

# Analysis of five-extraction technologies' environmental impact on the polyphenols production from *Moringa oleifera* leaves using the Life Cycle Assessment tool based on ISO 14040

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## Supplementary Material

**Table S1.** LCI of 1 g *Moringa oleifera* leaves production (8% moisture).

Outputs to technosphere: Products and co-products	Amount	Unit	Comments
<i>Moringa oleifera</i> leaves 8% moisture (DMPM)	1.00	g	100% allocation, no waste scenario
<b>INPUTS</b>			
<b>Inputs from nature</b>			
Water, unspecified natural origin, GR	32.90	mL	
<b>Inputs from technosphere: materials/fuels</b>			
Tap water {RoW}/ market for/ cut-off, S	1.00	g	
Diesel {GLO} / market group for / cut-off, S	$8.78 \times 10^{-4}$	Kg	
Polyvinylchloride, bulk polymerized {GLO} / market for / cut-off, S	$9.00 \times 10^{-5}$	Kg	
Polypropylene, granulate {GLO} / market for / cut-off, S	$8.00 \times 10^{-5}$	Kg	
Transport, freight, lorry 3.5–7.5 metric ton, euro 5 {RER} / market for transport, freight, lorry 3.5–7.5 metric ton, EURO5 / cut-off, S	$8.00 \times 10^{-4}$	tkm	
Transport, freight, lorry 3.5–7.5 metric ton, euro 5 {RER} / market for transport, freight, lorry 3.5–7.5 metric ton, EURO5 / cut-off, S	$1.00 \times 10^{-3}$	tkm	
<b>Inputs from technosphere: electricity/heat</b>			
Electricity, low voltage {GR} / market for / cut-off, S	$0.025 \times 10^{-2}$	KWh	
Electricity, low voltage {GR} / market for / cut-off, S	0.012	KWh	
<b>OUTPUTS</b>			
<b>Emissions to air</b>			
NO <sub>2</sub>	$5.82 \times 10^{-4}$	Kg	
CO <sub>2</sub>	$1.04 \times 10^{-4}$	Kg	
H <sub>2</sub> O	$9.55 \times 10^{-5}$	Kg	
O <sub>2</sub>	$7.81 \times 10^{-5}$	Kg	
CO	$8.68 \times 10^{-7}$	Kg	
CH <sub>4</sub>	$4.34 \times 10^{-7}$	Kg	
NO <sub>x</sub>	$4.34 \times 10^{-6}$	Kg	
Particulates, diesel soot	$2.60 \times 10^{-6}$	Kg	
SO <sub>2</sub>	$4.34 \times 10^{-7}$	Kg	

**Table S2.** LCI for the PEF (S1) extractor used.

Outputs to technosphere: Products and co-products	Amount	Unit	Comments
PEF (S1)	1	P	
<b>INPUTS</b>			
<b>Inputs from technosphere: materials/fuels</b>			
Chromium steel pipe {GLO} / market for / cut-off, S	6.05	Kg	
COPPER {GLO} / market for / cut-off, S	0.90	Kg	
Glass tube, borosilicate {GLO} / market for / cut-off, S	0.20	Kg	
Acrylonitrile-butadiene-styrene copolymer {GLO} / market for / cut-off, S	0.60	Kg	
Tetrafluoroethylene {GLO} / market for / cut-off, S	0.10	Kg	
Polyvinylchloride, bulk polymerized {GLO} / market for / cut-off, S	0.40	Kg	

**Table S3.** LCI for the Microwave (S2) extractor used.

Outputs to technosphere: Products and co-products	Amount	Unit	Comments
Microwave (S2)	1	P	
<b>INPUTS</b>			
<b>Inputs from technosphere: materials/fuels</b>			
Chromium steel pipe {GLO} / market for / cut-off, S	8.00	Kg	
COPPER {GLO} / market for / cut-off, S	1.00	Kg	
Glass tube, borosilicate {GLO} / market for / cut-off, S	0.05	Kg	
Acrylonitrile-butadiene-styrene copolymer {GLO} / market for / cut-off, S	1.00	Kg	

**Table S4.** LCI for the Ultrasound (S3) extractor used.

Outputs to technosphere: Products and co-products	Amount	Unit	Comments
Ultrasound (S3)	1	P	
<b>INPUTS</b>			
<b>Inputs from technosphere: materials/fuels</b>			
Chromium steel pipe {GLO} / market for / cut-off, S	4.40	Kg	
COPPER {GLO} / market for / cut-off, S	0.20	Kg	
Glass tube, borosilicate {GLO} / market for / cut-off, S	0.05	Kg	
Polyvinylchloride, bulk polymerized {GLO} / market for / cut-off, S	$3.04 \times 10^{-1}$	Kg	

**Table S5.** LCI for the Boiling Water (S4) extractor used.

Outputs to technosphere: Products and co-products	Amount	Unit	Comments
Boiling water (S4)	1	P	
<b>INPUTS</b>			
<b>Inputs from technosphere: materials/fuels</b>			
Chromium steel pipe {GLO} / market for / cut-off, S	1.95	Kg	
COPPER {GLO} / market for / cut-off, S	0.15	Kg	
Glass tube, borosilicate {GLO} / market for / cut-off, S	0.05	Kg	
Polyvinylchloride, bulk polymerized {GLO} / market for / cut-off, S	$2.21 \times 10^{-1}$	Kg	

**Table S6.** LCI for the Control (S5) extractor used.

Outputs to technosphere: Products and co-products	Amount	Unit	Comments
Control (S5)	1	P	
<b>INPUTS</b>			
<b>Inputs from technosphere: materials/fuels</b>			
Glass tube, borosilicate {GLO} / market for / cut-off, S	0.05	Kg	

**Table S7.** LCI for the production of 1 g of polyphenols using PEF (S1).

Outputs to technosphere: Products and co-products	Amount	Unit	Comments
PEF (S1) polyphenols	1.00	g	100% allocation, no waste scenario
<b>INPUTS</b>			
<b>Inputs from technosphere: materials/fuels/electricity</b>			
PEF (S1) extractor	$3.54 \times 10^{-4}$	P	
Tap water {Europe without Swiss} / market for / cut-off, S	749.00	g	
Electricity, low voltage {GR} / market for / cut-off, S	0.395	KWh	
<i>Moringa oleifera</i> leaves 8% moisture (DMPM)	27.00	g	
<b>OUTPUTS</b>			
<b>Emissions to air</b>			
Heat, waste	0	KJ	
<b>Final waste flows</b>			
Compost	236.50	g	

**Table S8.** LCI for the production of 1 g of polyphenols using Microwave (S2).

Outputs to technosphere: Products and co-products	Amount	Unit	Comments
Microwave (S2) polyphenols	1.00	g	100% allocation, no waste scenario
<b>INPUTS</b>			
<b>Inputs from technosphere: materials/fuels/electricity</b>			
Microwave (S2) extractor	$7.79 \times 10^{-5}$	P	
Tap water {Europe without Swiss} / market for / cut-off, S	914.00	g	
Electricity, low voltage {GR} / market for / cut-off, S	0.278	KWh	
<i>Moringa oleifera</i> leaves 8% moisture (DMPM)	29.70	g	
<b>OUTPUTS</b>			
<b>Emissions to air</b>			
Heat, waste	136.532	KJ	
<b>Final waste flows</b>			
Compost	350.36	g	

