Supplementary Materials

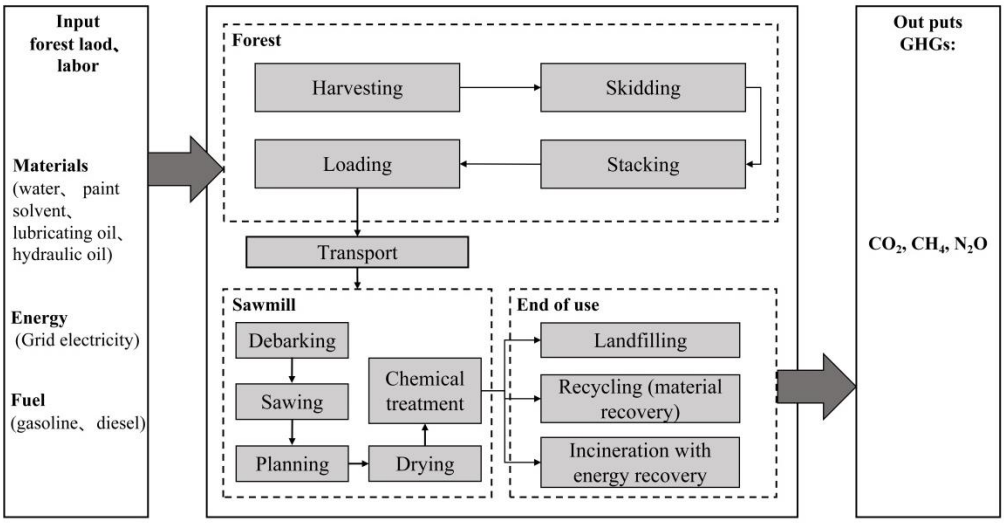


Figure S1. System boundaries for lumber production

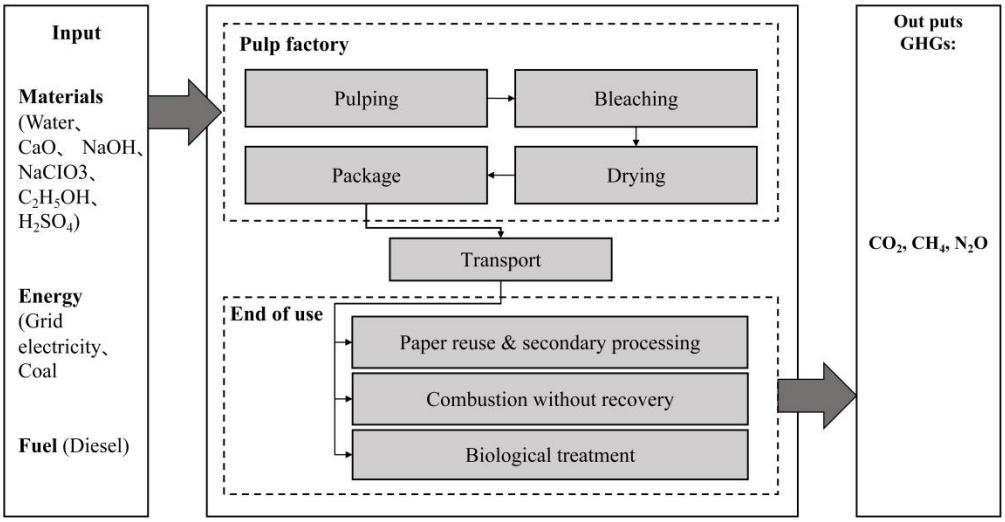


Figure S2. System boundaries for pulp production

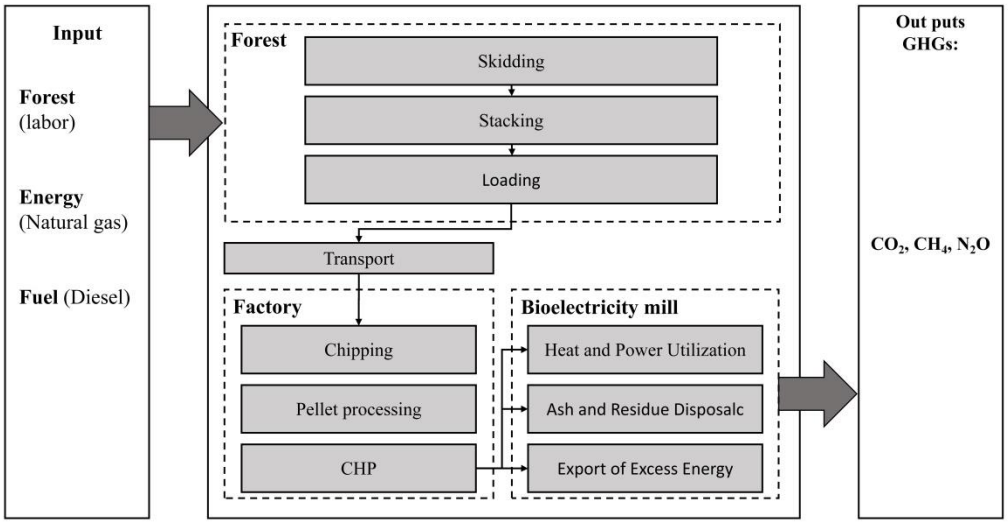


Figure S3. System boundaries for bioelectricity generation

Table S1. Model of *C. oleifera* forest residues, as lumber, pulp and bioenergy feedstocks, stemming from low-yield forest plantation management, harvesting systems

Input	Dry weight	Product
OC low-yielding forest transformation residues	2740 kg	
Product		
1 cubic meter of lumber	600kg	Lumber
By-product		
Forest residues	1397kg	Bioelectricity
Barks	53kg	Bioelectricity
Sawdust, shavings, etc.	406kg	Bioelectricity
Wood chips	284kg	Pulp

Table S2. Greenhouse gas emission coefficients of material use in OC lumber production system, OC pulp production system and bioelectricity generation plants.

Material category	Unit	Emission factors	Reference
