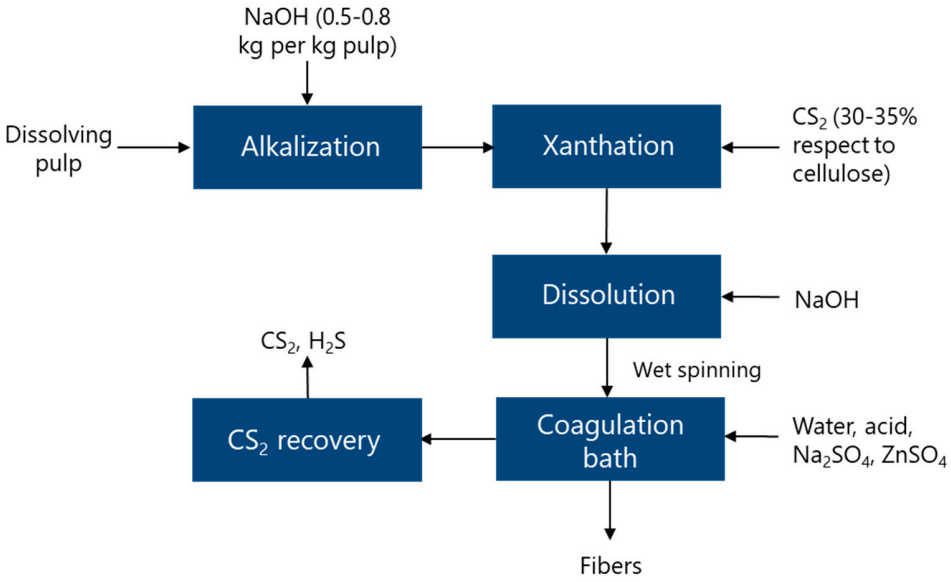
Supplemental Material

A Comparative Life Cycle Assessment of T-Shirt Production Using from Viscose, Lyocell, Cotton, and Polyester

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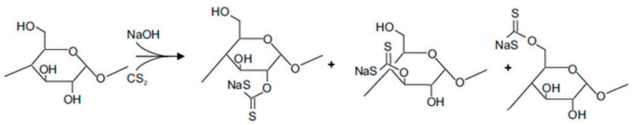


Chemical reactions:

(1) Aging: $Cell - OH + NaOH \rightarrow Cell - O^{-}Na^{+} + H_2O$

(2) Xanthogenation:

(2.1) Cellulose reactions:



(2.2) Side reactions: $2CS_2 + 6NaOH \rightarrow Na_2CO_3 + Na_2CS_3 + Na_2S + 3H_2O$

(3) Spinning:

(3.1) Cellulose reactions: $2Cell - O - CSS^{-}Na^{+} + H_2SO_4 \rightarrow 2Cell - OH + 2CS_2 + Na_2SO_4$

(3.2) Side reactions: $Na_2CS_3 + H_2SO_4 \rightarrow CS_2 + H_2S + Na_2SO_4$

$Na_2S + H_2SO_4 \rightarrow H_2S + Na_2SO_4$

Figure S1: Gate-to-gate system boundary for viscose fibers production. Chemicals reactions for different stages of production.

Country	Total production (tonnes/year)	%
China	4,481,000	70
Indonesia	615,000	10
India	847,000	13
Austria	284,000	4
Germany	80,000	1
Japan	30,000	0
Taiwan	27,000	0
	6,364,000	

