supply from an onshore wind turbine (c) the sulphuric acid production (e.g. used in pretreatment of biomass in the ATJ process and in the gasification) is changed from the global average market mix to its manufacture as coproduct of lead production form concentrate; (d) ammonia production (e.g. used in pretreatment of biomass and enzyme production process in the ATJ process) is changed from the average European market mix to the specific production process using steam reforming in Europe.
All improvements	Simultaneous consideration of all the previous improvements.

Supplementary Table 4. Age-dependent and species-specific biomass expansion factors.

Tree component	Spruce		Pine		Birch	
	a	**b**	**a**	**b**	**a**	**b**
Stem	0.4	-0.0462	0.4194	-0.0798	0.396	-0.019
Branches	0.0388	0.0849	0.0177	0.0499	0.101	-0.018
Branches. dead	0.0905	0.0719	0.0706	0.0212	0.005	0.008
Foliage	0.0088	0.004	0.0104	0.0059	0.025	
Bark	0.0353	0.0125	0.0254	0.0221	0.059	0.011
Stump	0.0488	0.0044	0.0472	-0.0039	0.047	-0.004
Roots. coarse >5 cm	0.1024	-0.0271	0.0838	-0.0365	0.042	
Roots. small < 5 cm	0.0201	0.0448	0.0272	0.0269	0.042	

Note: Age-dependent and species-specific biomass expansion factors from ref.[22] for spruce and pine, and for stem, branches, stump and bark estimation for birch, from ref.[23] for foliage estimation for birch, and from ref.[24] for roots estimation for birch, were applied to determine the mass of all tree. The factors *a* and *b* are used in the expression B_i (Mg m^{-3}) = $a_i + b_i e^{-0,01t}$, where *i* is the component of the three and *t* in the rotation period. It is here assumed a rotation period of 100 years for spruce and pine, and 60 years for birch.

Supplementary Table 5. Geographical grouping of counties in Norway, weighted transport for feedstock delivered and parameters used for estimating heterotrophic decomposition of forest residues in the selected regions of Norway. The equation $d(t) = a * e^{(b * t)} + x * e^{(y * t)}$ from ref. [25] is used to model the decay rate of forest residues. Wood residues from Southeast region of Norway are processed in a plant in Oslo; residues from western counties will be processed in Bergen and residues from Center-North in Trondheim. Bergen and Oslo are chosen because they host important oil refineries, making it more practicable blending RJF with FJF. Trondheim is chosen as an additional plant location because it is centrally located in the country.

	Southeast	**West**	**Center-North**
Counties included	Østfold, Akershus, Oslo, Hedmark, Oppland, Buskerud, Vestfold, Telemark, Aust-Agder, Vest-Agder	Rogaland, Hordaland, Sogn og Fjordane, Møre og Romsdal	Sør-Trøndelag, Nord-Trøndelag, Nordland, Troms-Romsa, Finnmark - Finnmárku
Weighted transport of feedstock (ton.km $m^{-3}_{\text{wood chips}}$)	54	127	67
a	46	58	54
b	-0.13	-0.22	-0.17
x	51	38	44
y	-0.013	-0.021	-0.018
t	0-100	0-100	0-100

Supplementary Table 6. Conversion process efficiency and uncertainty ranges.

	Value	**Min.**	**Max.**	**Reference for ranges**
ATJ process	31.9 %	22.1 %	39.1 %	Second generation ethanol process – minimum ref.[21], maximum ref.[17] ATJ process – minimum: -15%, maximum: +5% (own estimation)
FT process	51.4 %	24.0 %	53.0 %	Minimum ref.[26], maximum ref.[15]

Note: Efficiency is given in terms of energy from liquid fuels output divided by energy input in the feedstock.

Supplementary Table 7. Black carbon and organic carbon emission factors considered in the value chain of renewable and fossil jet fuels, and the associated uncertainty range

	Value	Min.	Max.	Reference for ranges
Black carbon, RJF[a]	0.0301	0.00075	0.185	[27]
Organic carbon, RJF[a]	0.1204	0.0015	0.185	[27]
Black carbon, FJF[b]	0.02349	0.00702	0.054	[27]
Organic carbon, FJF[b]	0.0070	0.002106	0.0162	[27]

Note: Values are given in kg of black carbon and organic carbon per kg of particulate matter emitted. [a] Ranges are derived from coefficients in ref.[27] for briquettes burnt in stoker and for open burning of solid wastes as minimum and maximum ranges, respectively. [b] Ranges are derived from coefficients in ref.[27] for middle distillate oil burnt in industry/power equipment considering the minimum and maximum ranges provided by different emission control systems.

Supplementary Table 8. Fossil jet fuel combustion emissions, and the associated uncertainty range.