Hydrogen peroxide (H_2O_2)	$kgCO_2e/kg$	2.316	[38]
Ethanol (C_2H_5OH)	$kgCO_2e/L$	1.63	[44]
Paint solvent	$kgCO_2e/kg$	1.19972	[42]
Sodium hydroxide (NaOH)	$kgCO_2e/kg$	1.12	[38]

Hydraulic oil	$kgCO_2e/L$	0.2	[53]
Lubricating oil	$kgCO_2e/kg$	1.2	[53]
Water	$kgCO_2e/m^3$	0.213	[40]
Calcium oxide (CaO)	$kgCO_2e/kg$	1.11	[41]
Sulfuric acid (H_2SO_4)	$kgCO_2e/kg$	0.0776	[40]
Sodium chlorate ($NaClO_3$)	$kgCO_2e/kg$	0.8638	[38]

Table S3. Greenhouse gas emission coefficients of energy consumption in OC lumber production system, OC pulp production system and bioelectricity generation plants.

Energy type	Unit	Emission factors	Reference
Grid electricity	tCO_2e/MWh	0.5207	[38]
Diesel fuel	tCO_2e/t	3.797	[38]
Natural gas	$kgCO_2e/kg$	1.072	[38]
Coal	$kgCO_2e/kg$	0.08	[38]
Gasoline	$kgCO_2e/L$	2.3	[53]
Liquefied petroleum gas	$kgCO_2/gallon$	5.68	[43]

Table S4. Greenhouse gas emission factors for the road- and rail-based vehicles across a range of fuel sources.