**Table S9.** LCI for the production of 1 g of polyphenols using Ultrasound (S3).

Outputs to technosphere: Products and co-products	Amount	Unit	Comments
Ultrasound (S3) polyphenols	1.00	g	100% allocation, no waste scenario
<b>INPUTS</b>			
<b>Inputs from technosphere: materials/fuels/electricity</b>			
Ultrasound (S3) extractor	$0.46 \times 10^{-3}$	P	
Tap water {Europe without Swiss} / market for / cut-off, S	$1.06 \times 10^3$	g	
Electricity, low voltage {GR} / market for / cut-off, S	3.740	KWh	
<i>Moringa oleifera</i> leaves 8% moisture (DMPM)	37.40	g	
<b>OUTPUTS</b>			
<b>Emissions to air</b>			
Heat, waste	34.431	KJ	
<b>Final waste flows</b>			
Compost	351.80	g	

**Table S10.** LCI for the production of 1 g of polyphenols using Boiling water (S4).

Outputs to technosphere: Products and co-products	Amount	Unit	Comments
Boiling water (S4) polyphenols	1.00	g	100% allocation, no waste scenario
<b>INPUTS</b>			
<b>Inputs from technosphere: materials/fuels/electricity</b>			
Boiling water (S4) extractor	$9.04 \times 10^{-5}$	P	
Tap water {Europe without Swiss} / market for / cut-off, S	$1.11 \times 10^3$	g	
Electricity, low voltage {GR} / market for / cut-off, S	2.070	KWh	
<i>Moringa oleifera</i> leaves 8% moisture (DMPM)	34.40	g	
<b>OUTPUTS</b>			
<b>Emissions to air</b>			
Heat, waste	181.377	KJ	
<b>Final waste flows</b>			
Compost	458.68	g	

**Table S11.** LCI for the production of 1 g of polyphenols using Maceration - Control (S5).

Outputs to technosphere: Products and co-products	Amount	Unit	Comments
Boiling water (S4) polyphenols	1.00	g	100% allocation, no waste scenario
<b>INPUTS</b>			
<b>Inputs from technosphere: materials/fuels/electricity</b>			
Control (S5) extractor	$1.03 \times 10^{-3}$	P	
Tap water {Europe without Swiss} / market for / cut-off, S	$1.08 \times 10^3$	g	
<i>Moringa oleifera</i> leaves 8% moisture (DMPM)	39.20	g	
<b>OUTPUTS</b>			
<b>Emissions to air</b>			
Heat, waste	0	KJ	
<b>Final waste flows</b>			
Compost	340.12	g	

**Table S12.** Process contribution for the system S5 (C) without sensitivity analysis.

<b>Product: 1 Kg control (S5) polyphenols (of project PEF)</b>								
<b>Method:</b> ReCiPe 2016 Endpoint (H) V1.03 / World (2010) H/A								
<b>Indicator:</b> Single score								
<b>Cut-off:</b> 0%								
<b>Default units:</b> No								
<b>Exclude infrastructure processes:</b> No								
<b>Exclude long-term emissions:</b> No								
<b>Sorted on item:</b> Total								
<b>Sort order:</b> Descending								
No	Process	Project	Unit	Total	Control (S5) polyphenols	Control (S5) extractor new	Tap water {Europe without Switzerland}   market for   Cut-off, S	Moringa leaves 8% moisture (DMPM)
	Total of all processes		Pt	57.255323	0	0.0061672	0.0724177	57.176738
1	Moringa leaves 8% moisture (DMPM)	PEF	Pt	27.883349	0	0	0	27.883349
2	Electricity, low voltage {GR}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	26.461639	0	0	0	26.461639
3	Transport, freight, lorry 3.5-7.5 metric ton, euro5 {RER}   market for transport, freight, lorry 3.5-7.5 metric ton, EURO5   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	1.2639092	0	0	0	1.2639092
4	Diesel {GLO}   market group for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	1.0952844	0	0	0	1.0952844
5	Polyvinylchloride, bulk polymerised {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.2640175	0	0	0	0.2640175
6	Polypropylene, granulate {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.2052454	0	0	0	0.2052454
7	Tap water {Europe without Switzerland}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.0724177	0	0	0.0724177	0
8	Glass tube, borosilicate {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.0061672	0	0.0061672	0	0
9	Tap water {RoW}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.0032941	0	0	0	0.0032941
10	Control (S5) polyphenols	PEF	Pt	0	0	0	0	0
11	Control (S5) extractor new	PEF	Pt	0	0	0	0	0

**Table S13.** Process contribution for the system S5 (C) with sensitivity analysis.

<b>Product:</b> 1 Kg control (S5) polyphenols (of project PEF with sensitivity analysis - electricity)								
<b>Method:</b> ReCiPe 2016 Endpoint (H) V1.03 / World (2010) H/A								
<b>Indicator:</b> Single score								
<b>Cut-off:</b> 0%								
<b>Default units:</b> No								
<b>Exclude infrastructure processes:</b> No								
<b>Exclude long-term emissions:</b> No								
<b>Sorted on item:</b> Total								
<b>Sort order:</b> Descending								
No	Process	Project	Unit	Total	Control (S5) polyphenols	Control (S5) extractor new	Tap water {Europe without Switzerland}   market for   Cut-off, S	Moringa leaves 8% moisture (DMPM)
	Total of all processes		Pt	32.986533	0	0.0061672	0.0724177	32.907948
1	Moringa leaves 8% moisture (DMPM)	PEF with sensitivity analysis (electricity)	Pt	27.883349	0	0	0	27.883349
2	Electricity, low voltage {GR}   electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	2.1928484	0	0	0	2.1928484
3	Transport, freight, lorry 3.5–7.5 metric ton, euro5 {RER}   market for transport, freight, lorry 3.5–7.5 metric ton, EURO5   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	1.2639092	0	0	0	1.2639092
4	Diesel {GLO}   market group for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	1.0952844	0	0	0	1.0952844
5	Polyvinylchloride, bulk polymerised {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.2640175	0	0	0	0.2640175
6	Polypropylene, granulate {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.2052454	0	0	0	0.2052454
7	Tap water {Europe without Switzerland}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.0724177	0	0	0.0724177	0
8	Glass tube, borosilicate {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.0061672	0	0.0061672	0	0
9	Tap water {RoW}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.0032941	0	0	0	0.0032941
10	Control (S5) polyphenols	PEF with sensitivity analysis (electricity)	Pt	0	0	0	0	0
11	Control (S5) extractor new	PEF with sensitivity analysis (electricity)	Pt	0	0	0	0	0

