

Supporting Information

Environmental and economic assessment of portable systems: Production of wood-briquettes and torrefied-briquettes to generate heat and electricity

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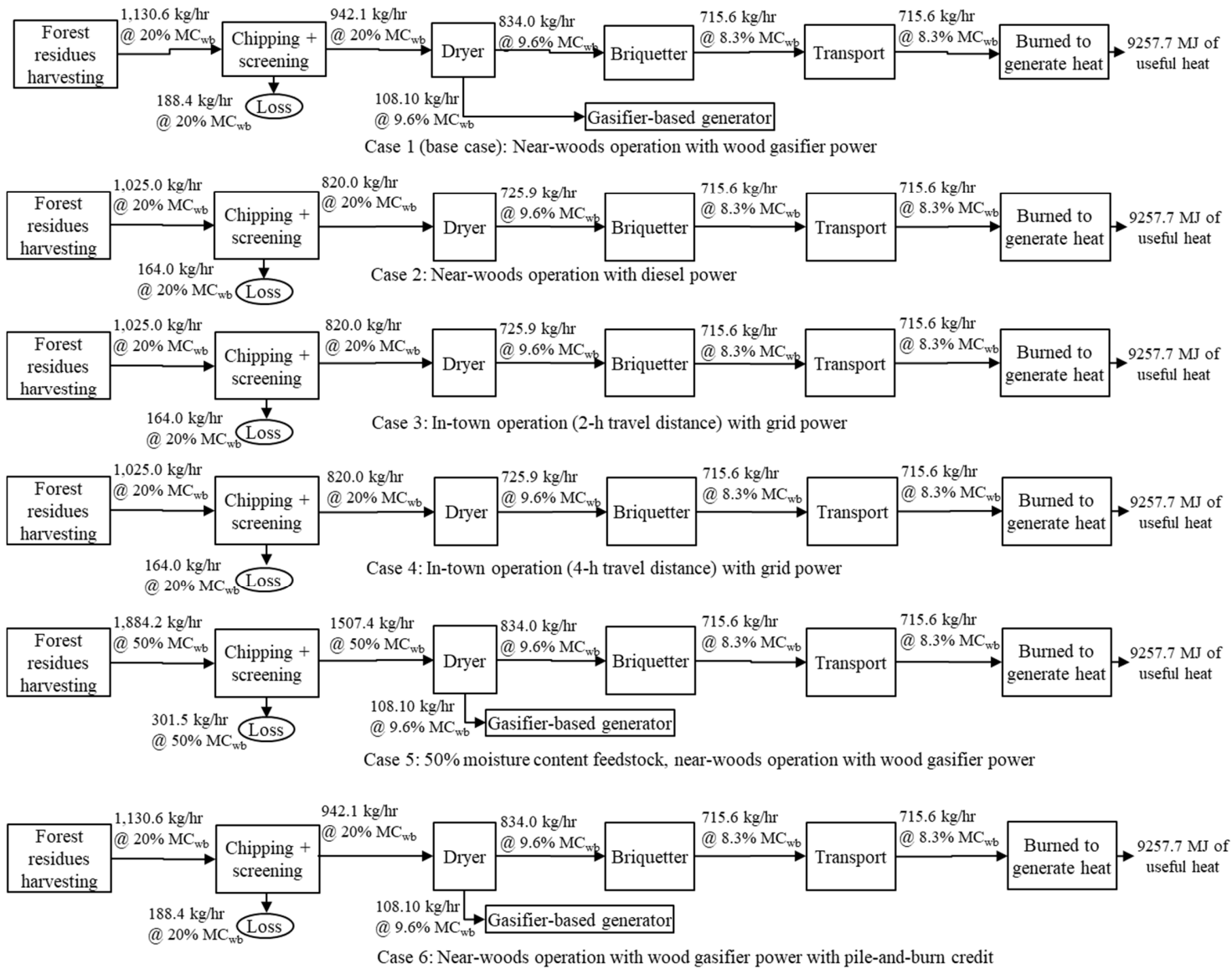


Figure S1: Mass balances of case studies for heat generation from wood briquettes (WB)

