

SUPPLEMENTARY INFORMATION

Quantifying the life cycle greenhouse gas emissions of a mechanized shelterwood harvest producing both sawtimber and woodchips

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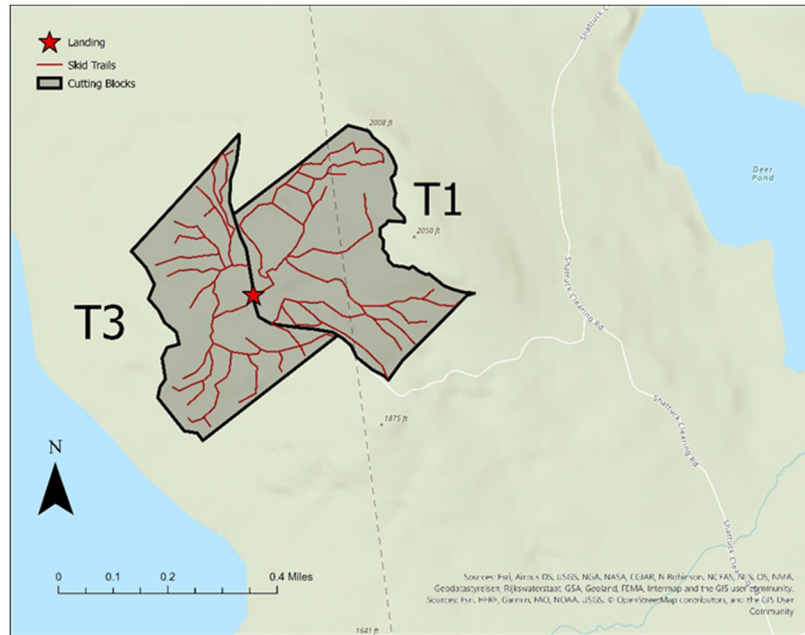


Figure S1. Harvesting blocks T1 and T3 with digitized skid trails and landing.

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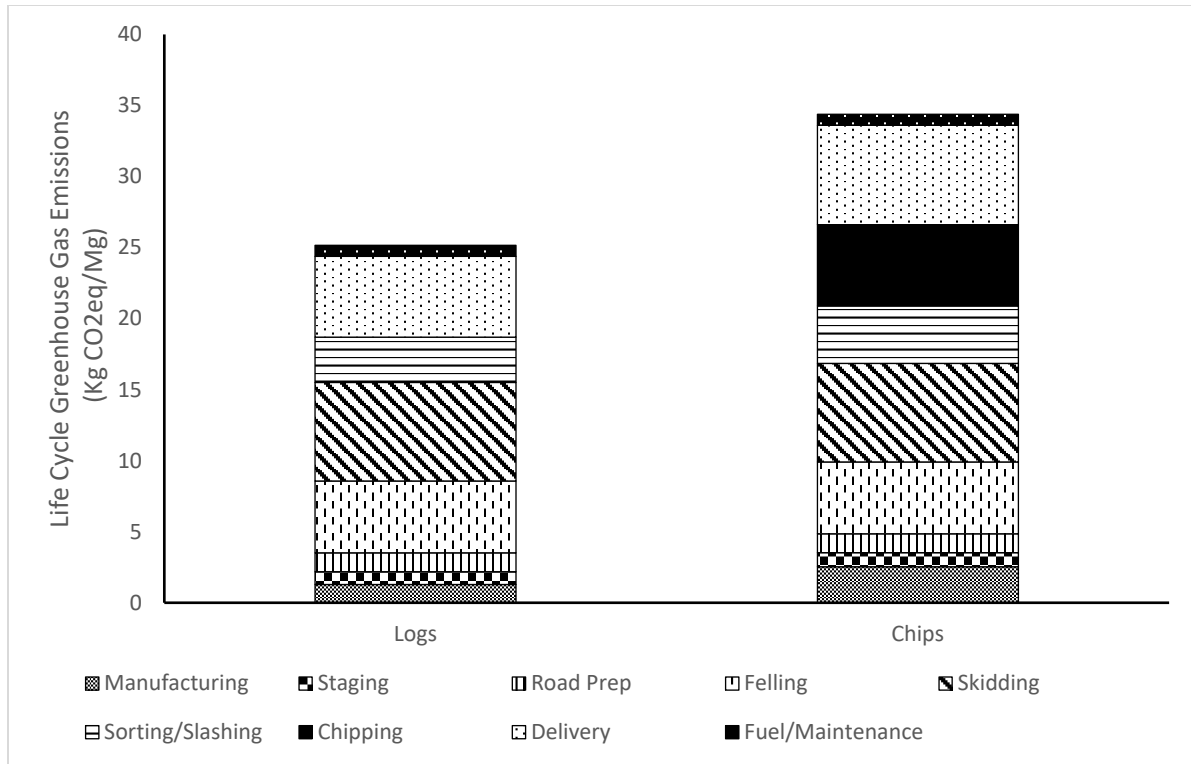