Transport	Unit	Emission factors	Reference
8-truck	$kgCO_2e/L$	2.7136	[39]
Pick-up truck	$kgCO_2e/L$	2.7069	[39]
Train	$kgCO_2e/tkm$	0.01	[39]

Table S5. The composition of impacts of production stages on the carbon footprint of a m^3 chemical treated planed dry OC lumber during camellia forest harvest phase to grave (for Figure 2a)

Stage	GWP, $kgCO_2e/m^3$ chemical treated planed dry OC lumber	%Total
Plantation management	17.307	7.09
Fibreboard mill	227.007	92.98
Total	244.314	100

Table S6. The composition of impacts of emission sources on the carbon footprint of a m^3 chemical treated planed dry OC lumber during camellia forest harvest phase to grave (for Figure 2b)

Emission sources	GWP, $kgCO_2e/m^3$ chemical treated planed dry OC lumber	%Total
Energy and fossil fuels	144.730	59.239
Other materials	81.331	33.290
Wood fiber materials	17.307	7.084
Emissions	0.939	0.384
Chemicals	0.006	0.003
Total	244.314	100

Table S7. Breakdown of emission sources for energy and fossil fuels consumption impacts on the carbon footprint of a m^3 chemical treated planed dry OC lumber (for Figure 2c)

Energy and fossil fuels	GWP, $kgCO_2e/m^3$ chemical treated planed dry OC lumber	%Total
Diesel	74.316	51.348
Electricity from national grid	34.077	23.545
Liquefied petroleum gas	12.145	8.391
Natural gas	9.835	6.795
On-site generated electricity	8.149	5.631
Gasoline	6.102	4.216
Propane	0.086	0.060
Lube oil	0.020	0.014
Total	144.730	100

Table S8. Breakdown of emission sources for the wood fiber materials use impacts on the carbon footprint of a m^3 chemical treated planed dry OC lumber (for Figure 2d)

Wood fiber materials	GWP, $kgCO_2e/m^3$ chemical treated planed dry OC lumber	%Total
Harvesting	12.087	69.835
Transportation	3.768	21.770
Direct emissions	1.453	8.394
Total	17.307	100

Table S9. The composition of impacts of production stages on the carbon footprint of a ton air-dried OC pulp during camellia forest harvest phase to grave (for Figure 3a)

Stage	GWP, $kgCO_2e$/ton air-dried pulp	%Total
Plantation management	32.509	6.750
Pulp mill	449.117	93.250
Total	481.626	100

Table S10. The composition of impacts of emission sources on the carbon footprint of a ton air-dried OC pulp during camellia forest harvest phase to grave (for Figure 3b)

Inputs/outputs	GWP, $kgCO_2e$/ton air-dried pulp	%Total
Chemicals	231.480	48.062
Energy and fossil fuels	94.221	19.563
Emissions to water	52.801	10.963
Emissions to air	33.989	7.057
Camellia oleifera pulpwood	32.509	6.750
Solid wastes	30.754	6.385
Other materials (water)	5.871	1.219
Total	481.626	100

Table S11. Breakdown of emission sources for energy and fossil fuels consumption impacts on the carbon footprint of a ton air-dried OC pulp (for Figure 3c)

Energy and fossil fuels	GWP, $kgCO_2e$/ton air-dried pulp	%Total
On-site generated electricity	29.374	31.176
Bunler oil	24.158	25.640
Diesel	17.716	18.803
Coal	15.742	16.707
Electricity from national grid	5.926	6.290
Internal used steam	1.305	1.385
Total	94.221	100

Table S12. Breakdown of emission sources for chemical use impacts on the carbon footprint of a ton air-dried OC pulp (for Figure 3d)

Chemicals	GWP, $kgCO_2e$/ton air-dried pulp	%Total
CaO	101.525	43.859
NaOH	41.246	17.818
H_2O_2	35.615	15.386
$NaClO_3$	25.135	10.859

On-site recovered NaOH	20.546	8.876
CH_3OH	5.874	2.537
H_2SO_4	1.539	0.665
Total	231.480	100

Table S13. The composition of impacts of production stages on the carbon footprint of a kWh bioelectricity generated from OC feedstock (for Figure 4a)

Stage	GWP, gCO_2e/kWh	%Total
Plantation management	8.577	20.544
Bioelectricity plant	33.173	79.456
Total	41.750	100

