

A comprehensive study from cradle-to-grave on the environmental profile of malted legumes

Mauro Moresi and Alessio Cimini

SUPPLEMENTARY MATERIAL S1

Table S1.1

Description of the product stages involved in the dried pulse life cycle network according to the Simapro software used in this work.

Product stage		Name	Main output	Unit	Ref. Table
Process	1	Pulse cultivation	Fresh pulse grains	kg	Table S1.2
Process	2	AIP production	AIP	kg	Table S1.3
Process	3	Fumigated pulse grains	Fumigated pulse grains	kg	Table S1.4
Process	4	1-Mg PE FIBC production	SS	kg	Table S1.5
Process	5	FIBC-packed cleaned dried pulse grains	Packed pulse grains	kg	Table S1.6
Process	6	Ready-to-pack dried pulse grains	Ready-to-pack pulse grains	kg	Table S1.7
Process	7	PP bag production	PP bags	kg	Table S1.8
Process	8	Cardboard collar production	Cardstocks	kg	Table S1.9
Process	9	Brass rivet production	Rivets	kg	Table S1.10
Process	10	Adhesive paper label production	Paper labels	kg	Table S1.11
Process	11	Carton production	Cartons	kg	Table S1.12
Process	12	Scotch tape production	Scotch tape	kg	Table S1.13
Process	13	PP semipallet production	PP semipallet	kg	Table S1.14
Process	14	Shrink & shrank PE film production	PE film	kg	Table S1.15
Assembly	15	Assembly of the primary packaging for dried pulses	Ass 1pack	p	Table S1.16
Assembly	16	Assembly of the secondary packaging for dried pulses	Ass 2pack	p	Table S1.17
Assembly	17	Assembly of the tertiary packaging for dried pulses	Ass 3pack	p	Table S1.18
Assembly	18	Assembly of the primary and secondary packages for dried pulses	Ass 1-2pack	p	Table S1.19
Assembly	19	Assembly of the primary, secondary and tertiary packages for dried pulses	Ass 1-2-3pack	p	Table S1.20
Assembly	20	Assembly of dried pulses	Ass dried pulses	p	Table S1.21
Processes	21	Use phase	Cooked pulses	kg	Table S1.22
Waste scenario	22	Waste scenario of plastic packaging wastes	PLW	kg	Table S1.23
Waste scenario	23	Waste scenario of paper and cardboard packaging wastes	PCW	kg	Table S1.24
Waste scenario	24	Waste scenario of non-ferrous metal wastes	NFMW	kg	Table S1.25
End of life scenario	25	Disposal scenario of primary packaging material wastes	DS-1pack	-	Table S1.26
End of life scenario	26	Disposal scenario of secondary packaging material wastes	DS-2pack	-	Table S1.27
End of life scenario	27	Disposal scenario of the tertiary packaging wastes	DS-3pack	-	Table S1.28
End of life scenario	28	Disposal scenario of the I, II, and III packaging material wastes	DS-1-2-3pack	-	Table S1.29
Reuse	29	Reuse of the PP semi-pallet	Pallet reuse	p	Table S1.30
Life cycle	30	Life cycle of dried pulses	LC-DP	p	Table S1.31
Life cycle	31	Life cycle of the primary, secondary and tertiary packaging materials	LC1-2-3pack	p	Table S1.32
Life cycle	32	Life cycle of the PP semi-pallet	LC-3pack	p	Table S1.33

Table S1.2

Inventory associated with the *Solco Dritto* chickpea cultivation phase.

Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment		
SDC- 1 grains			CropYield*1000 = 1.71E3	kg	Mass	100 %	Biopolymers	Agricult...\Market	Solco Dritto Chickpeas -		
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Inputs											
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Occupation, annual crop, non-irrigated, intensive,			1	ha a	Undefined						
Water, river, IT			0	m3	Undefined						
Inputs from technosphere: materials/fuels				Amount		Unit	Distrib	SD2 or 2SD	Min	Max	Comment
NPK (15-15-15) fertiliser (RER) market for NPK (15-15-15) fertiliser Cut-off, S				NPKU*A = 133		kg					
Poultry manure, fresh (GLO) market for poultry manure, fresh Cut-off, S				PM*A = 200		kg					
Pesticide, unspecified (GLO) market for pesticide, unspecified Cut-off, S				DIS*A = 0.125		kg					
Lubricating oil (RER) market for lubricating oil Cut-off, S				LO*A = 1		kg					
Diesel combustion in agricultural machine (GLO) diesel driven production mix, at plant 30kW to 180kW LCI result				DF*DDF*A = 88.8		kg					PCI042.6 MJ/kg: engineeringtoolb
SDC - seeds				0		kg	Unde				
SDC - Chickpea seeding Mass, S				Seed*A = 130		kg					
Inputs from technosphere: electricity/heat						Amount					
Transport, freight, light commercial vehicle (Europe without Switzerland) market for transport, freight, light commercial vehicle Cut-off, S						A*(Seed*25+NPKU*100+PM*100+DIS*25+DF*25+LO*25)/1000 = 39.2					
Transport, tractor and trailer, agricultural (CH) market for transport, tractor and trailer, agricultural Cut-off, S						CropYield*DISTCA = 4.28					
Outputs											
Emissions to air		Sub-compartment	Amount		Unit	Distrib	SD2 or	Min	Max	Comment	
Dinitrogen monoxide			FN2O*A = 1.14		kg						
Nitrogen monoxide, IT			NO*A = 0.731		kg						
Carbon dioxide, fossil			0		kg	Unde					
Emissions to water		Sub-compartment	Amount		Unit	Distributio	SD2 or 2SD	Min	Max	Comment	
Nitrate, IT		river, long-term	FNO3*A = 13.1		kg						
Phosphorus, IT		river, long-term	PLEACH*A = 0.611		kg						

Documentation	Input/output	Parameters	System description				
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment
CropYield	1.71	Triangle		1.11	2.35	<input type="checkbox"/>	Resa granella fresca [Mg/(ha a)]
NPK	100	Triangle		90	110	<input type="checkbox"/>	Fertilizzante NPK (20-20-20) [kg/ha]
PM	200	Triangle		180	220	<input type="checkbox"/>	Poltry manure (4-4-4) [kg/ha]
DIS	0.125	Normal	0.05			<input type="checkbox"/>	Herbicide [kg/ha]
DF	105	Triangle		90	120	<input type="checkbox"/>	Diesel Fuel [L/ha]
LO	1	Undefined				<input type="checkbox"/>	Lubricant Oil [L/ha]
A	1	Undefined				<input type="checkbox"/>	Area [ha]
FRACrenew	1	Undefined				<input type="checkbox"/>	Coltura annuale
RAG	2.1	Undefined				<input type="checkbox"/>	Residui superficiali/Crop
FRACremoved	0	Undefined				<input type="checkbox"/>	
FRACburned	0	Undefined				<input type="checkbox"/>	
SSCrop	0.88	Undefined				<input type="checkbox"/>	SS della granella raccolta [g/g]
NAG	0.008	Undefined				<input type="checkbox"/>	Frazione azoto nella biomassa sup [g/g]
NBG	0.008	Undefined				<input type="checkbox"/>	Frazione azoto nella biomassa radicale [g/g]
RBGBIO	0.19	Normal	0.07			<input type="checkbox"/>	SS in BG/SS in AG [g/g]
Aburnt	0	Undefined				<input type="checkbox"/>	Area ove si effettua l'incenerimento dei residui [ha]
Cf	0	Undefined				<input type="checkbox"/>	Fattore di combustione
FRACgasf	0.11	Triangle		0.02	0.33	<input type="checkbox"/>	kg N volatilizzato come NH3 e NOX/kg N sintetico applicato
FRACgasm	0.21	Triangle		0	0.31	<input type="checkbox"/>	kg N volatilizzato come NH3 e NOX/kg N organico applicato
EF4	0.01	Triangle		0.002	0.018	<input type="checkbox"/>	kg N2O-N/kg di NH3 e NOX volatilizzato
EF5	0.011	Triangle		0	0.02	<input type="checkbox"/>	kg N2O-N/kg di N lisciviato o dilavato
FPRP	0	Undefined				<input type="checkbox"/>	kg N nell'urina e sterco depositati da animali al pascolo [kg N/ha]