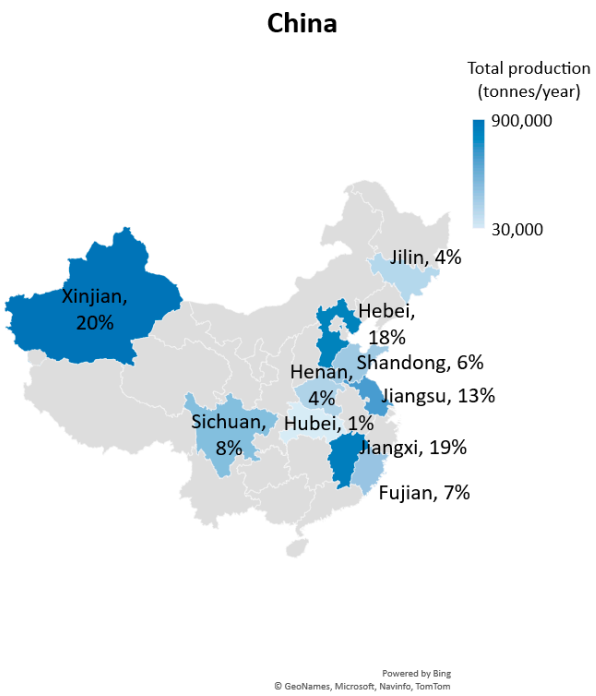


Figure S2: 2023 viscose staple fibers production worldwide and in China [15].

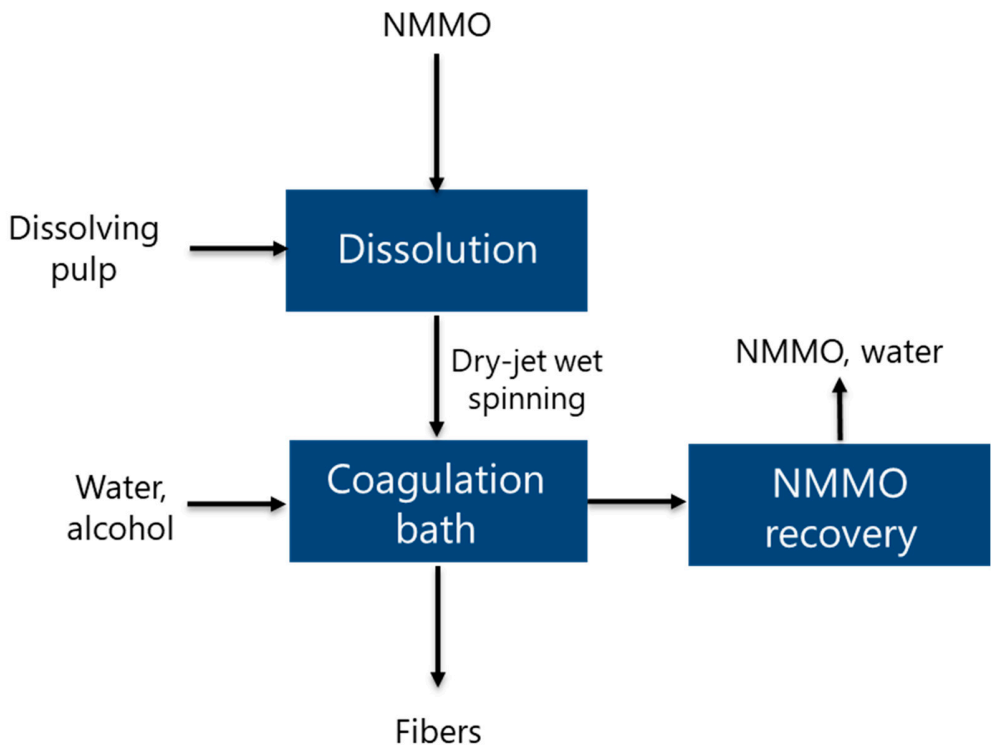


Figure S3: Gate-to-gate system boundary for Lyocell fibers production [18, 21].

Country	Lyocell production (tonnes)	%
China	361,000	48.6
Thailand	100000	13.5
Austria	164,000	22.1
United Kingdom	45,000	6.1
United States	51,000	6.9
Taiwan	1,000	0.1
Turkey	20,000	2.7
Finland	350	0.0
	742,350	