Table S14. The composition of impacts of life-cycle processes on the carbon footprint of a kWh bioelectricity generated from OC feedstock (for Figure 4b)

Life cycle	GWP, gCO_2e/kWh	%Total
Harvest and internal transport	8.577	20.544
Transportation (forest land to factory)	18.779	44.980
Processing	14.394	34.476
Total	41.750	100

Table S15. The composition of impacts of emission sources on the carbon footprint of a kWh bioelectricity generated from OC feedstock (for Figure 4c)

Item	GWP, gCO_2e/kWh	%Total
Gasoline	24.704	59.171
Natural gas	8.469	20.284
Labor	8.041	19.260
Electricity from national grid	0.536	1.285
Total	41.750	100

Table S16. Sensitivity analysis presenting the influence of input items to GWP impact for OC fibreboard production (for Figure 5a)

Input	Sensitivity (%)
Diesel	4.44E-01
Water	4.21E-01
Electricity from national grid	9.00E-02
Oil camellia wood fiber materials	2.35E-02

Liquefied petroleum gas	8.60E-03
Onsite generated electricity	5.08E-03
Natural gas	4.35E-03
Gasoline	1.73E-03
Propane	6.29E-04
Suspended solids, unspecified	3.71E-04
Acetaldehyde	2.68E-04
Others	2.49E-04
Methanol	1.21E-04
Saw dust	1.04E-04
Particulates, < 2.5 um	9.48E-05
Solvant paint	6.53E-05
Acrolein	6.13E-05
pins, fines	4.94E-05
Hydraulic fluid	4.39E-05
Lube oil	3.50E-05
Propanol	1.34E-05
Particulates, > 10 um	6.86E-06

Table S17. Sensitivity analysis presenting the influence of input items to GWP impact for OC pulp production (for Figure 5b)

Input	Sensitivity (%)
CaO	5.19E-01
Effluent	7.91E-02
NaOH	7.53E-02
Oil camellia pulpwood	5.59E-02
H_2O_2	4.95E-02
Sludge	3.87E-02
Waste heat	3.85E-02
Onsite generated electricity	3.71E-02
NaClO3	2.81E-02
Bunler oil	2.34E-02
Onsite recovered NaOH	1.86E-02
Diesel	1.40E-02
Coal	9.22E-03
COD	4.21E-03
Water	3.50E-03
Ash and dust	1.91E-03
CH_3OH	1.27E-03
Electricity from national grid	1.06E-03
H_2SO_4	6.28E-04
TSS	5.99E-04

BOD	1.40E-04
Internal used steam	7.94E-05
Total P	5.70E-05
Others	4.57E-05
SO_2	2.92E-05
TRS	2.91E-05

Table S18. Sensitivity analysis presenting the influence of input items to GWP impact for OC bioelectricity generation (for Figure 5c)

Input	Sensitivity (%)
Transport by 8t truck	6.74E-01
Natural gas	1.36E-01
Labor for harvesting	1.22E-01
Gasoline	6.53E-02
Electricity from national grid	1.48E-03
Particulates	2.67E-04
Waste heat	1.85E-04

Table S19. Multi-factor sensitivity analysis presenting the influence of four scenarios to GWP impact for OC fibreboard production (for Figure 5d)

Scenarios	GWP, $kgCO_2e/m^3$ chemical treated planed dry OC lumber	GWP change (%)
BAU	244.314	0
Green electricity	212.969	-12.83
Fuel-saving	184.860	-24.34
Green electricity and fuel-saving	153.515	-37.16

Table S20. Multi-factor sensitivity analysis presenting the influence of four scenarios to GWP impact for OC pulp production (for Figure 5e)

Scenarios	GWP, $kgCO_2e$/ton air-dried OC pulp	GWP change (%)
BAU	481.6258	0
Green material	448.4244	-6.89
Green technology	428.8246	-10.96
Green material and green technology	395.6232	-17.86

Table S21. Multi-factor sensitivity analysis presenting the influence of four scenarios to GWP impact for OC bioenergy generation (for Figure 5f)

