

Supplementary material for

“Considering Grouped or Individual NMVOC Emissions in Life Cycle assessment of composting
using three LCIA methods

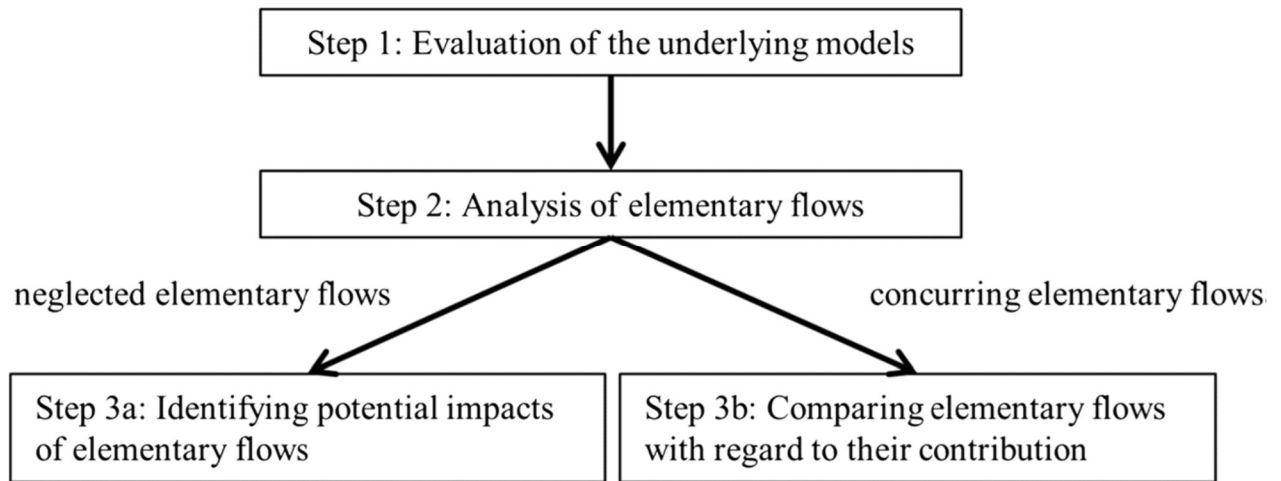


Figure S1: Overview of the three-step approach to evaluate LCIA methods developed by Bach und Finkbeiner (2017)

Table S1: Characterisation factor used for by the LCIA methods for individual NMVOCs for the impact categories ozone formation and freshwater ecotoxicity

	Ozone formation				Freshwater ecotoxicity				
	ReCiPe		EF 3.0	IMPACT+	ReCiPe	EF 3.0		IMPACT+	
	kg NOx eq.		kg NMVOC eq.		kg 1,4 DCB	kg CTUe	kg 1,4 DCB	kg CTUe	kg 1,4 DCB
Styrene	1.8E-02	-2.0E-02	2.4E-01	2.4E-01	5.4E-06	1.6E-02	3.46E-03	1.6E-02	4.2E-03
2-Pentanone	-3.6E-03	1.4E+00	9.3E-01	n.a	5.6E-05	5.8E-02	1.30E-02	5.0E-02	1.3E-02
Alpha-pinene	2.5E-01	6.7E-01	n.a	n.a	2.6E-08	2.9E-04	6.38E-05	7.3E-04	2.0E-04
Beta-pinene	1.2E-01	1.4E+00	n.a	n.a	2.5E-06	1.9E-02	4.31E-03	2.9E-02	7.6E-03
Limonene	n.a	n.a	n.a	n.a	6.3E-02	2.3E-03	2.16E-04	4.1E-03	5.4E-04
Dimethyl disulfide	n.a	n.a	n.a	n.a	n.a	7.3E-01*	0.00E+00	n.a	0.0E+00
Pyridine	n.a	n.a	n.a	n.a	3.8E-03	4.0E+00	8.86E-01	2.6E+00	6.8E-01
Toluene	1.6E-01	1.7E+00	1.1E+00	1.1E+00	1.5E-05	1.3E-02	2.86E-03	1.1E-02	3.0E-03
Xylene	3.1E-01	7.3E-01	n.a	n.a	8.2E-06	1.1E-02	4.13E-03	1.0E-02	4.8E-03
Decane	1.3E-01	8.9E-01	6.5E-01	6.5E-01	5.6E-07	2.0E-03	4.38E-04	4.7E-03	1.2E-03
Grouped NMVOC	1.8E-01	1	1	1	n.a	8.609	n.a	n.a	n.a