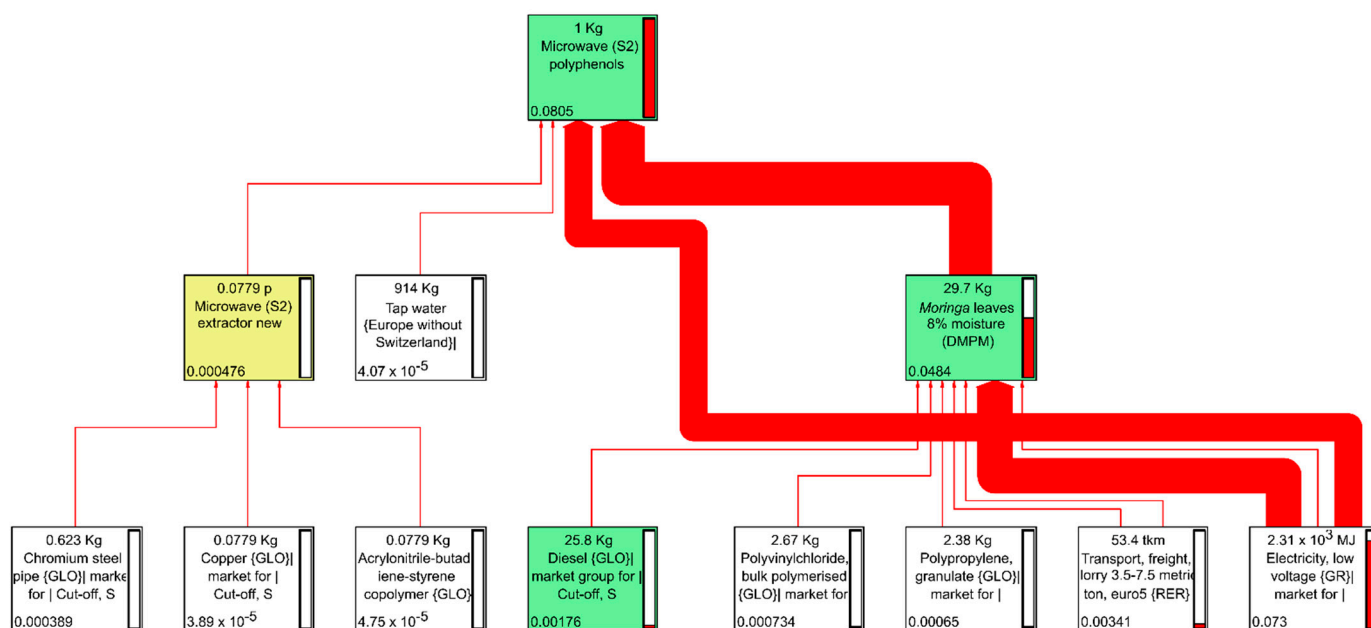


**Table S14.** Process contribution for the system S1 (PEF) with sensitivity analysis.

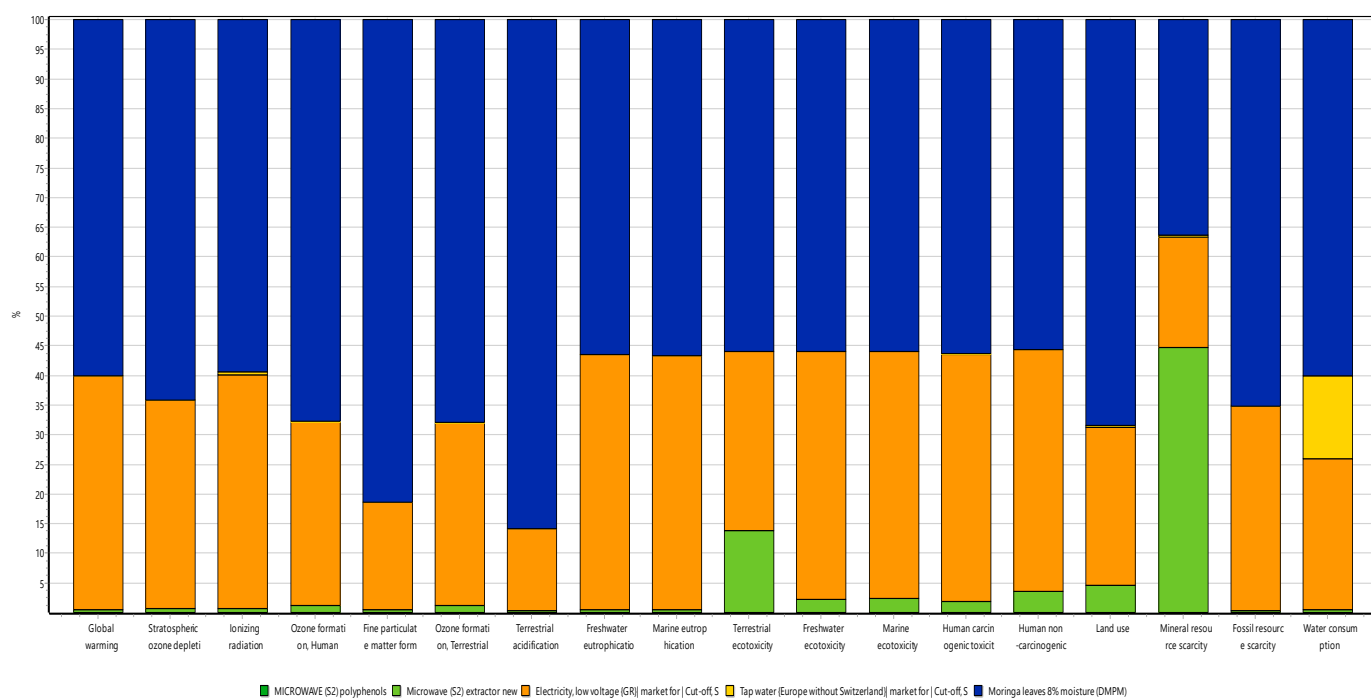
Calculation: Analysis of System 1 (PEF - Process contribution with sensitivity analysis)									
Results: Process contribution									
Product: 1 Kg PEF5 (S1) polyphenols (of project PEF with sensitivity analysis - electricity)									
Method: ReCiPe 2016 Endpoint (H) V1.03 / World (2010) H/A									
Indicator: Single score									
Cut-off: 0%									
Default units: No									
Exclude infrastructure processes: No									
Exclude long-term emissions: No									
Sorted on item: Total									
Sort order: Descending									
No	Process	Project	Unit	Total	PEF5 (S1) polyphenols	PEF5 (S1) extractor new	Tap water {Europe without Switzerland}   market for   Cut-off, S	Electricity, low voltage {GR}   electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted   Cut-off, S	Moringa leaves 8% moisture (DMPM)
1	Total of all processes		Pt	26.718349	0	2.1895459	0.0500391	1.8056109	22.673153
	Moringa leaves 8% moisture (DMPM)	PEF with sensitivity analysis (electricity)	Pt	19.211269	0	0	0	0	19.211269
2	Electricity, low voltage {GR}   electricity production, photovoltaic, 3 kWp slanted-roof installation, multi-Si, panel, mounted   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	3.3164553	0	0	0	1.8056109	1.5108444
3	Copper {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	1.1403451	0	1.1403451	0	0	0
4	Chromium steel pipe {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.90093169	0	0.9009317	0	0	0
5	Transport, freight, lorry 3.5–7.5 metric ton, euro5 {RER}   market for transport, freight, lorry 3.5–7.5 metric ton, EURO5   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.87081722	0	0	0	0	0.87081722
6	Diesel {GLO}   market group for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.75463687	0	0	0	0	0.75463687
7	Polyvinylchloride, bulk polymerised {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.19251444	0	0.0106098	0	0	0.18190466
8	Polypropylene, granulate {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.14141145	0	0	0	0	0.14141145
9	Tetrafluoroethylene {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.097681626	0	0.0976816	0	0	0
10	Tap water {Europe without Switzerland}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.05003908	0	0	0.0500391	0	0
11	Acrylonitrile-butadiene-styrene copolymer {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.031479473	0	0.0314795	0	0	0
12	Glass tube, borosilicate {GLO}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.008498254	0	0.0084983	0	0	0
13	Tap water {RoW}   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.002269603	0	0	0	0	0.002269603
14	PEF5 (S1) polyphenols	PEF with sensitivity analysis (electricity)	Pt	0	0	0	0	0	0
15	PEF5 (S1) extractor new	PEF with sensitivity analysis (electricity)	Pt	0	0	0	0	0	0