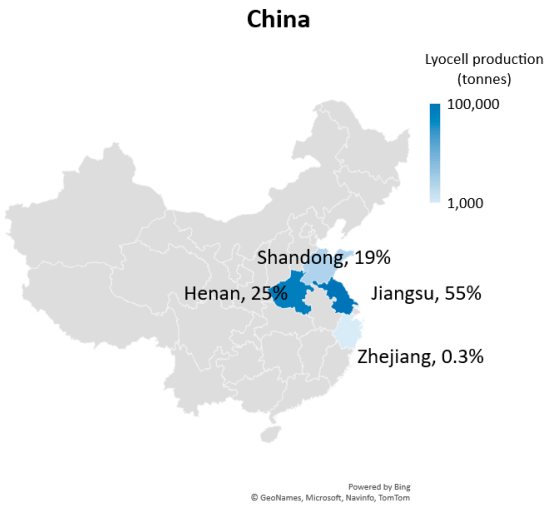


Figure S4: 2023 Lyocell staple fibers production worldwide and in China [15].

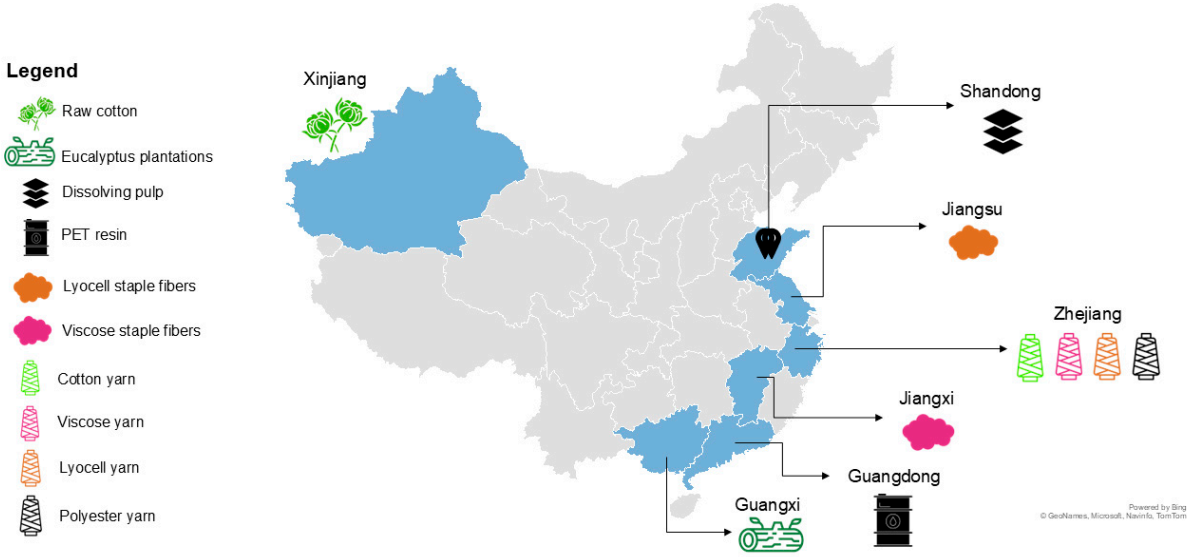


Figure S5: Geographical representation of Chinese study case.