Scenarios	GWP, gCO_2e/kWh bioelectricity generated from OC feedstock	GWP change (%)
BAU	41.75023	0
Green electricity	34.07143	-18.39
Low-carbon labor	36.51423	-12.54
Green electricity and low-carbon labor	28.83543	-30.93

Table S22. Comparison of life cycle assessments of common biomass-based panel, pulp, and bioenergy products

Products	Carbon footprint	Unit (GWP/FU)	Source
Panel			
Fibreboard	244.314	$kgCO_2e/m^3$ chemical-treated planed dry OC lumber	This study
Fibreboard	759	kg CO_2e/m^3	[16]
Particleboard	720	kg CO_2e/m^3	[59]
Plywood	538	kg CO_2e/m^3	[60]
Plywood	504.45	kg CO_2e/m^3	[15]
Pulp			
Chemi-mechanical pulp	481.626	$kgCO_2e$/t air-dried OC pulp	This study
Kraft pulp	722	kg CO_2e/t	[17]
Hygiene tissue pulp	448	kg CO_2e/t	[63]
Hygiene tissue pulp	388	kg CO_2e/t	[63]
Kraft pulp	508	kg CO_2e/t	[61]
Chemi-mechanical pulp	513	kg CO_2e/t	[61]
Recycled pulp	408	kg CO_2e/t	[61]
Corrugating medium/linerboard	510	kg CO_2e/t	[92]
Newsprint	2724.91	kg CO_2e/t	[18]
Newsprint	1619.27	kg CO_2e/t	[18]
Newsprint	2400.88	kg CO_2e/t	[18]
Newsprint	1742.39	kg CO_2e/t	[18]
Bioenergy			
Bioelectricity	0.04175	$kgCO_2e$/kWh bioelectricity generated from OC feedstock	This study
Wood Pellets	0.138	kg CO_2e/kWh	[65]
Wood Pellets	0.143	kg CO_2e/kWh	[66]
Wood Pellets	0.173	kg CO_2e/kWh	[66]

Bioelectricity	0.068	kg CO_2e/kWh	[67]
Bioelectricity	0.087	kg CO_2e/kWh	[68]

Table S23. Comparison of compositional carbon emissions across different panel, pulp and bioenergy products