**Table S15.** Process contribution for the system S2 (MAE) with sensitivity analysis.

Calculation: Analysis of System 2 (Microwave - Process contribution with sensitivity analysis)									
Results: Process contribution									
Product: 1 Kg Microwave (S2) polyphenols (of project PEF with sensitivity analysis - electricity)									
Method: ReCiPe 2016 Endpoint (H) V1.03 / World (2010) H/A									
Indicator: Single score									
Cut-off: 0%									
Default units: No									
Exclude infrastructure: No									
Exclude long-term emissions: No									
Sorted on item: Total									
Sort order: Descending									
No	Process	Project	Unit	Total	Microwave (S2) polyphenols	Microwave (S2) extractor new	Electricity, low voltage (GR)   electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted   Cut-off, S	Tap water (Europe without Switzerland)   market for   Cut-off, S	Moringa leaves 8% moisture (DMPM)
	Total of all processes		Pt	26.818446	0	0.5527308	1.2695751	0.0610576	24.935083
1	Moringa leaves 8% moisture (DMPM)	PEF with sensitivity analysis (electricity)	Pt	21.127833	0	0	0	0	21.127833
2	Electricity, low voltage (GR)   electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	2.931145	0	0	1.2695751	0	1.6615699
3	Transport, freight, lorry 3.5–7.5 metric ton, euro5 (RER)   market for transport, freight, lorry 3.5–7.5 metric ton, EURO5   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.9576921	0	0	0	0	0.9576921
4	Diesel (GLO)   market group for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.8299213	0	0	0	0	0.8299213
5	Copper (GLO)   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.2786908	0	0.2786908	0	0	0
6	Chromium steel pipe (GLO)   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.2620326	0	0.2620326	0	0	0
7	Polyvinylchloride, bulk polymerised (GLO)   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.2000519	0	0	0	0	0.2000519
8	Polypropylene, granulate (GLO)   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.155519	0	0	0	0	0.155519
9	Tap water (Europe without Switzerland)   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.0610576	0	0	0	0.0610576	0
10	Acrylonitrile-butadiene-styrene copolymer (GLO)   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.01154	0	0.01154	0	0	0
11	Tap water (RoW)   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.002496	0	0	0	0	0.002496
12	Glass tube, borosilicate (GLO)   market for   Cut-off, S	Ecoinvent 3 - allocation, cut-off by classification - system	Pt	0.0004673	0	0.0004673	0	0	0
13	Microwave (S2) polyphenols	PEF with sensitivity analysis (electricity)	Pt	0	0	0	0	0	0
14	Microwave (S2) extractor new	PEF with sensitivity analysis (electricity)	Pt	0	0	0	0	0	0



**Figure S1.** Data model for system S2 (MAE) from SimaPro (ecoinvent) Release 9.0.0.30, PRé Sustainability B.V. software.



**Figure S2.** Environmental impact data of the FU manufacture for the system S2 (MAE).

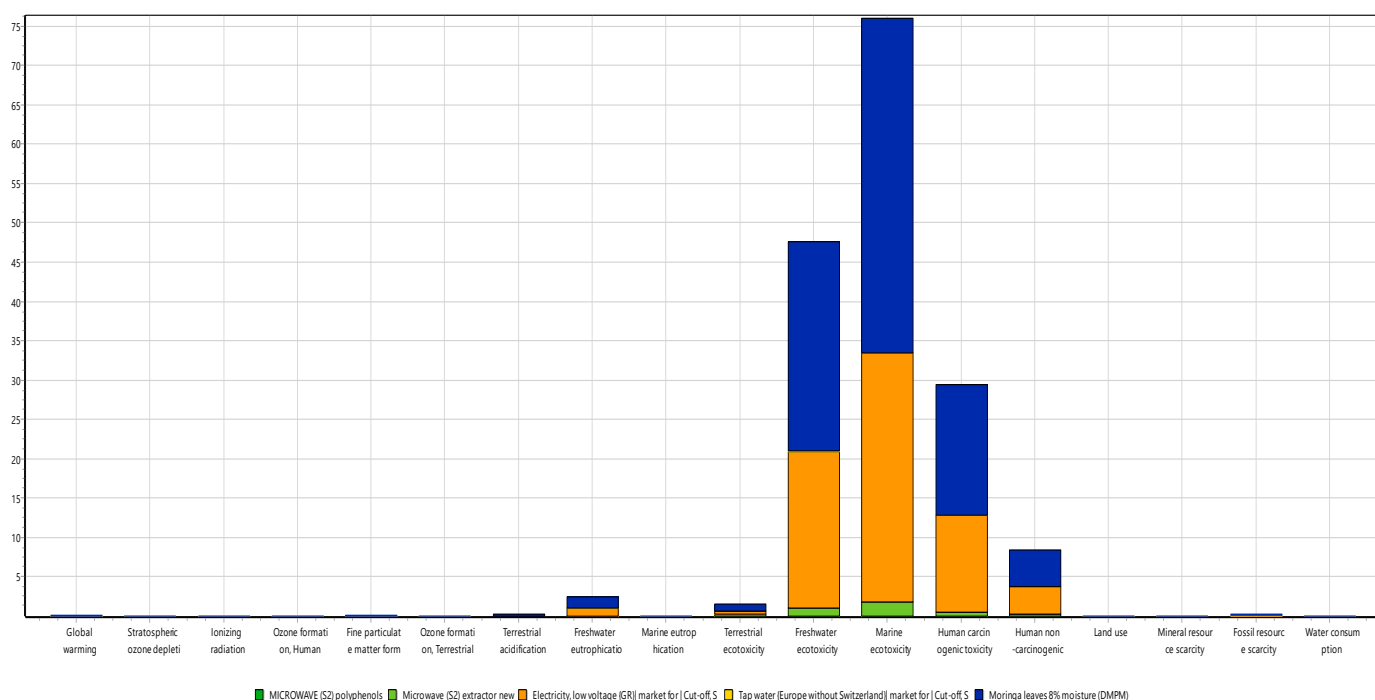


Figure S3. Normalized Environmental impact data of the FU manufacture for the system S2 (MAE).