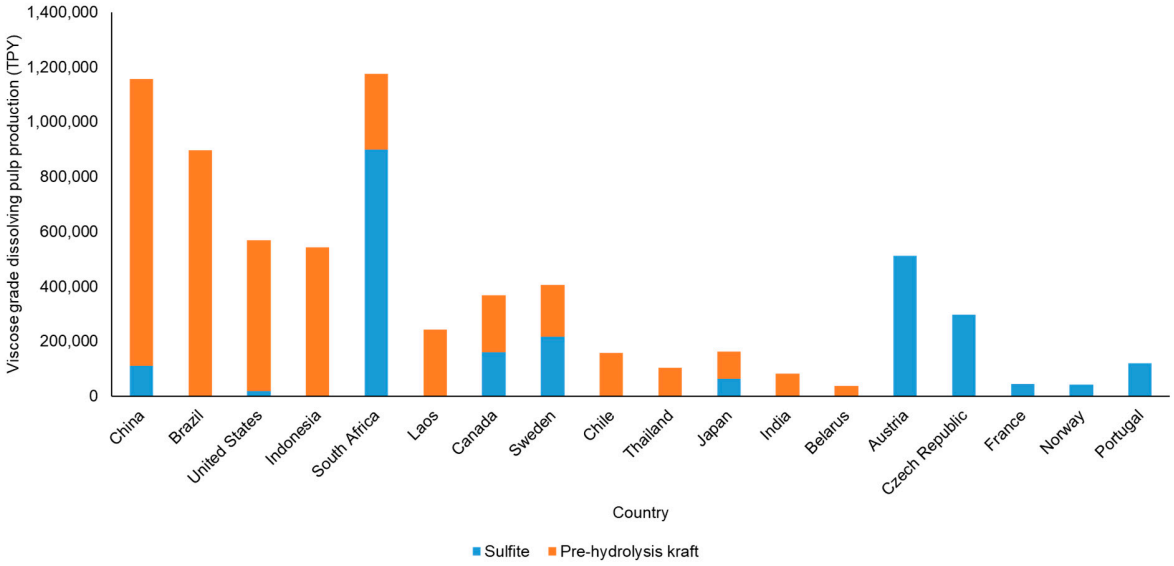


Figure S6: Viscose grade dissolving pulp production worldwide [32].

Table S1: Life cycle inventory for the production of 1 air-dry ton of dissolving pulp grade using pre-hydrolysis kraft in China.

Inputs		
	Value	Unit per air-dry ton of dissolving pulp
Chips (dry basis), before all losses	2476.8	Kg
Make up chemicals		
NaOH (100%)	42.7	Kg
Na_2SO_4 required	51.0	Kg
Na_2SO_4 from R-10	18.2	Kg
Na_2SO_4 make-up (net using salt cake)	32.9	Kg
CaO makeup	17.8	Kg
Bleaching Chemicals		
H_2O_2 (100%)	1.9	Kg
$MgSO_4$	2.0	Kg
H_2SO_4	9.4	Kg
ClO_2	16.5	Kg
NaOH (100%)	9.5	Kg
O_2	24.7	Kg
Chlorine dioxide generation		
$NaClO_3$	27.1	Kg
CH_3OH	2.8	Kg
H_2SO_4	13.2	Kg
Fuels	0.0	
Coal, LK	36.0	Kg
Coal, PB	139.2	Kg
Sludge, PB	11.6	OD kg
Others		
Freshwater	26.5	m3
Electricity	186.2	kWh
Outputs		
CO_2 fossil, lime kiln	100.6	Kg
CO_2 fossil, power boiler	388.9	Kg
CO_2 biogenic, recovery boiler	2,442.7	Kg
CO_2 biogenic, hog fuel	157.9	Kg
CO_2 biogenic lime kiln	129.6	Kg

CH_4	115.0	G
N_2O	25.3	G
SO_2	4.7	Kg
AOX	0.1	Kg
Sludge	0.0	Kg
Total suspended solids	4.0	Kg
BOD	17.8	Kg
Ashes	0.0	Kg
Dregs and grits	19.4	Kg
Mud inert	27.1	Kg
Dust losses	0.4	Kg

Table S2: Simplified LCI for the production of 1kg of NMMO monohydrate [60].

	Value	Unit	Description
Thermal energy	1.27	MJ	For water evaporation and monohydrate production from NMMO solution
Thermal energy	6.6417	MJ	For NMMO solution production
Electric energy	0.1521	MJ	For NMMO solution production
Hydrogen peroxide	0.845	kg	For NMMO solution production
Thermal energy	7.1656	MJ	For NMM production
Electric energy	0.0338	MJ	For NMM production
Diethylene glycol	0.7436	kg	For NMM production
Thermal energy	2.9068	MJ	For methylamine production
Electric energy	0.0338	MJ	For methylamine production
Ammonia	0.2197	kg	For methylamine production
Methanol	0.4225	kg	For methylamine production

Table S3: Hotspot categories for viscose T-shirt production.