Figure S2. Life cycle greenhouse gas emissions of sawlogs and clean chips under the hypothetical scenario that both the paper mill and the sawmill are located 71 kilometers away from the landing.

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Table S1. Details of fuel, lubricant, and coolant consumption for all the machines

S3A-Fuel.

Machine	Average Fuel Rate (L/hour)	Hours	Fuel Consumption (L)
Feller-Buncher	33.69	139	4683
Feller-Buncher	32.93	153.17	5044
Skidder	27.44	184.65	5068
Skidder	22.33	152.42	3404
Skidder	19.87	170.88	3396
Skidder	24.61	81.75	2011
Loader	23.66	141.58	3350
Loader	23.66	172.48	4081
Bulldozer	20.28	28	568
Grader	17.10	27	462
Excavator	30.66	50	1533
Utility Truck	13.52	112	1514
	Fuel Rate (L/load)	Loads	
Flail Chipper	66.24	150	9936
	Fuel Rate (L/km)	km	
Tractor-Trailer	1.74	39645	68982

S3B- Lubricant

Machine	Oil Capacity (L)	Oil Consumption (L/hr)	Oil Consumption (kg/hr)	Hours	Oil Subtotal (kg)	Hydraulic Fluid (L)	Fluid Mass (kg)	Total Lubricant (kg)
Feller-buncher	26.5	0.106	0.092	153	14.2	75.7	66.6	80.8
Feller-buncher	22.7	0.091	0.079	139	11.0	75.7	66.6	77.6
Skidder	15.1	0.061	0.053	185	9.8	18.9	16.7	26.4
Skidder	18.9	0.076	0.066	152	10.1	18.9	16.7	26.7
Skidder	15.1	0.061	0.053	171	9.0	18.9	16.7	25.7
Skidder	18.9	0.076	0.066	82	5.4	18.9	16.7	22.1
Loader	18.9	0.076	0.066	142	9.4	75.7	66.6	76.0
Loader	18.9	0.076	0.066	172	11.4	75.7	66.6	78.0
Bulldozer	24.6	0.098	0.086	28	2.4	56.8	49.7	3.0
Grader	24.6	0.098	0.086	27	2.3	143.8	124.4	3.7
Excavator	26.5	0.106	0.092	50	4.6	246.1	215.4	8.9
Utility Truck	6.6	0.026	0.023	112	2.6			2.6
Flail Chipper	68.1	0.273	0.238	150	35.7	193.1	169.9	205.6
		Consumption (L/km)	Consumption (kg/km)	Km				
Tractor-Trailer	37.9	0.0029	0.0026	39645	101.7			101.7

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S3C- Coolant

Machine	Coolant Type	System Volume (L)	Antifreeze Volume (L)	Antifreeze (kg)	Ethylene Glycol (kg)	Diethylene Glycol (kg)	Mass for 5 Years (kg)	Mass for 1 Month (kg)	Total Mass
Feller-Buncher	extended life	37.85	18.93	21.50	18.92	0.86	19.78	0.21	0.41
Skidder	extended life	37.85	18.93	21.50	18.92	0.86	19.78	0.21	0.82
Loader	extended life	37.85	18.93	21.50	18.92	0.86	19.78	0.21	0.41
Bulldozer	green	37.85	18.93	21.34	20.48	0.00	20.48	0.21	0.21
Grader	green	45.42	22.71	25.60	24.58	0.00	24.58	0.26	0.26
Excavator	extended life	34.83	17.41	19.78	17.41	0.79	18.20	0.19	0.19
Utility Truck	extended life	4.73	2.37	2.69	2.37	0.11	2.47	0.03	0.03
Flail Chipper	extended life	49.21	24.61	27.95	24.60	1.12	25.72	0.27	0.27
Tractor-Trailer	extended life	45.42	22.71	25.80	22.71	1.03	23.74	0.36	1.98