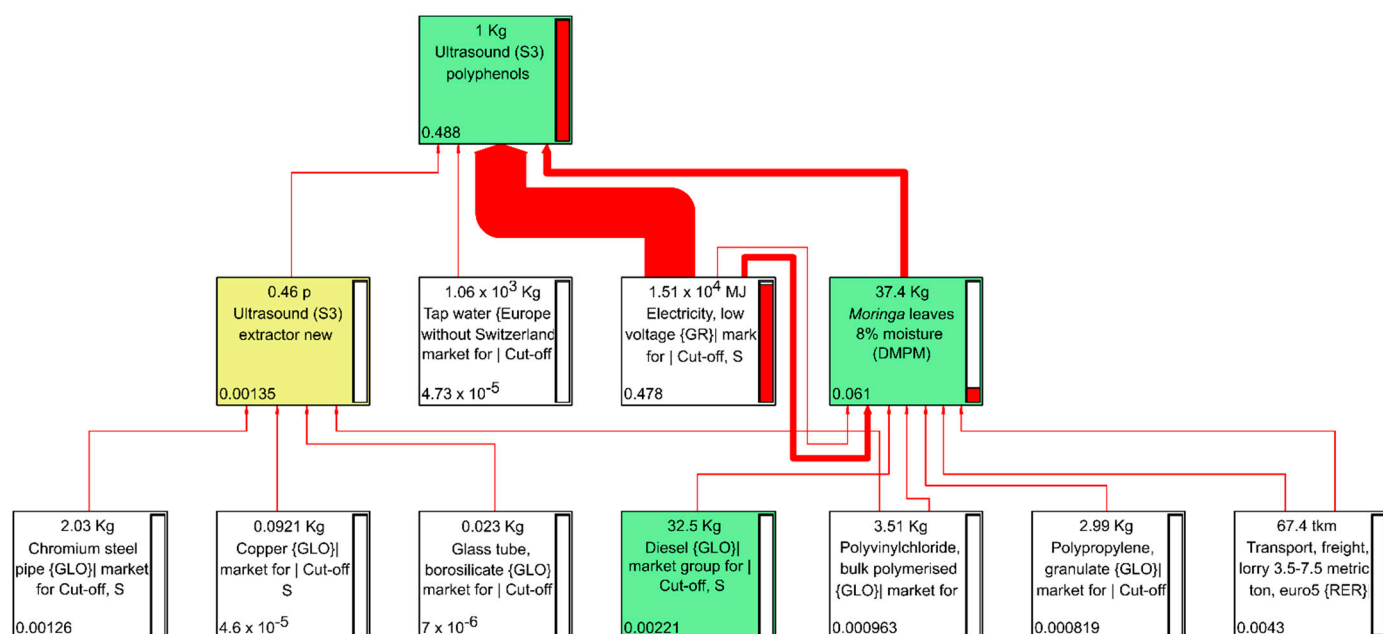
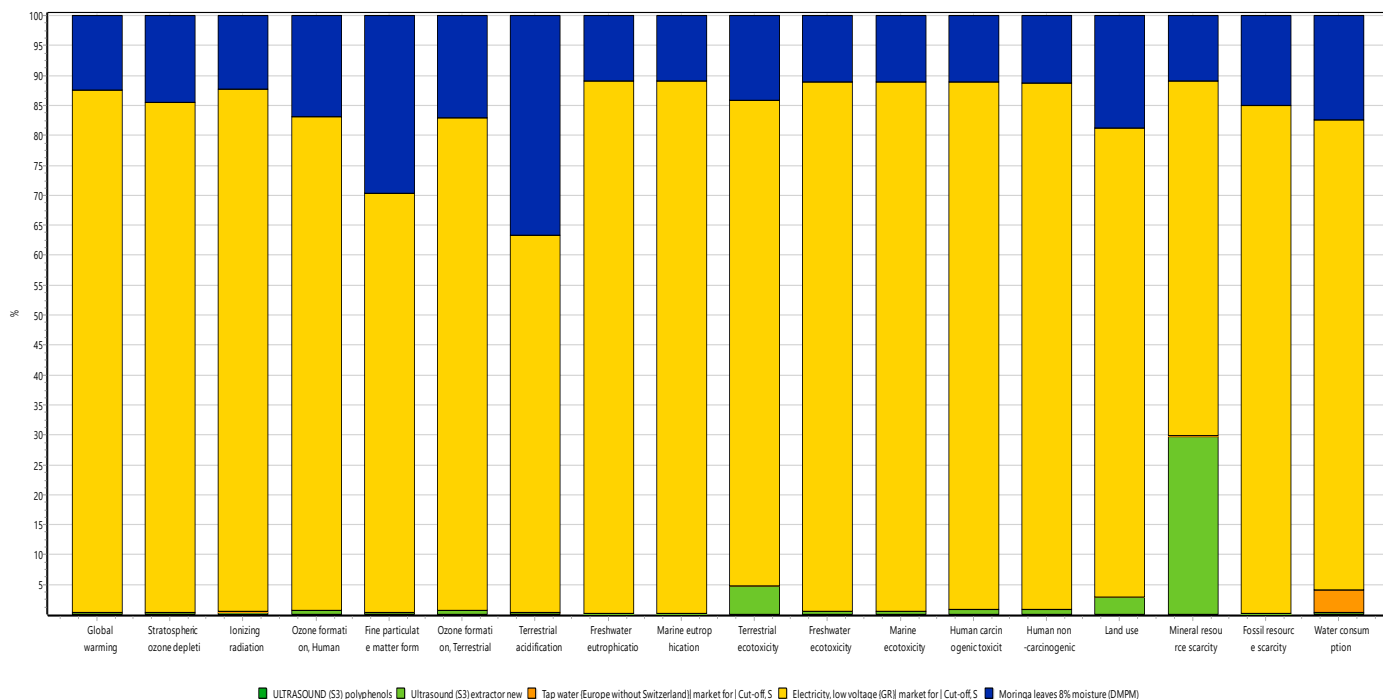
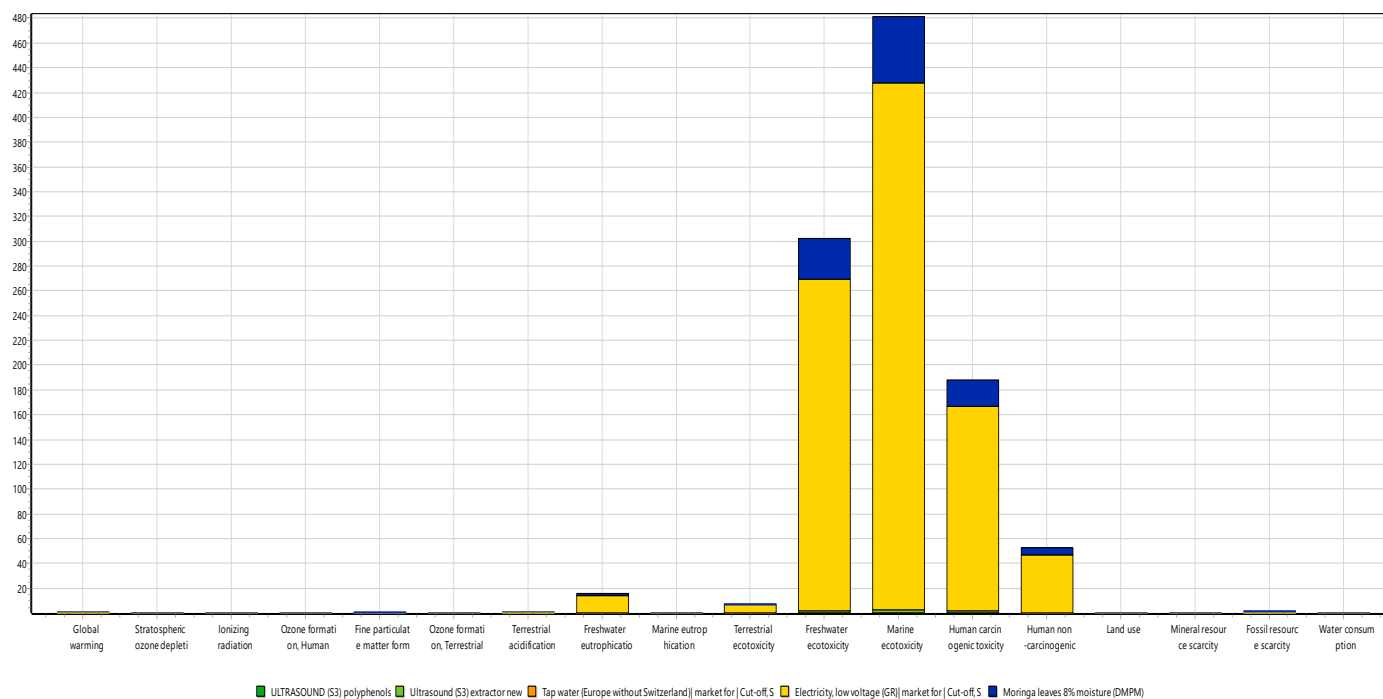