Kg CO_2eq/kg shirt	Heat	Purchased electricity	Chemicals	Others	Total
Raw material	0.97	0.34	0.48	0.99	2.79
Spinning	4.37	1.33	2.12	0.01	7.82

Yarn production	0.00	3.56	0.00	0.00	3.56
Knitting	0.00	0.61	0.00	0.00	0.62
Wet processing / finishing	3.44	0.56	1.25	0.01	5.26
T-shirt manufacture	0.00	0.51	0.00	0.00	0.51
Transport	0.00	0.00	0.00	0.12	0.12

Table S4: Hotspot categories for Lyocell T-shirt production.

Kg CO2eq/kg shirt	Heat	Purchased electricity	Chemicals	Others	Total
Raw material	1.00	0.35	0.49	1.01	2.85
Spinning	5.07	2.42	1.25	0.00	8.75
Yarn production	0.00	3.56	0.00	0.00	3.56
Knitting	0.00	0.61	0.00	0.00	0.62
Wet processing / finishing	3.44	0.56	1.25	0.01	5.26
T-shirt manufacture	0.00	0.51	0.00	0.00	0.51
Transport	0.00	0.00	0.00	0.06	0.06

Table S5: Hotspot categories for cotton T-shirt production.

Kg CO2eq/kg shirt	Heat	Purchased electricity	Chemicals	Others	Total
Raw material	0.08	0.86	1.43	1.46	3.83
Spinning	0.00	0.00	0.00	0.00	0.00
Yarn production	0.00	3.56	0.00	0.00	3.56
Knitting	0.00	0.61	0.00	0.00	0.62
Wet processing / finishing	3.44	0.56	1.25	0.01	5.26
T-shirt manufacture	0.00	0.51	0.00	0.00	0.51
Transport	0	0	0	0.30	0.30

Table S6: Hotspot categories for polyester T-shirt production.

Kg CO2eq/kg shirt	Heat	Purchased electricity	Chemicals	Others	Total
Raw material	3.89	0.00	0.00	0.04	3.93
Spinning	0.87	0.82	0.00	0.00	1.69
Yarn production	0.00	3.34	0.00	0.00	3.35
Knitting	0.02	0.36	0.00	0.05	0.43
Wet processing / finishing	3.27	0.48	0.34	0.07	4.16
T-shirt manufacture	0.00	0.51	0.00	0.26	0.76
Transport	0.00	0.00	0.00	0.09	0.09

Table S7: ReCiPe (H) midpoint categories for 1 kg of T-shirt manufactured with cotton, polyester, viscose, and Lyocell fibers in China.

	Cotton	Polyester	Viscose	Lyocell	Unit per kg shirt
Fine particulate matter formation	0.03	0.02	0.05	0.04	kg PM2.5 eq
Fossil resource scarcity	2.74	2.02	4.15	4.27	kg oil eq
Freshwater ecotoxicity	0.56	0.34	0.90	0.58	kg 1,4-DCB
Freshwater eutrophication	0.01	0.00	0.01	0.01	kg P eq
Global warming	14.09	14.41	20.68	21.61	kg CO2 eq
Human carcinogenic toxicity	1.61	0.89	2.36	2.27	kg 1,4-DCB
Human non-carcinogenic toxicity	10.85	7.68	36.16	13.91	kg 1,4-DCB
Ionizing radiation	0.61	0.59	0.89	0.69	kBq Co-60 eq
Land use	6.74	0.27	1.47	1.47	m2a crop eq
Marine ecotoxicity	0.88	0.45	1.28	0.85	kg 1,4-DCB
Marine eutrophication	0.00	0.00	0.00	0.00	kg N eq
Mineral resource scarcity	0.03	0.01	0.05	0.03	kg Cu eq
Ozone formation, Human health	0.07	0.02	0.05	0.05	kg NOx eq
Ozone formation, Terrestrial ecosystems	0.07	0.02	0.05	0.05	kg NOx eq
Stratospheric ozone depletion	0.00	0.00	0.00	0.00	kg CFC11 eq
Terrestrial acidification	0.11	0.06	0.14	0.13	kg SO2 eq
Terrestrial ecotoxicity	189.07	26.11	159.11	107.46	kg 1,4-DCB
Water consumption	2.91	0.15	0.50	0.12	m3