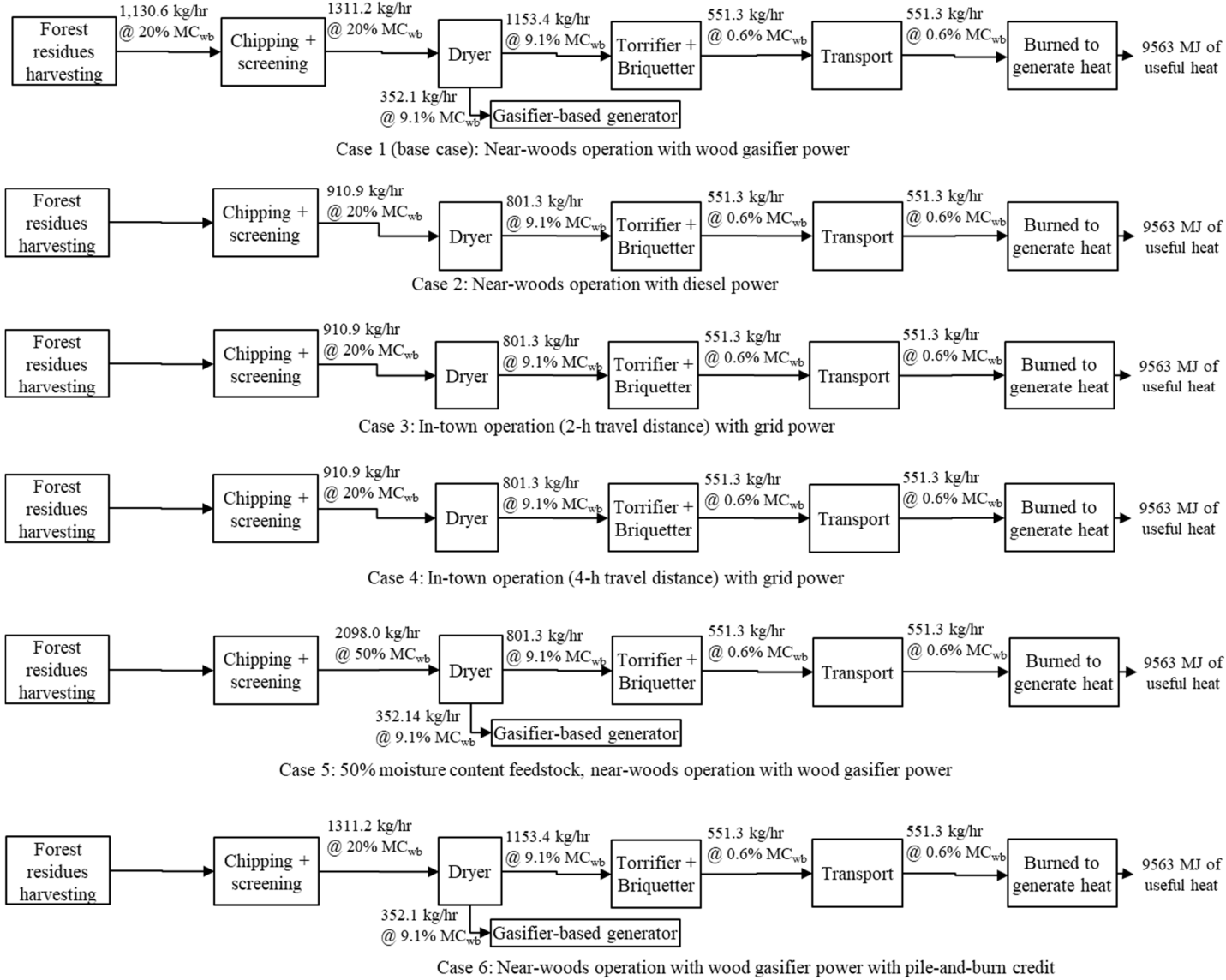
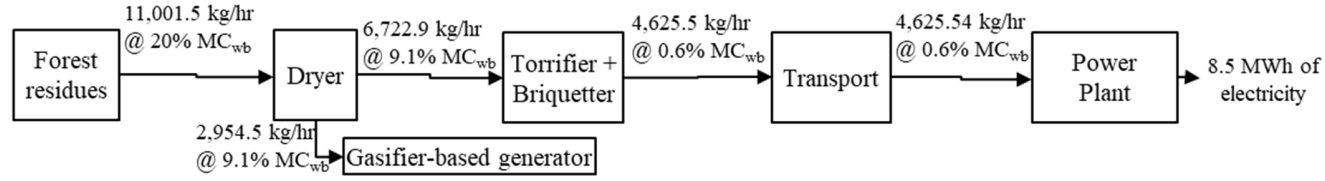
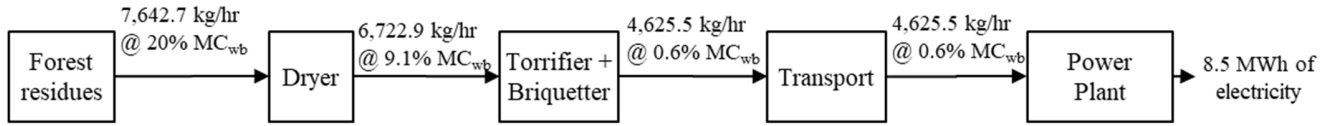