S3D- Grease

Machine	Tubes of Grease/Day	Days	USD of Grease
Feller-Buncher	1	30	67.50
Skidder	1	68	153.00
Loader	1	34	76.50
Bulldozer	1	4	9.00
Grader	1	3	6.75
Excavator	1	6	13.50
Utility Truck	0.14	14	4.50
Flail Chipper	1.2	19	51.30
Tractor-Trailer	0.14	168	54.05

S3E-Material Densities

Fluid	Density (kg/L at STP)
15w40 motor oil	0.8725
AW46 hydraulic fluid	0.88
30W motor oil	0.8754
10w30 (tractor fluid)	0.865
Ethylene glycol	1.11
Diethylene glycol	1.12

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Table S2. Summaries of material produced and all fuel, lubricant, coolant, grease and equipment used during a mechanized shelterwood harvest producing both sawtimber and woodchips.

Input Parameter names	Baseline value	Unit
Chips production	4894	Mg
Log production	527	Mg
Chipper staging coolant	0.02	kg
Chipper staging diesel fuel	79.2	L
Chipper staging grease	0.38	USD
Chipper staging oil	0.71	kg
Chip delivery coolant	2.0	kg
Chip delivery diesel fuel	10836	L
Chip delivery grease	45	USD
Chip delivery oil	97	kg
Chipper coolant	0.27	kg
Bulldozer coolant	0.2	kg
Excavator coolant	0.19	kg
Feller-buncher coolant	0.41	kg
Fuel/maintenance coolant	0.03	kg
Grader coolant	0.3	kg
Skidder coolant	0.824	kg
Slashing/loading logs coolant	0.033	kg
Sort/slash and chipping coolant	0.38	kg
Diesel fuel – chipper *	4968	L
Diesel fuel – bulldozer *	284	L
Diesel fuel – excavator *	766.5	L
Diesel fuel - feller buncher *	4864	L
Diesel fuel – fuel/maintenance *	757.1	L
Diesel fuel – grader *	231	L
Diesel fuel – skidder *	6694	L
Diesel fuel – sorting/loading logs *	297.3	L
Diesel fuel – sort/slash and chipping *	3502	L
Chipper grease	51	USD
Bulldozer grease	9	USD
Excavator grease	13.5	USD
Feller-buncher grease	68	USD
Fuel/maintenance grease	4.5	USD
Grader grease	6.75	USD
Skidder grease	153	USD
Slashing/loading logs grease	6.3	USD
Sort/slash and chipping grease	72.45	USD
Chipper hours	171	hrs
Bulldozer hours	28	hrs
Excavator hours	50	hrs
Feller-buncher hours	292	hrs
Fuel/maintenance hours	112	hrs
Grader hours	27	hrs
Skidder hours	565	hrs
Slashing/loading logs hours	26	hrs

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Sort/slash chipping hours	296.1	hrs
Lifetime hours chipper	15000	hrs
Lifetime hours bulldozer	5000	hrs
Lifetime hours excavator	5000	hrs
Lifetime hours feller-buncher	15000	hrs
Lifetime hours grader	5000	hrs
Lifetime hours loader	15000	hrs
Lifetime hours skidder	15000	hrs
Lifetime hours maintenance truck	321869	hrs
Lifetime trailer	15800000	Mgkm
Lifetime truck	15800000	Mgkm
Coolant – log delivery	0.18	kg
Diesel – log delivery	536	L
Grease – log delivery	4.5	USD
Engine oil – log delivery	4.8	kg
Lubricant – chipper	190	kg
Lubricant – bulldozer	3.0	kg
Lubricant - excavator	8.9	kg
Lubricant - feller buncher	158	kg
Lubricant – fuel/maintenance	2.6	kg
Lubricant – grader	3.7	kg
Lubricant - skidder	58	kg
Lubricant – sorting/loading logs	12.4	kg
Lubricant – sort/slash and chipping	142	kg
Mass 4 wheeled skidder	21865	kg
Mass 6 wheeled skidder	24720	kg
Chipper mass	45631	kg
Bulldozer mass	19208	kg
Excavator mass	30900	kg
Feller buncher mass	36775	kg
Grader mass	18634	kg
Loader mass	26445	kg
Mass maintenance truck	4309	kg
Mass trailer	5075	kg
Mass truck	6033	kg
Chips transportation	675363	Mgkm
Log transportation	37945	Mgkm
Staging coolant	0.2	kg
Staging diesel	871.4	L
Staging grease	4.1	USD
Staging oil	7.8	kg