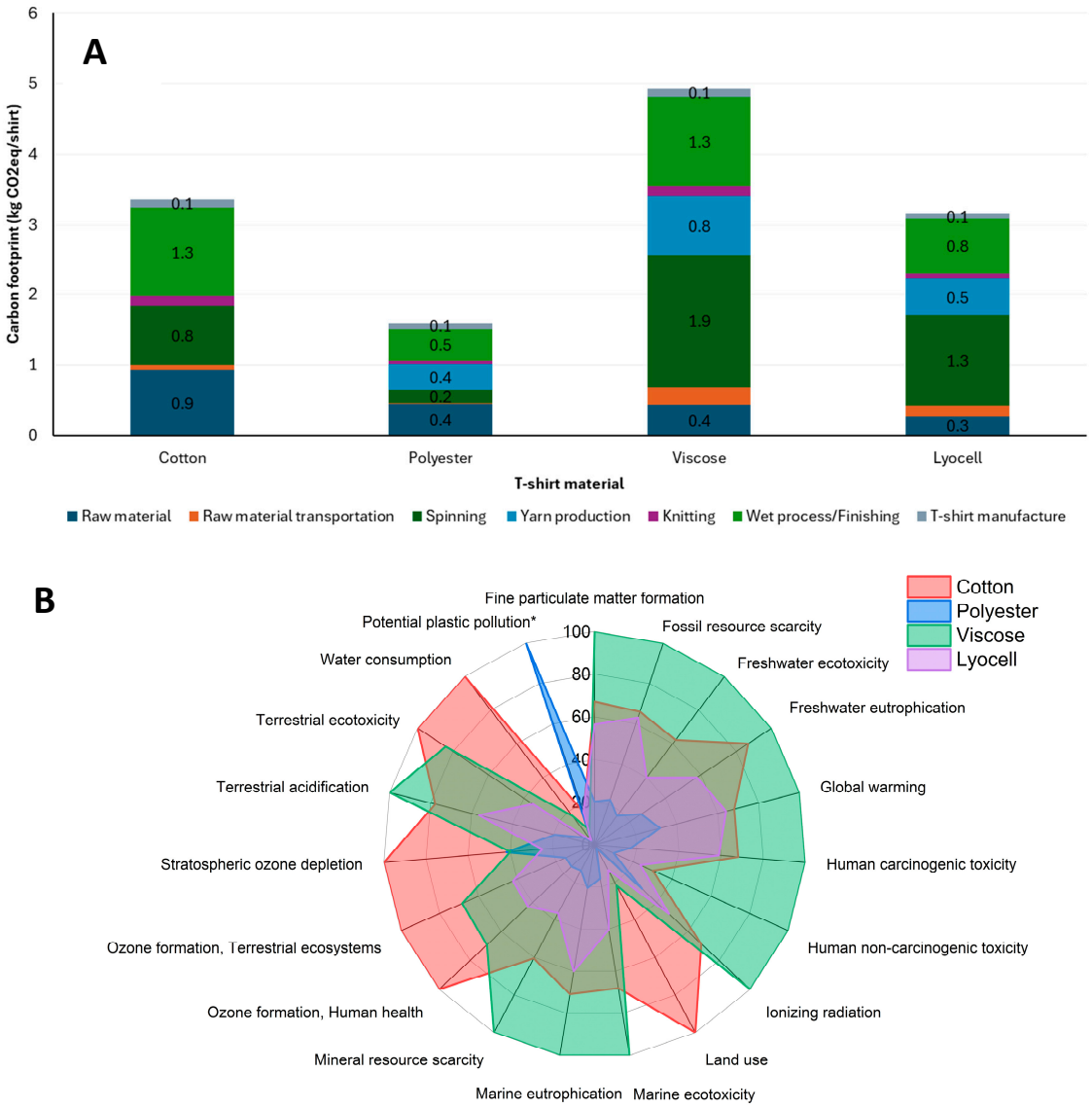


Figure S7: LCA to produce a shirt of cotton, polyester, viscose, and Lyocell T-shirts (250g, 115g, 250g, and 153g, respectively); A) GWP per shirt. B) Normalized LCA, the asterisk in the potential plastic pollution category denotes that this is an impact calculated by the authors and does not belong to the ReCiPe methodology.