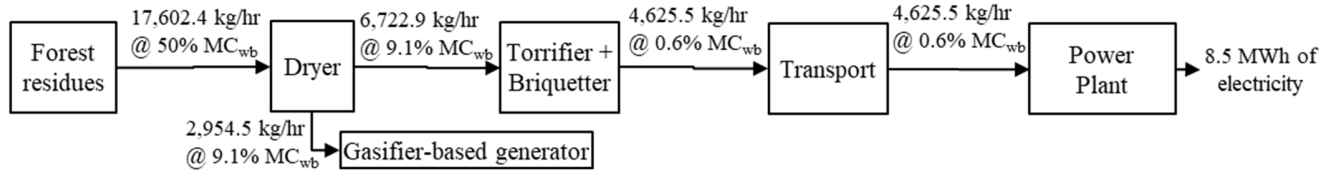
Figure S2: Mass balances of cases studies for heat generation from torrefied wood briquettes (TWB)



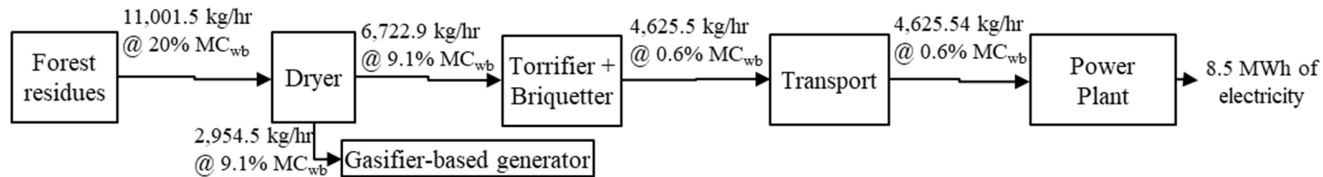
Case 1 (base case): Near-woods operation with wood gasifier power



Case 4: in-town operation (4-h travel distance) with grid power



Case 5: 50% moisture content feedstock, near-woods operation with wood gasifier power



Case 6: Near-woods operation with wood gasifier power with pile-and-burn credit

Figure S3: Mass balances of case studies for electricity from torrefied wood briquettes (TWB)

Table S1: Cradle-to-gate input-output flow analysis for one bone-dry metric ton of wood chips [1]

Feedstock Procurement			Feedstock Preparation		
	Units	Value			
<i>Processing</i>			<i>Chipper</i>		
Diesel	L	1.0115	Diesel	L	0.5461
Lubricants	L	0.0182	Lubricants	L	0.0098
<i>Sorting</i>			<i>Screener</i>		
Diesel	L	0.346	Diesel	L	1.5939
Lubricants	L	0.006	Lubricants	L	0.0287
<i>Loading</i>			<i>Dryer</i>		
Diesel	L	0.708	Electricity	kWh	7.14
Lubricants	L	0.013	Propane	L	20.9
VOC	g	8.54	VOC	g	2.13
<i>Hauling</i>	km	18.77	Torgas	m ³	212
			Waste heat	MJ	391

Table S2: Input-output flows of non-torrefied briquette (NTB) and torrefied briquette (TOB) production and use^a[1]

<i>Torrefaction Inputs</i>	Units	TOB	
Dry wood chip	kg db/MJ torrefied chips	0.063	
Lubricants	ml/MJ torrefied chips	0.002	
Electricity	kWh/MJ torrefied chips	0.019	
NaOH	gr/MJ torrefied chips	0.667	
<i>Torrefaction Outputs</i>			
Bio-oil	L/MJ torrefied chips	0.011	
Torgas	m ³ /MJ torrefied chips	0.043	
Briquetter		TOB	NTB
Electricity	kWh/MJ TOB	0.0037	0.0039
Lubricants	ml/MJ TOB	0.0002	0.0002
<i>Packaging</i>		TOB	NTB
LDPE packaging	gr/BDT	0.632	0.686
Distribution to user	km	90	90