* The logger used a 50% mixture of diesel and kerosene fuel. Therefore, the volume of diesel fuel reported here for each machine type represents half the total fuel that was consumed.

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Table S3. Sensitivity analysis results of the life cycle greenhouse gas emissions (kg CO₂eq/Mg) of wood chips when varying the input parameters by a given percentage from their baseline values.

Variable input parameters	Life cycle GHG emissions (kg CO ₂ /Mg chips)						
	-25%	10%	5%	0%	5%2	10%	25%
Chip delivery diesel fuel	38.27	39.17	39.47	39.77	40.07	40.38	41.28
Diesel fuel – skidder	38.93	39.44	39.61	39.77	39.94	40.11	40.61
Diesel fuel – chipper	39.08	39.50	39.64	39.77	39.91	40.05	40.46
Diesel fuel – feller buncher	39.16	39.53	39.65	39.77	39.90	40.02	40.38
Diesel fuel – sort/slash and chipping	39.29	39.58	39.68	39.77	39.87	39.97	40.26
Chips transportation	39.60	39.71	39.74	39.77	39.81	39.84	39.94
Lifetime hours chipper	39.97	39.84	39.80	39.77	39.75	39.72	39.66
Chipper hours	39.63	39.72	39.74	39.77	39.80	39.83	39.92
Lifetime hours skidder	39.93	39.83	39.80	39.77	39.75	39.73	39.68
Skidder hours	39.66	39.73	39.75	39.77	39.80	39.82	39.89
Staging coolant	39.66	39.73	39.75	39.77	39.80	39.82	39.88
Lifetime hours feller-buncher	39.91	39.82	39.79	39.77	39.75	39.74	39.69
Feller-buncher hours	39.67	39.73	39.75	39.77	39.79	39.81	39.87
Lifetime truck	39.90	39.82	39.79	39.77	39.76	39.74	39.70
Diesel fuel – excavator	39.68	39.74	39.75	39.77	39.79	39.81	39.87
Diesel fuel – fuel/maintenance	39.68	39.74	39.75	39.77	39.79	39.81	39.87
Lifetime trailer	39.88	39.81	39.79	39.77	39.76	39.75	39.71
Mass trailler	39.70	39.74	39.76	39.77	39.79	39.80	39.85
Lifetime hours loader	39.83	39.79	39.78	39.77	39.77	39.76	39.74
Sort/slash chipping hours	39.73	39.76	39.76	39.77	39.78	39.79	39.82
Diesel fuel – bulldozer	39.74	39.76	39.77	39.77	39.78	39.79	39.81
Diesel fuel – grader	39.74	39.76	39.77	39.77	39.78	39.79	39.80
Lifetime hours excavator	39.81	39.78	39.78	39.77	39.77	39.76	39.75
Loader mass	39.81	39.78	39.78	39.77	39.77	39.76	39.75
Excavator hours	39.75	39.76	39.77	39.77	39.78	39.78	39.80
Excavator mass	39.75	39.76	39.77	39.77	39.78	39.78	39.80
Lifetime hours bulldozer	39.79	39.78	39.78	39.77	39.77	39.77	39.76
Mass 4 wheeled skidder	39.79	39.78	39.78	39.77	39.77	39.77	39.76
Bulldozer hours	39.76	39.77	39.77	39.77	39.78	39.78	39.79
Bulldozer mass	39.76	39.77	39.77	39.77	39.78	39.78	39.79
Chipper staging diesel fuel	39.76	39.77	39.77	39.77	39.78	39.78	39.78
Lubricant – chipper	39.76	39.77	39.77	39.77	39.78	39.78	39.78
Lifetime hours maintenance truck	39.79	39.78	39.78	39.77	39.77	39.77	39.77
Mass truck	39.79	39.78	39.78	39.77	39.77	39.77	39.77
Mass maintenance truck	39.76	39.77	39.77	39.77	39.78	39.78	39.78
Lifetime hours grader	39.79	39.78	39.78	39.77	39.77	39.77	39.77
Mass 6 wheeled skidder	39.79	39.78	39.78	39.77	39.77	39.77	39.77
Skidder grease	39.76	39.77	39.77	39.77	39.78	39.78	39.78
Grader hours	39.77	39.77	39.77	39.77	39.78	39.78	39.78
Grader mass	39.77	39.77	39.77	39.77	39.78	39.78	39.78
Lubricant - feller buncher	39.77	39.77	39.77	39.77	39.78	39.78	39.78