Table S2: Characterisation factor used for by the LCIA methods for individual NMVOCs for the impact categories ozone formation and freshwater ecotoxicity

	Human toxicity, Carcinogenic			Human toxicity, Non-carcinogenic		
	ReCiPe	EF 3.0	IMPACT+	ReCiPe	EF 3.0	IMPACT+
	kg 1,4-DCB	CTUh	CTUh	kg 1,4-DCB	CTUh	CTUh
Styrene	1.3E+00	5.1E-07	5.1E-07	8.6E-01	1.0E-07	1.0E-07
2-Pentanone	n.a	n.a	n.a	n.a	n.a	n.a
Alpha-pinene	n.a	n.a	n.a	n.a	n.a	n.a
Beta-pinene	n.a	n.a	n.a	n.a	n.a	n.a
Limonene	6.3E-02	4.3E-08	4.3E-08	n.a	n.a	n.a
Dimethyl disulfide	n.a	n.a	n.a	n.a	n.a	n.a
Pyridine	7.5E+00	1.8E-06	1.6E-06	7.7E+01	5.6E-06	4.7E-06
Toluene	1.3E-02	3.2E-12	4.6E-12	8.6E-01	5.3E-08	5.1E-08
Xylene	2.0E-02	4.8E-09	4.7E-09	1.6E+00	1.1E-07	1.1E-07
Decane	n.a	n.a	n.a	n.a	n.a	n.a
Grouped NMVOC	n.a	n.a	n.a	n.a	6.22E-08	n.a

Table S3: List of LCA studies investigating VOC emissions from composting processes.

	VOCs	Material composted	Impacts covered	MP-EP	Location	Measured?	Bio-filter	Type of composting	Scale	Composting stages	Compost LCA study	Composting time	LCIA method
(Cadena et al. 2009)	Grouped	MSW	CO ₂ , VOC, NH ₃	-	Spain	Yes	Yes	Intensive - Closed aeration, biofilter Open windrow		Intensive, Maturation	Partially	2 weeks Intensive 6-8 weeks Mature	
(Cadena et al. 2009)	Grouped	MSW	CC, AP, POF, EP, HAT, ODP	MP	Spain	Yes	Yes		6,000 t OFMSW /year	Intensive, Maturation		4 weeks Intensive 6-8 weeks Mature	CML
(Quirós et al. 2014)	Grouped	MSW	CC, AP, POF, EP, ODP, CED	MP	Spain	No	No		Pilot-home composting		Yes		CML
(Colón et al. 2012)	Grouped	MSW	CC, AP, POF, ODP, CED, HT, ADP	MP	Spain	Yes	Yes	In-vessel composting	7435t /year	Decomposition phase, Curing	Yes		CML
(Al-Rumaihi et al. 2020)	Grouped	MSW			Qatar	No							
(Martínez-Blanco et al. 2010)	Grouped	MSW	CC, AP, POF, ODP, CED, EP, ADP	MP	Spain	Yes	Yes		Industrial	Decomposition phase, Curing			
(Colón et al. 2009)	Grouped	MSW	CC, AP, POF, ODP, CED, EP, ADP	MP	Spain	Yes			Home				

Table S4: List of LCA studies investigating individual NMVOC emissions arising from composting. The individual VOC numbers are elaborated in Table S5.