FSOM	0	Undefined				<input type="checkbox"/>	kg N mineralizzato nei suoli ove si verifica perdita di C nella sostanza organica [kg N/ha]
FRACleach	0.24	Triangle		0.01	0.73	<input type="checkbox"/>	kg N ₂ O-N/kg di N lisciviato o dilavato/kg N applicato
EF1	0.01	Triangle		0.001	0.018	<input type="checkbox"/>	kg N ₂ O-N/kg N applicato
Seed	130	Triangle		120	140	<input type="checkbox"/>	Densità di semina kg semi/ha]
DISTCA	2.5	Triangle		1	4	<input type="checkbox"/>	Distanza campo-ammassatore [km]
Add							

Calculated parameters	Expression	Comment
Crop	$\text{CropYield} \times \text{SSCrop} \times 1000 = 1.5\text{E}3$	SS nella granella raccolta [kg/ha]
AG	$(\text{Crop}/1000 \times 1.13 + .85) \times 1000 = 2.55\text{E}3$	Sostanza secca nella biomassa sup [kg/h]
RBG	$\text{RBGBIO} \times (\text{AG} + \text{Crop}) / \text{Crop} = 0.512$	Rapporto fra la SS nei residui radicali/SS nella biomassa raccolta g/g]
BG	$\text{RBG} \times \text{Crop} = 770$	SS nei residui sotterranei [kg/ha]
FCR	$\text{FRACrenew} \times ((\text{A} - \text{Aburnt} \times \text{Cf}) \times \text{AG} \times \text{NAG} \times (1 - \text{FRACremoved}) + \text{A} \times \text{BG} \times \text{NBG}) = 26.6$	N nei residui sup e sott restituiti al suolo [kg/ha]
NPKU	$\text{NPK} \times 20 / 15 = 133$	Fertilizzante NPK (15-15-15) [kg/ha]
FSN	$0.15 \times \text{NPKU} = 20$	N sintetico [kg/ha]
FON	$0.04 \times \text{PM} = 8$	N organico [kg/ha]
FNH3NOX	$\text{FSN} \times \text{FRACgasf} + (\text{FON} + \text{FPRP}) \times \text{FRACgasm} = 3.88$	kg NH ₃ e NOX volatilizzato/ha
FNO3	$(\text{FSN} + \text{FON} + \text{FPRP} + \text{FCR} + \text{FSOM}) \times \text{FRACleach} = 13.1$	kg N lisciviato o dilavato/ha
FN2OD	$44/28 \times \text{A} \times (\text{FSN} + \text{FON} + \text{FCR} + \text{FSOM}) \times \text{EF1} = 0.857$	kg N ₂ O-N dirette
FN2OIND	$44/28 \times \text{A} \times (\text{FNH3NOX} \times \text{EF4} + \text{FNO3} \times \text{EF5}) = 0.287$	kg N ₂ O-N indirette
FN2O	$\text{FN2OD} + \text{FN2OIND} = 1.14$	kg N ₂ O-N totali
NOAN	$0.5 \times \text{NPK} / (2 \times 14 + 4 + 3 \times 16) \times (2 \times 14) = 17.5$	kg N/ha se 50% NPK = AN (NH ₄ NO ₃)
NOCAN	$0.5 \times \text{NPK} \times (4 \times 14) / (40 + 4 + 4 \times 14 + 9 \times 16) = 11.5$	kg N/ha se 50% NPK = CAN (Ca NH ₄ (NO ₃) ₃)
NO	$\text{NOAN} \times 0.029 + \text{NOCAN} \times 0.016 + \text{FON} \times 0.005 = 0.731$	EPD (2020) Emissioni NO [kg/ha]
PLEACH	$(\text{NPKU} \times .15 + \text{PM} \times .04) \times (2 \times 31) / (2 \times 31 + 5 \times 16) \times .05 = 0.611$	P lisciviato= 0.05 P sint ed organico [kg/ha]

Table S1.3

Inventory associated with the production of Aluminum phosphide (AIP) tablets.