Distribution to PP	km	211	211
Grinding	Wh/MJ briquette	5.393	17.989
<i>Combustion at stove (Use phase)</i>	Units	TOB	NTB
CO	gr/MJ briquette	3.4756	5.0638
NO _x	gr/MJ briquette	0.0277	0.0375
SO ₂	gr/MJ briquette	0.0079	0.0073
CH ₄	gr/MJ briquette	0.0023	0.0039
VOC	gr/MJ briquette	0.7295	0.7638
PM _{2.5}	gr/MJ briquette	0.0143	0.0354
PM ₁₀	gr/MJ briquette	0.1036	0.2175
CO ₂ (biogenic)	gr/MJ briquette	76.873	85.43
<i>Combustion at power plant (Use phase)</i>	Units	TOB	
CH ₄	gr/MJ briquette	0.0003	
N ₂ O	gr/MJ briquette	0.0021	
CO	gr/MJ briquette	0.0021	
VOC	gr/MJ briquette	0.0013	
NO _x	gr/MJ briquette	0.0751	
SO ₂	gr/MJ briquette	0.0161	
CO ₂ biogenic	gr/MJ briquette	72.87	
PM _{2.5}	gr/MJ briquette	0.059	
PM ₁₀	gr/MJ briquette	0.2	

^a LDPE, low-density polyethylene; BDT, bone-dry ton; VOC, volatile organic compounds; PM, particulate matter.

Table S3: Capital cost and operating costs of WB and TWB production systems for six scenarios [2].

WB system	Case 1 (Base case)	Case 2	Case 3	Case 4	Case 5	Case 6
Capital cost (\$)	390,000	364,694	315,000	315,000	390,000	390,000
Feedstock cost (\$/ODMT)	17.36	17.36	25.19	41.17	17.36	17.36
Operational cost (\$/year)	273,312	324,365	409,735	453,961	525,225	273,312
Product transport (\$/DOMT)	15.16	15.16	-	-	15.16	15.16
TWB system	Case 1 (Base case)	Case 2	Case 3	Case 4	Case 5	Case 6
Capital cost (\$)	960,000	921,375	810,000	810,000	960,000	960,000
Feedstock cost (\$/ODMT)	26.36	26.36	34.19	50.17	31.40	26.36
Operational cost (\$/year)	427,349	561,401	394,834	439,874	483,468	427,349
Product transport (\$/DOMT)	14.21	14.21	-	-	14.21	14.21

Table S4: Summary of inputs for TEA study with uncertainty distributions.

Descriptions	Minimum	Base	Maximum	Distribution	Source
Discount rate	10%	15%	20%	Triangular	[2,3]
Loan financing	0%	50%	100%	Triangular	[2,3]
Economic life	5	10	15	Triangular	[2,3]
Operating hour	8	16	24	Triangular	[2,3]
Operating days	240	300	360	Triangular	[2,3]
Capital investment	-20%	Scenario-specific	20%	Triangular	[2,3]
Fixed OPEX	-20%	Scenario-specific	20%	Triangular	[2,3]
Feedstock price	-20%	Scenario-specific	20%	Triangular	[4]
Products transport cost	-20%	Scenario-specific	20%	Triangular	Primary data
Propane cost (\$/liter)	-20%	0.59	20%	Triangular	[5]
Labor costs (\$/hr)	-20%	Scenario-specific	20%	Triangular	[2]
Torrefaction conversion rate	-15%	Scenario-specific	15%	Triangular	Primary data
Feedstock moisture content	15%	Scenario-specific	50%	Triangular	Primary data

Table S5: Environmental impacts of 1 MJ of heat generated for domestic heating from WB.

Impact category	Unit	Feedstock procurement	Hauling	Feedstock preparation	Briquetter	Packaging	Distribution	Use
Ozone depletion	kg CFC-11 eq	1.11E-12	2.22E-13	1.33E-11	1.75E-13	1.08E-15	1.10E-12	0.00E+00
Global warming	kg CO ₂ eq	6.08E-04	1.99E-04	7.58E-03	9.93E-05	1.08E-07	6.61E-04	1.24E-04
Smog	kg O ₃ eq	4.86E-04	3.21E-05	7.82E-04	1.01E-04	3.06E-09	1.05E-04	1.70E-03
Acidification	kg SO ₂ eq	8.00E-06	1.05E-06	2.80E-05	3.64E-06	2.29E-10	3.65E-06	4.67E-05
Eutrophication	kg N eq	6.14E-07	8.72E-08	3.13E-06	2.19E-07	7.69E-10	3.38E-07	2.34E-06
Carcinogenics	CTUh	1.01E-11	2.01E-12	1.20E-10	1.59E-12	1.42E-15	1.00E-11	0.00E+00
Non carcinogenics	CTUh	9.93E-11	1.98E-11	1.19E-09	1.56E-11	3.86E-14	9.87E-11	0.00E+00
Respiratory effects	kg PM _{2.5} eq	1.58E-07	1.62E-08	5.24E-07	1.11E-07	9.19E-12	5.63E-08	5.21E-05
Ecotoxicity	CTUe	2.54E-03	5.08E-04	3.04E-02	4.00E-04	4.51E-06	2.53E-03	0.00E+00
Fossil fuel depletion	MJ surplus	1.25E-03	2.49E-04	1.49E-02	1.96E-04	5.60E-07	1.24E-03	0.00E+00

Table S6: Environmental impacts of 1 MJ of heat generated for domestic heating from TWB.