	VOCs	Material composted	Impacts covered	Location	Measured emissions	Biofilter	Filtration efficiency	Type of composting	Scale	Composting stages	Composting time	Compost Emission study	Compost LCA study
(Sánchez-Monedero et al. 2018)	1-31	MSW	None	Spain	Yes	No		Open composting	40000 t/year 30m*2m height	Intensive+ Maturation	Week 1,2,3 and 8	Yes	
(Nie et al. 2018)	1,2,5,6,10,24,26, 30, 32-67	MSW	Human health risk-Non-carcinogenic, Carcinogenic	China	Yes	No		n.d	2000 t/d	Tipping, Intensive, Maturation	Intensive 2 Weeks Maturation 3 Weeks	Yes	
(Maulini-Duran et al. 2014)	5, 7, 17, 24, 26, 27, 30, 37, 44, 68	MSW	None	Spain	Yes	No		n.d	pilot scale- 100 kg	Intensive composting	Total 25 days	Yes	
Kumar et al., 2011 (Colón et al. 2009)			ADP, AP, EP, GWP, ODP, POP, CED						home composting				Yes
(Pagans et al. 2006)	Grouped VOCs	MSW		Spain	Yes	Yes	0-60%		Lab scale, 30l		6 days	Yes	
(Komilis et al. 2004)	5, 7, 43, 44, 46, 47, 67, 69, 70, 71, 72, 73	mixed waste including paper, food waste	None	Greece	Yes	No			Lab-scale 25l		47 days	Yes	

(Saldarria et al. 2014)	Grouped VOCs	MSW	Human health	Colombia	Yes	No	1300 kg/batch			
(Lehtinen et al. 2013)	1, 8, 10, 24, 26, 37, 40, 43, 45, 86-96	MSW	Human health	Finland	Yes	No	Composting plant	Sorting and Separation stage	Yes	
(Delgado-Rodríguez et al. 2012)	1, 5, 16, 24, 27, 30, 52, 75	MSW		Spain	Yes	No	Composting plant	Intensive composting	5 weeks	Yes
(Pierucci et al. 2005)	5, 24, 26, 45, 97, 98, 99	MSW		Italy	Yes	Yes	pilot plant	Intensive composting	1 week	Yes
(Tsai et al. 2008)	5, 7, 8, 24, 26, 27, 39, 40, 43, 44, 45, 52, 89, 100-103	MSW		Taiwan	Yes	No	Composting plant			Yes
(Mao et al. 2006)	5, 7, 40, 42 -45, 100-104	MSW		Taiwan	Yes	Yes	Composting plant- 20 -30 tonne/day		20 to 30 days	Yes

Table S5: List of NMVOC emissions arising from composting of MSW

	(Sánchez-Monedero et al. 2018)	(Nie et al. 2018)	(Maulini-Duran et al. 2014)	(Komilis et al. 2004)	(Lehtinen et al. 2013)	(Delgado-Rodríguez et al. 2012)	(Pierucci et al. 2005)	(Tsai et al. 2008)	(Mao et al. 2006)	Number of studies investigating the NMVOC
1	Undecane	Undecane			Undecane	Undecane				4
2	Dodecane	Dodecane								2
3	Tridecane									1
4	Tetradecane									1
5	Toluene	Toluene	Toluene	Toluene		Toluene	Toluene	Toluene	Toluene	8

6	1,2,3-Trimethyl benzene	1,2,3-trimethyl-Benzene							2
7	Styrene		Styrene	Styrene			Styrene	Styrene	5
8	p-Cymene				p-Cymene		p-Cymene		3
9	o-Isopropeniltoluene								1
10	Ethanol	Ethanol			Ethanol				3
11	1-Butanol								1
12	1-Pentanol								1
13	1-Hexanol								1
14	2-Ethyl-1-hexanol								1
15	4-Methyl phenol								1
16	Phenol				Phenol				2
17	2-Pentanone		2-Pentanone						2
18	2-Heptanone								1
19	Ethanoic acid/Acetic								1
20	Propanoic acid								1
21	2-Methyl propanic acid								1
22	Butanoic acid								1
23	Hexanoic acid								1
24	D-Limonene	Limonene	Limonene		Limonene	Limonene	Limonene	Limonene	7
25	Beta-Myrcene								1
26	Alpha-Pinene	Alpha-Pinene	Alpha-Pinene		Alpha-Pinene		Alpha-Pinene	Alpha-Pinene	6
27	Beta-Pinene		Beta-Pinene			Beta-Pinene		Beta-Pinene	4
28	Pyrazine								1