Table S8: End-point categories for viscose T-shirt production.

Per kg	Europe	USA	Brazil	China
Ecosystem quality (Species.yr/kg shirt)	7.3E-08	7.8E-08	7.0E-08	1.0E-07
Human health (DALYs/kg shirt)	4.2E-05	4.8E-05	4.1E-05	6.5E-05
Natural resources (USD 2013/kg shirt)	1.3	1.5	1.2	0.9
Per shirt (250g)	**Europe**	**USA**	**Brazil**	**China**
Ecosystem quality (Species.yr/shirt)	1.8E-08	2.0E-08	1.7E-08	2.6E-08

Human health (DALYs/shirt)	1.1E-05	1.2E-05	1.0E-05	1.6E-05
Natural resources (USD 2013/shirt)	0.3	0.4	0.3	0.2

Table S9: End-point categories for 1 kg of Lyocell T-shirt production.

Per kg	**Europe**	**USA**	**Brazil**	**China**
Ecosystem quality (Species.yr/kg shirt)	7.0E-08	7.4E-08	6.4E-08	1.0E-07
Human health (DALYs/kg shirt)	3.5E-05	4.0E-05	3.2E-05	5.8E-05
Natural resources (USD 2013/kg shirt)	1.3	1.5	1.2	0.9
Per shirt (153g)	**Europe**	**USA**	**Brazil**	**China**
Ecosystem quality (Species.yr/shirt)	1.1E-08	1.1E-08	9.9E-09	1.6E-08
Human health (DALYs/shirt)	5.4E-06	6.1E-06	4.9E-06	8.9E-06
Natural resources (USD 2013/shirt)	0.2	0.2	0.2	0.1

Table S10: End-point categories for 1 kg of cotton T-shirt production.

Per kg	**Europe**	**USA**	**Brazil**	**China**
Ecosystem quality (Species.yr/kg shirt)	1.1E-07	1.2E-07	1.1E-07	1.4E-07
Human health (DALYs/kg shirt)	2.7E-05	3.0E-05	2.6E-05	4.0E-05
Natural resources (USD 2013/kg shirt)	7.6E-01	8.7E-01	7.2E-01	5.9E-01
Per shirt (250g)	**Europe**	**USA**	**Brazil**	**China**
Ecosystem quality (Species.yr/shirt)	2.9E-08	2.9E-08	2.8E-08	3.4E-08
Human health (DALYs/shirt)	6.9E-06	7.6E-06	6.5E-06	1.0E-05
Natural resources (USD 2013/shirt)	0.2	0.2	0.2	0.1

Table S11: End-point categories for 1 kg of polyester T-shirt production.

Per kg	**Europe**	**USA**	**Brazil**	**China**
Ecosystem quality (Species.yr/kg shirt)	4.1E-08	4.3E-08	3.8E-08	6.1E-08
Human health (DALYs/kg shirt)	1.8E-05	2.1E-05	1.6E-05	3.1E-05
Natural resources (USD 2013/kg shirt)	5.5E-01	6.6E-01	5.0E-01	3.4E-01
Per shirt (250g)	**Europe**	**USA**	**Brazil**	**China**
Ecosystem quality (Species.yr/shirt)	4.7E-09	5.0E-09	4.3E-09	7.0E-09
Human health (DALYs/shirt)	2.1E-06	2.4E-06	1.8E-06	3.6E-06
Natural resources (USD 2013/shirt)	6.3E-02	7.5E-02	5.7E-02	3.8E-02