Impact category	Unit	Feedstock procurement	Hauling	Feedstock preparation	Torrefaction	Briquetter	Distribution	Packaging	Use
Ozone depletion	kg CFC-11 eq	1.26E-12	2.51E-13	1.49E-11	1.46E-10	3.42E-13	8.17E-13	8.02E-16	0.00E+00
Global warming	kg CO ₂ eq	6.89E-04	2.26E-04	5.02E-03	9.82E-03	1.96E-04	4.89E-04	8.02E-08	7.57E-05
Smog	kg O ₃ eq	2.97E-04	3.64E-05	7.51E-04	1.46E-03	1.99E-04	7.75E-05	2.27E-09	4.61E-03
Acidification	kg SO ₂ eq	9.07E-06	1.20E-06	2.65E-05	5.87E-05	7.18E-06	2.70E-06	1.69E-10	3.59E-05
Eutrophication	kg N eq	6.96E-07	9.89E-08	2.63E-06	6.83E-06	4.30E-07	2.50E-07	5.70E-10	1.61E-06
Carcinogenics	CTUh	1.15E-11	2.28E-12	7.98E-11	1.63E-10	3.11E-12	7.41E-12	1.05E-15	0.00E+00
Non carcinogenics	CTUh	1.13E-10	2.25E-11	7.91E-10	1.70E-09	3.06E-11	7.31E-11	2.86E-14	0.00E+00
Respiratory effects	kg PM _{2.5} eq	1.79E-07	1.84E-08	5.31E-07	1.63E-06	2.18E-07	4.17E-08	6.81E-12	2.13E-05
Ecotoxicity	CTUe	2.88E-03	5.77E-04	2.00E-02	3.72E-02	7.83E-04	1.88E-03	3.34E-06	0.00E+00
Fossil fuel depletion	MJ surplus	1.41E-03	2.83E-04	9.80E-03	1.83E-02	3.84E-04	9.20E-04	4.15E-07	0.00E+00

Table S7: Environmental impacts of 1 kWh generated at coal-fired power plant from TWB.

Impact category	Unit	Feedstock procurement	Hauling	Feedstock preparation	Torrefaction	Briquetter	Distribution	Grinding	Use
Ozone depletion	kg CFC-11 eq	1.02E-11	2.03E-12	1.20E-10	1.18E-09	2.76E-12	1.54E-11	8.05E-10	0.00E+00
Global warming	kg CO ₂ eq	5.57E-03	1.82E-03	4.05E-02	7.93E-02	1.58E-03	9.25E-03	2.88E-02	6.01E-05
Smog	kg O ₃ eq	2.40E-03	2.94E-04	6.06E-03	1.18E-02	1.61E-03	1.46E-03	9.88E-04	1.97E-02
Acidification	kg SO ₂ eq	7.32E-05	9.65E-06	2.14E-04	4.74E-04	5.80E-05	5.11E-05	1.17E-04	7.25E-04
Eutrophication	kg N eq	5.62E-06	7.99E-07	2.12E-05	5.52E-05	3.47E-06	4.73E-06	6.21E-05	3.52E-05
Carcinogenics	CTUh	9.25E-11	1.84E-11	6.44E-10	1.32E-09	2.51E-11	1.40E-10	8.82E-10	0.00E+00
Non carcinogenics	CTUh	9.09E-10	1.82E-10	6.38E-09	1.37E-08	2.47E-10	1.38E-09	3.25E-09	0.00E+00
Respiratory effects	kg PM _{2.5} eq	1.45E-06	1.49E-07	4.29E-06	1.32E-05	1.76E-06	7.89E-07	6.95E-06	7.51E-05
Ecotoxicity	CTUe	2.33E-02	4.66E-03	1.61E-01	3.00E-01	6.32E-03	3.55E-02	7.59E-02	0.00E+00
Fossil fuel depletion	MJ surplus	1.14E-02	2.29E-03	7.91E-02	1.48E-01	3.10E-03	1.74E-02	3.35E-02	0.00E+00

References

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