Products									
Outputs to technosphere: Products and co-products		Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment	
SDC - 3 AIP		ALPTABLET = 1	kg	Mass	100 %	Aluminium	Chemicals		
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Inputs									
Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Inputs from technosphere: materials/fuels		Amount	Unit	Distrik	SD2 c	Min	Max	Comment	
Aluminium, primary, liquid {GLO} market for aluminium, primary, liquid Cut-off, S		ALPTABLET*0.46552*xAIP = 0.261	kg						
Phosphorus, white, liquid {GLO} market for phosphorus, white, liquid Cut-off, S		ALPTABLET*0.53448*xAIP = 0.299	kg						
Aluminium oxide, non-metallurgical {IAI Area, Russia & RER w/o EU27 & EFTA} aluminium ox		ALPTABLET*(xAIO+xAIS) = 0.17	kg						
Graphite {GLO} market for graphite Cut-off, S		ALPTABLET*xG = 0.015	kg						
Urea {RER} urea production Cut-off, S		ALPTABLET*xU = 0.18	kg						
Ammonium carbonate {RER} market for ammonium carbonate Cut-off, S		ALPTABLET*xAMC = 0.05	kg						
Paraffin {GLO} market for paraffin Cut-off, S		ALPTABLET*xPW = 0.025	kg						
Inputs from technosphere: electricity/heat				Amount	Unit	Dis	S	Comment	
Heat, district or industrial, natural gas {Europe without Switzerland} market for heat, district or industrial, natural gas Cut-off, S				ALPTABLET*xAIP*(0.46552*En	kJ				
Dolomite grinding {GLO} dolomite grinding production mix, at plant 2.90 g/cm3 Partly terminated system				ALPTABLET*xAIP = 0.56	kg			Grinding of P and Al	
Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {RER} transport, freight, lorry 3.5-7.5 metric ton, EURO5 Cut-off, S				ALPTABLET/1000*300 = 0.3	tkm			TR: MP - Fondi: 200 km	
Transport, freight, light commercial vehicle {Europe without Switzerland} transport, freight, light commercial vehicle Cut-off, S				ALPTABLET/1000*280 = 0.28	tkm			TR: Fondi-AP: 280 km	

Documentation	Input/output	Parameters	System description				
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment
xAIP	0.56	Undefined				<input type="checkbox"/>	Frazione di AIP nelle tablets
xAMC	0.05	Undefined				<input type="checkbox"/>	Frazione di ammonium carbonate (w/w)
xAIS	0.025	Undefined				<input type="checkbox"/>	Frazione di aluminium stearate (w/w)
xAIO	0.145	Undefined				<input type="checkbox"/>	Frazione di aluminium oxide/hydroxide (w/w)
xU	0.18	Undefined				<input type="checkbox"/>	Frazione di urea (w/w)
xG	0.015	Undefined				<input type="checkbox"/>	Frazione di graphite (w/w)
xPW	0.025	Undefined				<input type="checkbox"/>	Frazione di paraffin wax (w/w)
ALPTABLET	1	Undefined				<input type="checkbox"/>	Massa di una compressa [g]
CpPS	0.77	Undefined				<input type="checkbox"/>	Specifi heat value of solid P [kJ/(kg K)]: https://www.periodic-table.org/phosphorus-latent-heat-vaporization/
CpPL	0.85	Undefined				<input type="checkbox"/>	Specific heat value of liquid P [kJ/(kg K)]: https://webbook.nist.gov/cgi/inchi?ID=C7723140&Mask=2
CpPV	0.5	Undefined				<input type="checkbox"/>	Specific heat value of vapor P [kJ/(kg K)]
DELTAHfusP	0.657	Undefined				<input type="checkbox"/>	[kJ/mol]
DELTAHvapP	51.9	Undefined				<input type="checkbox"/>	[kJ/mol]
CpAIS	0.9	Undefined				<input type="checkbox"/>	Specifi heat value of solid Al [kJ/(kg K)]
CpAIL	1.127	Undefined				<input type="checkbox"/>	Specifi heat value of liquid Al [kJ/(kg K)]
DELTAHfusAl	10.79	Undefined				<input type="checkbox"/>	[kJ/mol]
TfusP	44.1	Undefined				<input type="checkbox"/>	Temperatura di fusione P [°C]
TBP	280	Undefined				<input type="checkbox"/>	Temperatura di ebollizione P °C
TfusAL	660	Undefined				<input type="checkbox"/>	Temperatura di fusione Al [°C]
TR	700	Undefined				<input type="checkbox"/>	Temperatura di reazione °C]
Calculated parameters	Expression	Comment					
EntP	$CpPS \cdot (TfusP - 20) + DELTAHfusP / 0.031 + CpPL \cdot (TBP - TfusP) + DELTAHvapP / 0.031 + CpPV \cdot (TR - TBP) = 2.1$	Calore di riscald P [kJ/kg]					
EntAl	$CpAIS \cdot (TfusAL - 20) + DELTAHfusAl / 0.027 + CpAIL \cdot (TR - TfusAL) = 1.02E3$	Calore di riscald Al [kJ/kg]					

Inventory associated with the pulse grain fumigation step.