	Value	Min.	Max.	Reference for ranges
NO_x	0.014	0.012	0.017	[28]
SO_x	0.0008	0.0006	0.001	[28]
Black carbon[a]	1.71E-05	1.34E-05	8.51E-05	[29]

Note: Values given in kg per kg of jet fuel. Other emissions for fossil jet fuel combustion are taken from ref. [30]. [a]Ranges represent different engine tests and cruise conditions from ref. [29].

Supplementary Table 9. Renewable jet fuel combustion emissions relative to fossil jet fuel, and associated uncertainty range. Other emissions are assumed to be equal to those from FJF.

	Value	**Min.**	**Max.**	**Reference for ranges**
Contrail formation[a]	1.08	0.96	1.18	[31]
Black carbon and organic carbon	0.37	0.3	0.5	[29]
NO_x	0.95	0.9	1	[32]
CO_2	0.98	0.96	1	Derived from energy density from ref.[32]

[a]Values modelled for US form ref.[31] assumed as valid for the entire world.

Supplementary Table 10. Global climate metrics for ground level emissions of NTCFs from value chain, and associated uncertainty range.

	GWP20			GWP100			GTP100		
	Value	**Min.**	**Max.**	**Value**	**Min.**	**Max.**	**Value**	**Min.**	**Max.**
NO_x	-108	-143	-73	-29	-38	-20	-2	-3.9	-0.1
CO	7.8	5.8	9.8	2.1	1.6	2.6	-0.2	-0.3	-0.1
VOC	18.7	11.2	26.2	5.5	3.2	7.8	0.8	0.4	1.2
SO_x	-141	n.a.	n.a.	-38	n.a.	n.a.	-5		
OC	-160	-320	-60	-43	-86	-17	-6.7	-8.6	-4.8
BC	3200	270	6200	846	94	1600	120	5	313

Note: Values selected by ref.[33] from ref.[34]. All values are given on a per unit of emission basis (e.g. per kg BC, OC, CO, VOC and SO_x, respectively. with NO_x calculated per kg N).

Supplementary Table 11. European climate metrics for ground level emissions of NTCFs from value chain and associated uncertainty range.

	GWP20			GWP100			GTP100		
	Value	**Min.**	**Max.**	**Value**	**Min.**	**Max.**	**Value**	**Min.**	**Max.**
NO_x	-39.4	-56.9	-21.9	-15.6	-21.4	-9.8	-2.5	-3.8	-1.2
CO	4.9	3.4	6.4	1.6	1.1	2.1	-0.24	-0.35	-0.13
VOC	18	9.5	26.5	5.6	2.8	8.4	0.8	0.3	1.3
SO_x	-141	n.a.	n.a.	-38	n.a.	n.a.	-5	n.a.	n.a.
OC	-172	-240	-104	-49	-69	-30	-7,7	-10,1	-5,3
BC	1480	720	2240	425	207	644	71	46	96

Note: Values selected from ref.[34]. All values are given on a per unit of emission basis (e.g. per kg BC, OC, CO, VOC and SO_x, respectively, with NO_x calculated per kg N).

Supplementary Table 12. Global climate metrics for NTCFs from aviation combustion emissions and associated uncertainty range.

	GWP20			GWP100			GTP100		
	Value	**Min.**	**Max.**	**Value**	**Min.**	**Max.**	**Value**	**Min.**	**Max.**
NO_x	411	111	711	77	21	133	9	2	16
SO_x	-559	-749	-369	-152	-204	-100	-21	-28	-14
OC	-282	-375	-189	-77	-102	-52	-11	-15	-7
BC	3910	2385	5435	1060	647	1473	147	90	204
Contrail cirrus	3.1	1.24	6.20	0.84	0.34	1.68	0.12	0.05	0.24

Note: Values from ref.[35]. All values are given on a per unit aviation emission basis (per kg BC. OC and SO_2, respectively, with contrail cirrus calculated per kg aviation CO_2 and NO_x per kg N).

Supplementary Table 13. European climate metrics for NTCFs from aviation combustion emissions and associated uncertainty range.

	GWP20			GWP100			GTP100		
	Value	**Min.**	**Max.**	**Value**	**Min.**	**Max.**	**Value**	**Min.**	**Max.**
NO_x	210	57	363	37	10	64	4.0	1.1	6.9
SO_x	-378	-507	-249	-103	-138	-68	-14	-18.8	-9.2
OC	-197	-262	-132	-54	-72	-36	-7.4	-9.8	-5.0
BC	2300	1403	3197	816	498	1134	112	68	156
Contrail cirrus	2.5	1.00	5.00	0.67	0.27	1.34	0.10	0.04	0.20

Note: Values form ref.[35]. All values are given on a per unit aviation emission basis (per kg BC. OC and SO_2, respectively, with contrail cirrus calculated per kg aviation CO_2 and NO_x per kg N).

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