Figure S4. Data model for system S3 (UAE) from SimaPro (ecoinvent) Release 9.0.0.30, PRé Sustainability B.V. software.



**Figure S5.** Environmental impact data of the FU manufacture for the system S3 (UAE).



**Figure S6.** Normalized Environmental impact data of the FU manufacture for the system S3 (UAE).

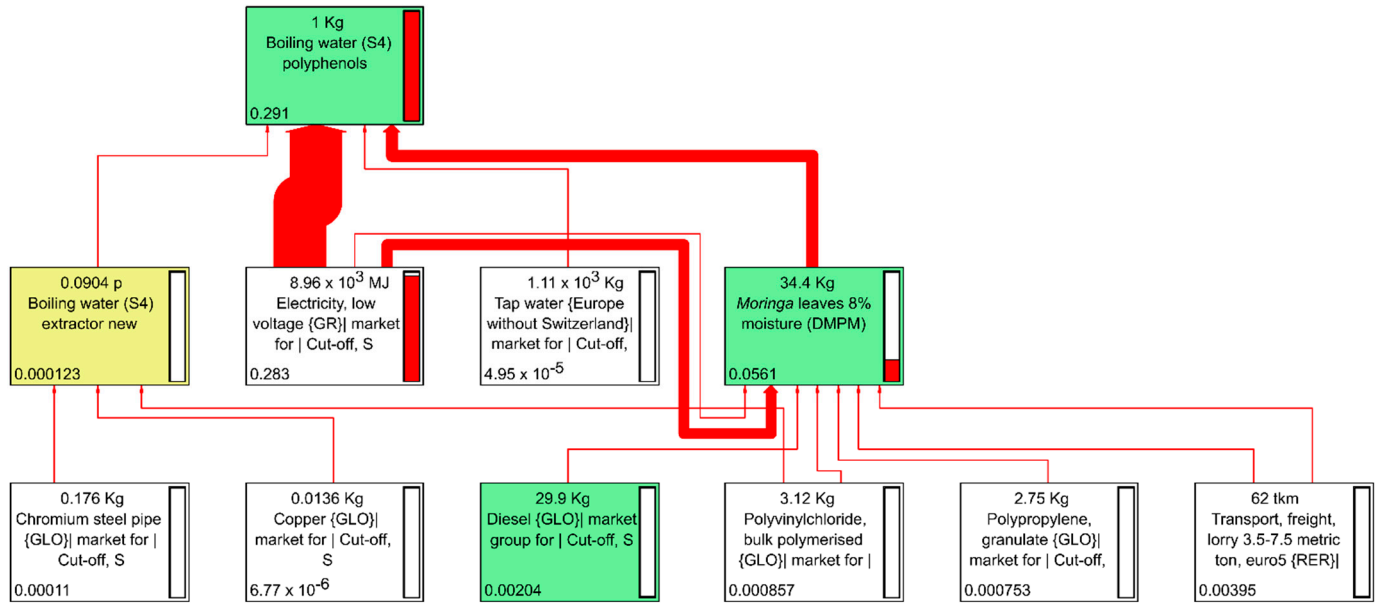


Figure S7. Data model for system S4 (BW) from SimaPro (ecoinvent) Release 9.0.0.30, PRé Sustainability B.V. software.