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Lubricant – sort/slash and chipping	39.77	39.77	39.77	39.77	39.78	39.78	39.78
Chip delivery oil	39.77	39.77	39.77	39.77	39.77	39.78	39.78
Sort/slash and chipping grease	39.77	39.77	39.77	39.77	39.77	39.78	39.78
Feller-buncher grease	39.77	39.77	39.77	39.77	39.77	39.78	39.78
Chipper grease	39.77	39.77	39.77	39.77	39.77	39.78	39.78
Chip delivery grease	39.77	39.77	39.77	39.77	39.77	39.77	39.78
Lubricant - skidder	39.77	39.77	39.77	39.77	39.77	39.77	39.78
Excavator grease	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Bulldozer grease	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Lubricant - excavator	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Grader grease	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Staging oil	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Chip delivery coolant	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Fuel/maintenance grease	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Staging diesel	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Lubricant – grader	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Lubricant – bulldozer	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Lubricant – fuel/maintenance	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Skidder coolant	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Sort/slash and chipping coolant	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Feller-buncher coolant	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Chipper staging oil	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Chipper coolant	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Grader coolant	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Bulldozer coolant	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Chipper staging grease	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Excavator coolant	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Log transportation	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Fuel/maintenance coolant	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Chipper staging coolant	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Slashing/loading logs coolant	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Diesel fuel – sorting/loading logs	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Slashing/loading logs grease	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Fuel/maintenance hours	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Slashing/loading logs hours	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Coolant – log delivery	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Diesel – log delivery	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Grease – log delivery	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Engine oil – log delivery	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Lubricant – sorting/loading logs	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Chipper mass	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Feller buncher mass	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Staging grease	39.77	39.77	39.77	39.77	39.77	39.77	39.77
Mass fraction - chips	39.85	39.85	39.85	39.77	39.67	39.67	39.67

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Table S4. Sensitivity analysis results of the life cycle greenhouse gas emissions (kg CO₂eq/Mg)

of logs when varying the input parameters by a given percentage from their baseline values.

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Lubricant - excavator	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Grader grease	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Staging oil	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Fuel/maintenance grease	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Staging diesel	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Coolant – log delivery	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Lubricant – grader	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Lubricant – bulldozer	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Lubricant – fuel/maintenance	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Skidder coolant	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Feller-buncher coolant	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Slashing/loading logs coolant	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Grader coolant	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Bulldozer coolant	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Excavator coolant	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Log transportation	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Fuel/maintenance coolant	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chipper staging coolant	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chipper staging diesel fuel	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chipper staging grease	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chipper staging oil	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chip delivery coolant	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chip delivery diesel fuel	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chip delivery grease	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chip delivery oil	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chipper coolant	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Sort/slash and chipping coolant	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Diesel fuel–sort/slash and chipping	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chipper grease	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Sort/slash and chipping grease	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chipper hours	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Fuel/maintenance hours	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Sort/slash chipping hours	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Lifetime hours chipper	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Lubricant – chipper	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Lubricant – sort/slash and chipping	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chipper mass	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Feller buncher mass	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Chips transportation	25.15	25.15	25.15	25.15	25.15	25.15	25.15
Mass fraction - logs	24.42	24.42	24.42	25.15	26.05	26.05	26.05