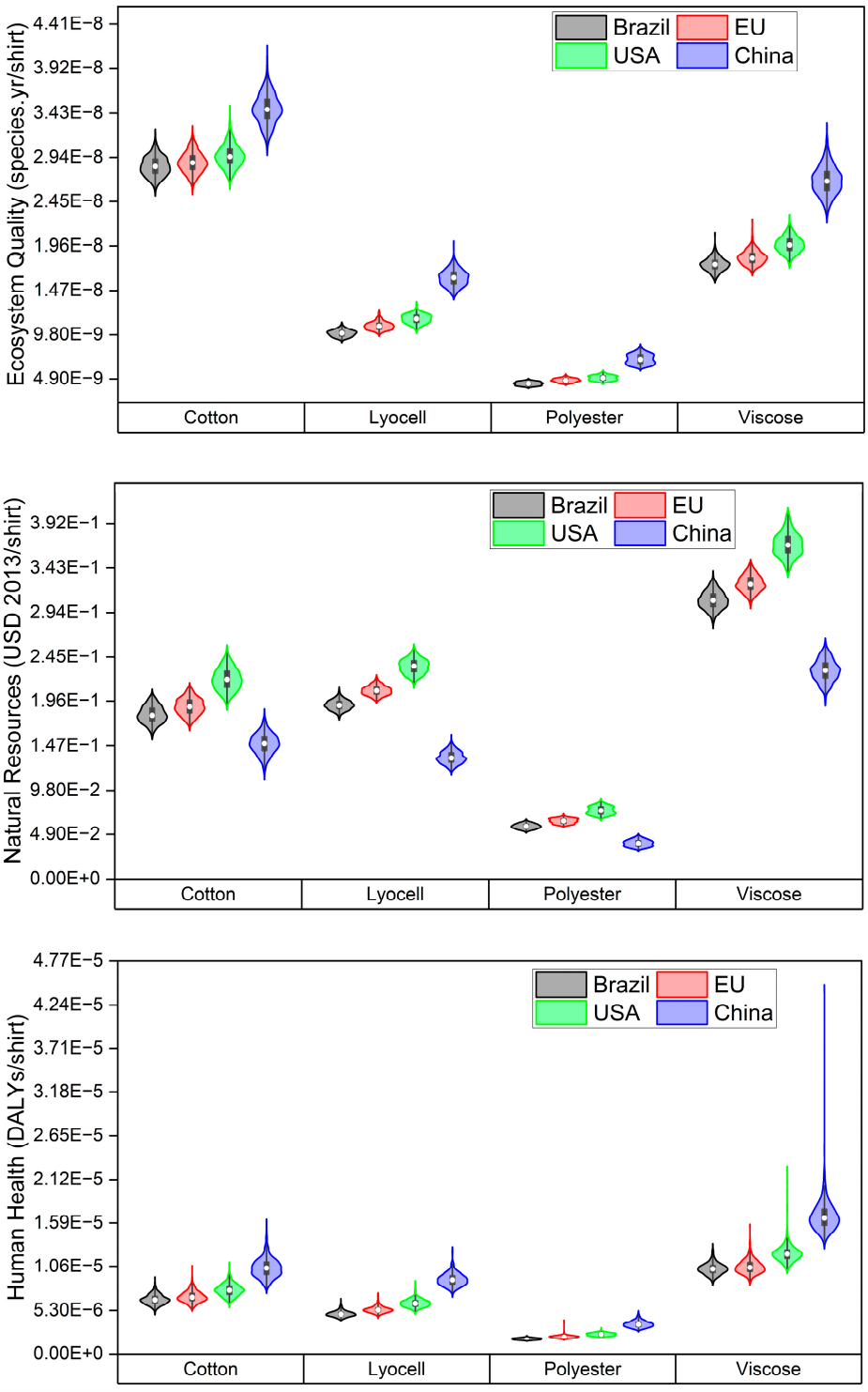


Figure S8: End-point ReCiPe categories for cotton, polyester, viscose, and Lyocell T-shirts (250g, 115g, 250g, and 153g, respectively). Violin plots reflect the probability density of 1,000 Monte Carlo iterations per scenario. White dot = median; thick bar = interquartile range; thin line = 95% confidence interval.

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