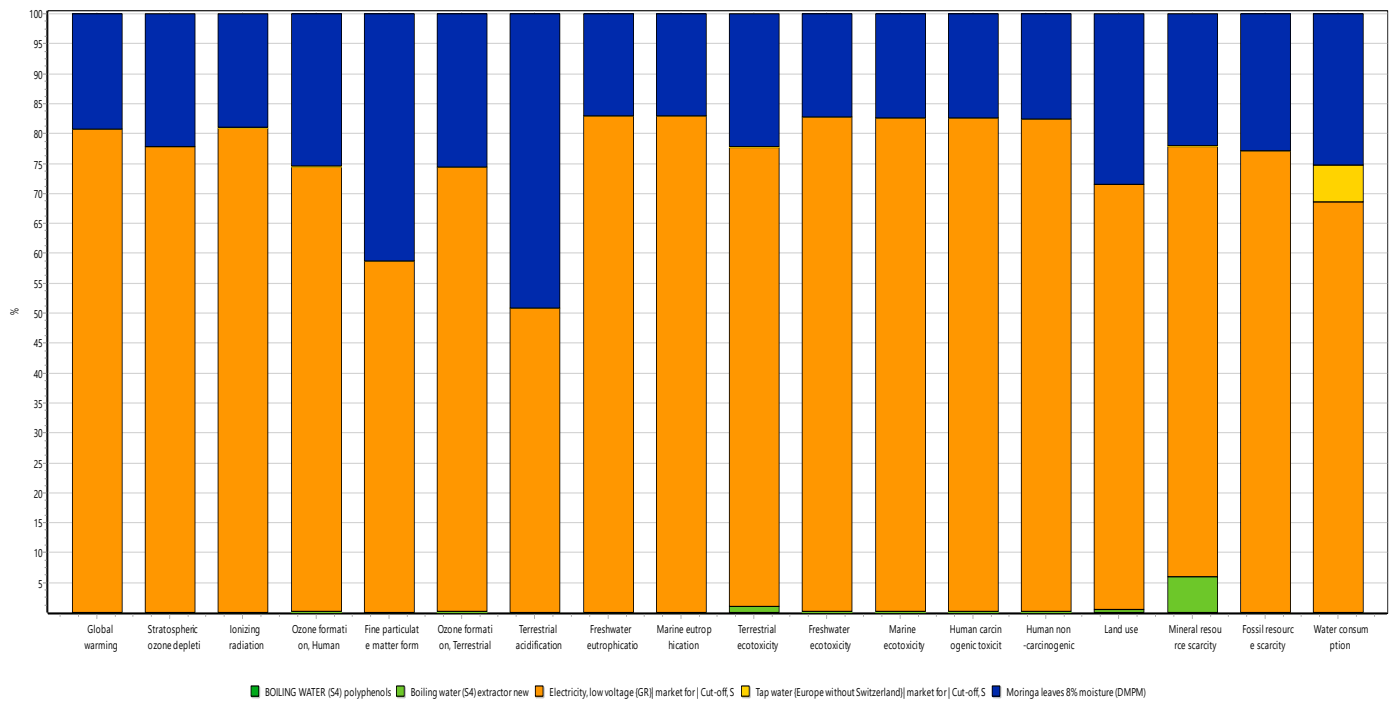


Figure S8. Environmental impact data of the FU manufacture for the system S4 (BW).

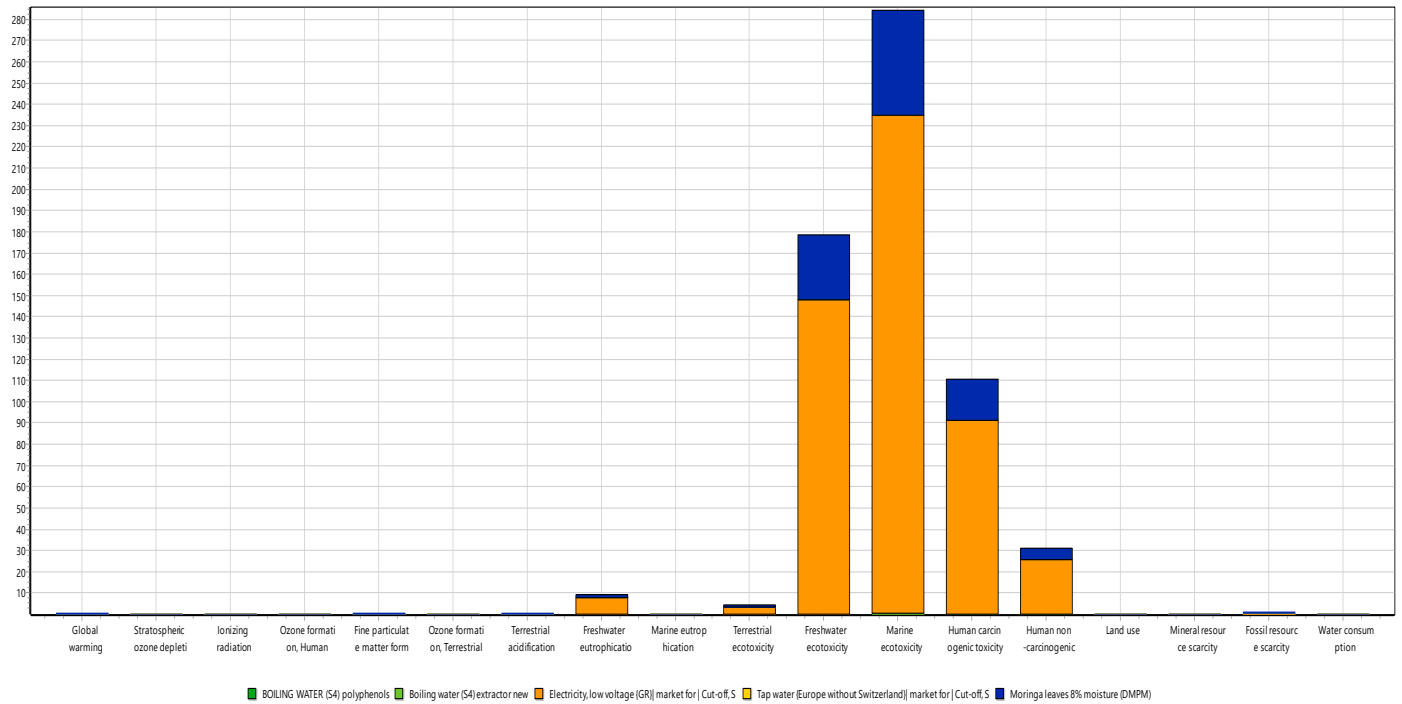


Figure S9. Normalized Environmental impact data of the FU manufacture for the system S4 (BW).