Products	Carbon footprint	Unit (GWP/FU)	Percentage / Component	reference
Panel	244.314	$kgCO_2e/m^3$	Plantation management (7.08%, 17.307 $kgCO_2e/m^3$); Fibreboard mill (92.92%, 227.007 $kgCO_2e/m^3$)	This study
	244.314	$kgCO_2e/m^3$	Energy and fossil fuels (59.239%, 144.703 $kgCO_2e/m^3$); Other materials (33.290%, 55.55 $kgCO_2e/m^3$); Wood fiber materials (7.084%, 17.307 $kgCO_2e/m^3$); Emissions (0.384%, 0.939 $kgCO_2e/m^3$); Chemicals (0.003%, 0.006 $kgCO_2e/m^3$)	This study
	144.730 Energy and fossil fuels	$kgCO_2e/m^3$	Diesel (51.35%, 74.316 k $kgCO_2e/m^3$); Electricity from national grid (23.55%, 34.077 $kgCO_2e/m^3$); Liquefied petroleum gas (8.39%, 12.145 $kgCO_2e/m^3$); Natural gas (6.80%, 9.835 $kgCO_2e/m^3$); On-site generated electricity (5.63%, 8.149 $kgCO_2e/m^3$); Gasoline (4.22%, 6.102 $kgCO_2e/m^3$); Propane (0.06%, 0.086 $kgCO_2e/m^3$); Lube oil (0.01%, 0.020 $kgCO_2e/m^3$)	This study
	17.307 Wood fiber materials	$kgCO_2e/m^3$	Harvesting (69.84%, 12.087 $kgCO_2e/m^3$); Transportation (21.77%, 3.768 $kgCO_2e/m^3$); Direct emissions (8.39%, 1.453 $kgCO_2e/m^3$)	This study
	133.35	$kgCO_2e/m^3$	IPCC Tier 1, primary data	[69]
	477	$kgCO_2e/m^3$	Raw materials (9.1%, 43.2 $kgCO_2e/m^3$); Manufacturing (62.5%, 298 $kgCO_2e/m^3$); Transportation &Disposal (22.8%, 109.63 $kgCO_2e/m^3$)	[70]
	305	$kgCO_2e/m^3$	Cradle-to-Gate (64.3%, 196.11 $kgCO_2e/m^3$); Gate-to-Grave (35.7%, 109.63 $kgCO_2e/m^3$)	[71]
Pulp	481.626	$kgCO_2e/t$ air-dried pulp	Plantation management (6.75%, 32.509 $kgCO_2e/t$); Pulp mill (93.25%, 449.117 $kgCO_2e/t$)	This study
	481.626	$kgCO_2e/t$ air-dried pulp	Chemicals (48.06%, 231.480 $kgCO_2e/t$); Energy and fossil fuels (19.56%, 94.221 $kgCO_2e/t$); Emissions to water (10.96%, 52.801 $kgCO_2e/t$); Emissions to air (7.06%, 33.989 $kgCO_2e/t$); *Camellia oleifera* pulpwood (6.75%, 32.509 $kgCO_2e/t$); Solid wastes (6.39%, 30.754 $kgCO_2e/t$); Other materials (water) (1.22%, 5.871 $kgCO_2e/t$)	This study
	94.221 Energy and fossil fuels	$kgCO_2e/t$ air-dried pulp	On-site generated electricity (31.18%, 29.374 $kgCO_2e/t$); Bunker oil (25.64%, 24.158 $kgCO_2e/t$); Diesel (18.80%, 17.716 $kgCO_2e/t$); Coal (16.71%, 15.742 $kgCO_2e/t$); Electricity from national grid (6.29%, 5.926 $kgCO_2e/t$); Internal used steam (1.38%, 1.305 $kgCO_2e/t$)	This study

	231.480 Chemicals	$kgCO_2e/t$ air-dried pulp	CaO (43.86%, 101.525 $kgCO_2e/t$); NaOH (17.82%, 41.246 $kgCO_2e/t$); H_2O_2 (15.39%, 35.615 $kgCO_2e/t$); $NaClO_3$ (10.86%, 25.135 $kgCO_2e/t$); On-site recovered NaOH (8.88%, 20.546 $kgCO_2e/t$); CH_3OH (2.54%, 5.874 $kgCO_2e/t$); H_2SO_4 (0.66%, 1.539 $kgCO_2e/t$)	This study
	UFS 1734 CFS 2064 Ground wood 1575	$kgCO_2e/t$	Raw materials (9–11%, 157–227 $kgCO_2e/t$); Energy use (73–77%, 1149–1589 $kgCO_2e/t$); Transportation & others (12–18%, 189–372 $kgCO_2e/t$)	[72]
	~1900–2500 (context-dependent)	$kgCO_2e/t$	Steam production (30–40%); Electricity (20–30%); Fuel use (15–25%); Transport and Chemicals (5–10%)	[73]
	145.1	$kgCO_2e/m^3$	Raw materials (41%, 59.5 $kgCO_2e/m^3$); Manufacturing & transport (59%, 85.6 $kgCO_2e/m^3$)	[74]
	Not reported	$kgCO_2e/t$	Not applicable (no emission data)	[75]
Bioenergy	OC biomass 41.75	gCO_2e/kWh bioelectricity	Plantation management (20.54%, 8.58 g CO_2e/kWh); Bioelectricity plant (79.46%, 33.17 gCO_2e/kWh)	This study
	OC biomass 41.75	gCO_2e/kWh	Harvest and internal transport (20.54%, 8.58 gCO_2e/kWh); Transportation (forest land to factory) (44.98%, 18.78 gCO_2e/kWh); Processing (34.48%, 14.39 gCO_2e/kWh)	This study
	OC biomass 41.75	gCO_2e/kWh	Gasoline (59.17%, 24.70 gCO_2e/kWh); Natural gas (20.28%, 8.47 gCO_2e/kWh); Labor (19.26%, 8.04 gCO_2e/kWh); Electricity from national grid (1.28%, 0.54 gCO_2e/kWh)	This study
	291.25–1731.36 (biomass-only); 926.1–1065.9 (co-firing)	gCO_2e/kWh	Forestry (43 gCO_2e/kWh); Agriculture (291.25 gCO_2e/kWh); Waste (1731.36 gCO_2e/kWh)	[76]
	With CCS 38.7–62.1 Without CCS ~178	gCO_2e/kWh	Biomass Combustion (36%, ~64.1 gCO_2e/kWh); Transport & Pre-treatment (18%, ~32 gCO_2e/kWh	[81]
	Substitution benefit: −161 to −196	gCO_2e/kWh	Baseline Fossil Emissions (e.g., coal) (full offset); Wood Pellet combustion ~15% actual emissions; Net benefit depends on avoided source	[79]
	100–192(dependent on distance and source)	gCO_2e/kWh	Transport (up to 54% if long distance); Combustion (25–40%); Feedstock prep (10–15%)	[80]