29	Trimethyl- pyrazine								1
30	Dimethyl disulfide	Dimethyl disulfide	Dimethyl disulfide			Dimethyl disulfide			4
31	2-Pentyl furan								1
32		Butane							1
33		Pentane							1
34		Cyclopentan e							1
35		Heptane							1
36		Octane							1
37		Decane	Decane		Decane				3
38		Propylene							1
39		Acetone					Acetone	Acetone	3
40		Ethyl acetate			Ethyl acetate		Ethyl acetate	Ethyl acetate	4
41		2-Hexanone							1
42		Benzene						Benzene	2
43		Ethylbenzen e		Ethylbenzen e	Ethylbenzen e		Ethylbenze ne	Ethylbenz ene	5
44		m+p-Xylenes	Xylene	p/m-Xylene			m,o- xylene	o- xylene	5
45		o-Xylene			p-xylene	p-xylene	p-xylene	p-xylene	5
46		1,3,5- trimethyl- Benzene		1,3,5- trimethyl- Benzene					2
47		1,2,4- trimethyl- Benzene		1,2,4- trimethyl- Benzene					2
48		m- Diethylbenze ne							2

49	p-Diethylbenzene				1
50	Styrene				1
51	Methanethiol				1
52	Dimethylsulfide	Dimethylsulfide	Dimethylsulfide		3
53	Carbon disulfide				2
54	Chloromethane				1
55	Methylene chloride				1
56	Chloroform				1
57	Carbon tetrachloride				1
58	Ethyl chloride				1
59	1,1-Dichloroethane				1
60	1,2-Dichloroethane				1
61	1,1,2-Trichloroethane				1
62	1,1-Dichloroethane				1
63	(E)-1,2-Dichloroethene				1
64	(Z)-1,2-Dichloroethene				1

65	1,3-Dichloro-Benzene			2
66	Chlorobenzene			2
67	1,4-Dichloro-Benzene	1,4-Dichloro-Benzene		2
68		Pyridine		1
69		Isopropylbenzene		1
70		n-Propylbenzene		1
71		p-Isopropyltoluene		1
72		n-Butylbenzene		1
73		Naphthalene		1
74				1
75			2-butanone	1
76				1
77				1
78				1
79				1
80				1
81				1

82			1
83			1
84			1
85			1
86	2- Propanol		1
87	2,3- Butanedione		1
88	3-Hydroxy-2- butanone		1
89	Acetic acid	Acetic acid	2
90	Propyl benzene		1
91	Nonane		1
92	4-Methyl nonane		1
93	2-Methyl nonane		1
94	3-methyl nonane		1
95	Trichloro ethene		1
96	Tetrachloro ethene		1
97		Trichloroeth ylene	1
98		Tetrachloroe thylene	1

99		Trimethylbenzene		1
100		Pentene	Pentene	2
101		Hexene	Hexene	2
102		Methylacetate	Methylacetate	2
103		Butanone	Butanone	2

Table S6: Amount of NMVOC compounds before and after biofiltration (kg/t compost produced)

	Pre-biofiltration	Elimination rate in Biofilter ¹	Post-biofiltration
Styrene	8.3E-04	90%	8.3E-05
2-Pentanone	2.8E-03	90%	2.8E-04
Alpha-pinene	2.8E-03	93%	2.0E-04
Beta-pinene	9.5E-04	97%	2.9E-05
Limonene	6.9E-02	25%	5.2E-02
Dimethyl disulfide	1.4E-01	74%	3.7E-02
Pyridine	8.2E-04	80%	1.6E-04
Toluene	5.1E-03	83%	8.6E-04
Xylene	1.4E-03	96%	5.5E-05
Decane	5.3E-03	93%	3.7E-04
Total VOC	2.3E-01		9.0E-02

1- The elimination rate was estimated from (Pagans et al. 2005) and (Liu et al. 2009)

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