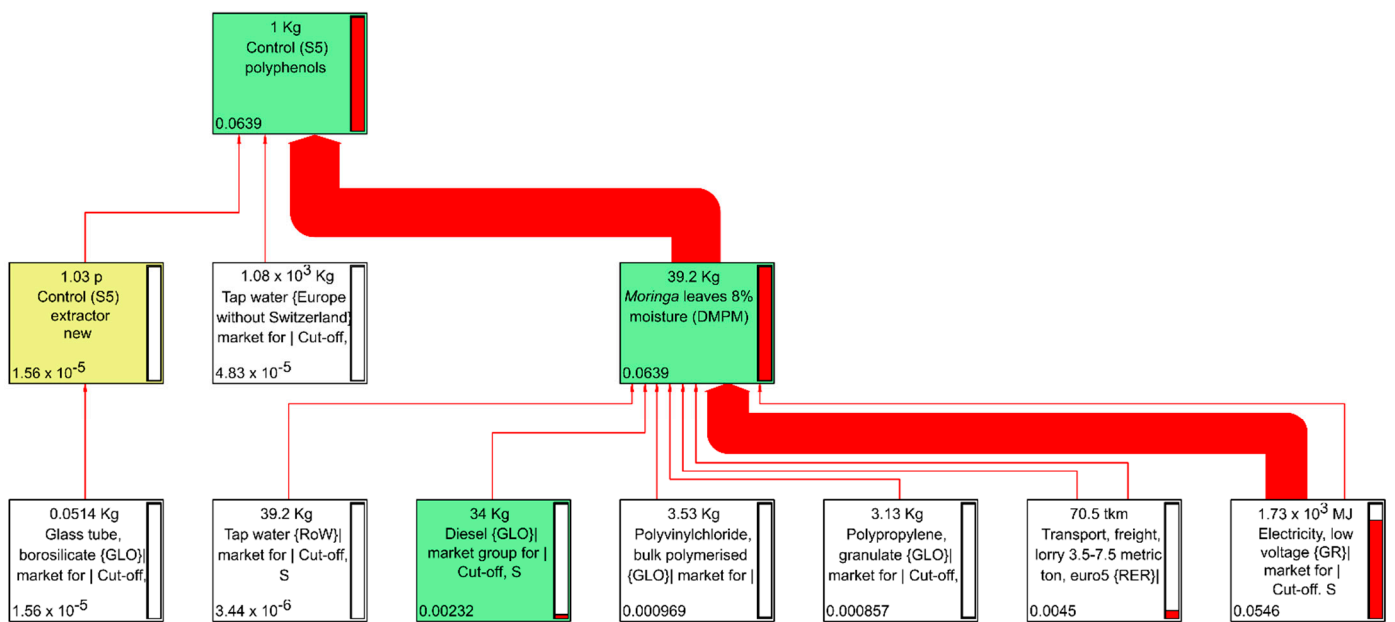
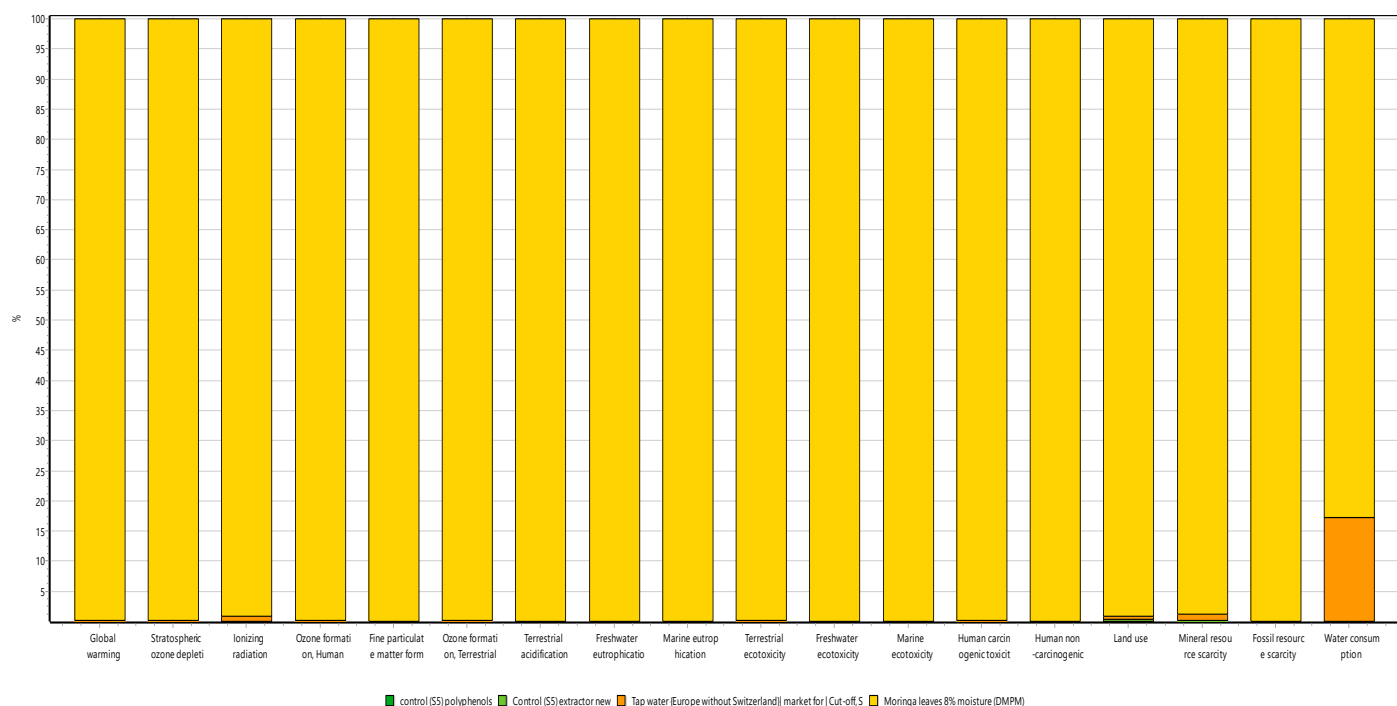
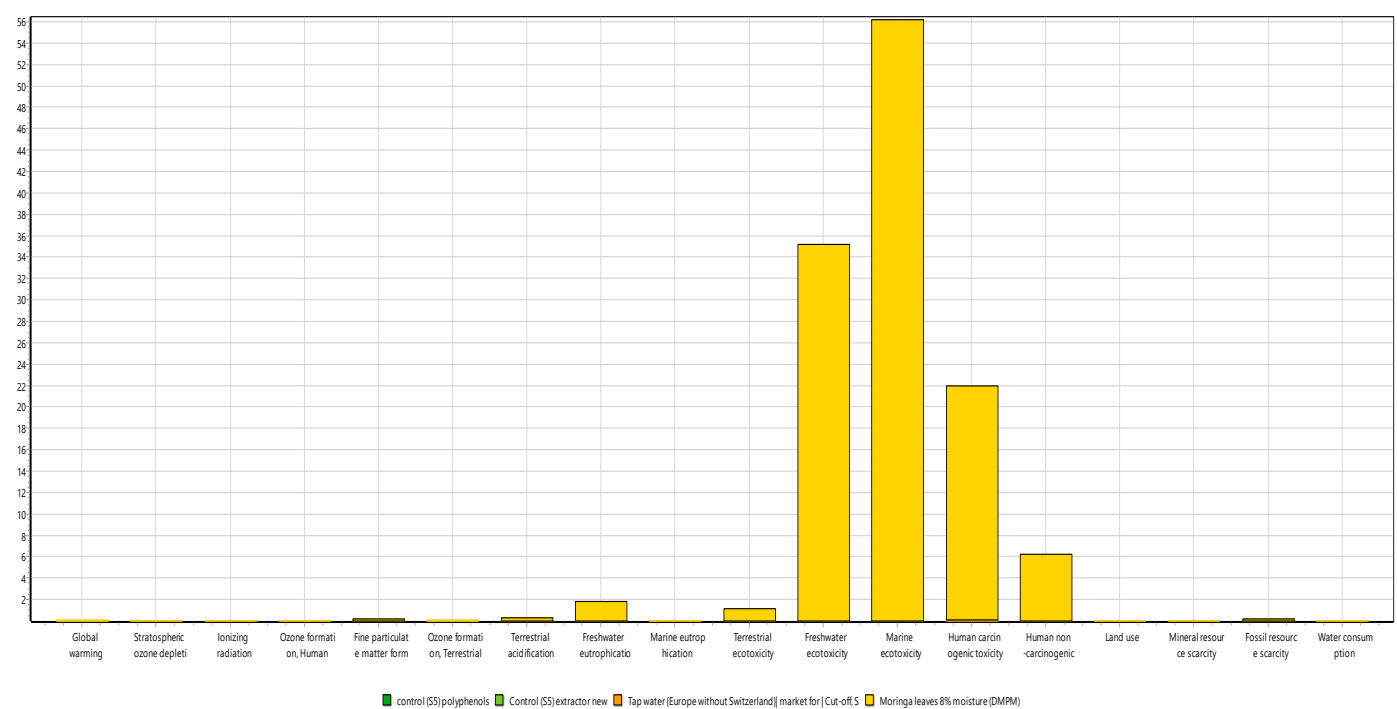


Figure S10. Data model for system S5 (C) from SimaPro (ecoinvent) Release 9.0.0.30, PRé Sustainability B.V. software.



**Figure S11.** Environmental impact data of the FU manufacture for the system S5 (C).



**Figure S12.** Normalized Environmental impact data of the FU manufacture for the system S5 (C).