Table S24. Life cycle inventory for various raw materials in production of panel, pulp, and bioenergy products

Production	Raw Material Type	Material Source	Emission	Unit (GWP/FU)	Amount, m^3 (China)	Percentage (%)	Sources
Panel	Fibreboard	China	244.314	$kgCO_2e/m^3$ chemical-treated planed dry OC lumber			This study
	Plywood (PLY)	China	538	$kgCO_2e/m^3$	64204800	82.7	[60]
	Fiberboard (FB)	China	406	$kgCO_2e/m^3$	20582400	82.7	[60]
	Particleboard (PB)	China	348	$kgCO_2e/m^3$	10752000	82.7	[60]
	Oriented Strand Board (OSB)	China	552	$kgCO_2e/m^3$	6144000	82.7	[60]
Pulp	Chemi-mechanical Pulp	China	481.626	$kgCO_2e$/t air-dried OC pulp	85870000		This study
	Imported waste paper (5% impurity)	China	826.54	$kgCO_2e/t$	85870000	8.82	[81]
	Imported waste corrugated board (1%)	China	337.56	$kgCO_2e/t$	85870000	8.32	[81]
	Domestic waste paper (2%)	China	338.4	$kgCO_2e/t$	85870000	8.00	[81]
	Eucalyptus Wood	China	1245.576	$kgCO_2e/t$	85870000	60	[36]
	Primary Wood	China	3.40	$kgCO_2e/t$	85870000	100	[80]
	Recycled Material	Imported & Domestic	2.72	$kgCO_2e/t$	85870000	46.8	[80]

	Non-Wood Fiber	China	1.42	$kgCO_2e/t$	85870000	15	[80]
Bioenergy	Bioelectricity	China	41.75	gCO_2e/kWh bioelectricity generated from OC feedstock	3494000000	100%	This study
	Fuel	China	19.4	gCO_2e/kWh	3494000000	100%	[83]
	Renewable	China	30.5	gCO_2e/kWh	3494000000	100%	[82]
	Renewable	China	36.2	gCO_2e/kWh	3494000000	100%	[82]
	Non-Renewable	China	7.5	gCO_2e/kWh	3494000000	100%	[82]
	Renewable	China	4	gCO_2e/kWh	3494000000	100%	[82]
	Renewable	China	57.4	gCO_2e/kWh	3494000000	100%	[82]
	Non-Renewable	China	1079.3	gCO_2e/kWh	3494000000	100%	[82]
	Fuel	China	1330	gCO_2e/kWh	3494000000	100%	[84]
	Fuel	China	1330	gCO_2e/kWh	3494000000	100%	[84]
	Fuel	China	770	gCO_2e/kWh	3494000000	100%	[84]