Products									
Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment
SDC - 4 Fumigated grains			17100.171	kg	Mass	100 %	Biopolymers	Agr...\Plant seeds	
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Inputs									
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Inputs from technosphere: materials/fuels			Amount	Unit	Distrib	SD2 or 2SD	Min	Max	Comment
SDC - 1 grains			17100	kg	Under				
SDC - 3 AIP			0.2565	kg	Under				
Inputs from technosphere: electricity/heat					Amount	Unit	Dis	S	Comment
Outputs									
Emissions to air		Sub-compartment	Amount	Unit	Distrib	SD2 or 2SD	Min	Max	Comment
Phosphine			85.5	g	Under				
Documentation	Input/output	Parameters	System description						
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment		
SCPUL	12.5	Triangle		10	15	<input type="checkbox"/>	Scarto di pulitura [%]		
DUST	2	Triangle		1.6	2.4	<input type="checkbox"/>	Polvere [%]		
GI	6	Triangle		4.8	7.2	<input type="checkbox"/>	Grass & Insects [%]		
WASTE	4.5	Triangle		3.6	5.4	<input type="checkbox"/>	Legumi spezzati etc [%]		
Calculated parameters Expression					Comment				

Table S1.5

Inventory associated with the production of 1-Mg PE bags.

Products										
Outputs to technosphere: Products and co-products		Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment		
SDC - 2 PE Supersacks		3	kg	Mass	100 %	LDPE	P...\Thermoplasts			
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Inputs										
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Inputs from technosphere: materials/fuels		Amount			Unit	Distrik	SD2	Min	Max	Comment
Packaging film, low density polyethylene (RER) packaging film production, low density polye		3/0.976 = 3.07			kg					Resa di conversione in film: 0.976 kg/kg F
Inputs from technosphere: electricity/heat		Amount			Unit	Dis	S	Comment		
Extrusion, plastic film (RER) extrusion, plastic film Cut-off, S		3/.976 = 3.07			kg					0.976 kg
Transport, freight, light commercial vehicle (Europe without Switzerland) transport, freight, light commercial vehicle Cut-off, S		3/1000*355 = 1.06			tkm					Distanza SS - Azienda conf: 355 km
Transport, freight, lorry 16-32 metric ton, EURO5 (RER) transport, freight, lorry 16-32 metric ton, EURO5 Cut-off, S		(3/.976)/1000*300 = 0.922			tkm					Distanza Fornitore PE - Azienda RE: 300 km
Outputs to technosphere: Waste and emissions to treatment		Amount			Unit	Distri				
Waste polyethylene (Europe without Switzerland) market group for waste polyethylene Cut-off, S		3*(1-0.976) = 0.072			kg					

Table S1.6

Inventory associated with the flexible intermediate bulk container (FIBC)-packed cleaned dry pulse grain production step.

Products											
Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment		
SDC - 5 FIBC-packed cleaned dry pulse grains			GPP = 1.5E4	kg	Mass	99.6 %	Biopolymers	Agr...\Plant seeds	Legumi puliti nei supersacch		
SDC - waste			2137.7	kg	Mass	0.4 %	Biopolymers	Agr...\Plant seeds			
Add											
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Add											
Inputs											
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Add											
Inputs from technosphere: materials/fuels			Amount			Unit	Distrik	SD2 <	Min	Max	Comment
SDC - 4 Fumigated grains			17100.171			kg	Unde				
SDC - 2 PE Supersacks			44.9			kg	Unde				
Add											
Inputs from technosphere: electricity/heat				Amount			Unit	Dis	S	Comment	
Add											

Table S1.7

Inventory associated with the production of ready-to-pack dried pulses.

Documentation	Input/output	Parameters	System description						
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment		
GP	14962.5	Undefined				<input type="checkbox"/>	Cleaned pulses grains [kg]		
SS	44.9	Undefined				<input type="checkbox"/>	PE-sacks [kg]		
Add									
Calculated parameters	Expression						Comment		
GPP	GP+SS = 1.5E4						PE-bagged cleaned pulse grains [kg]		
Add									
Products									
Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment
SDC - 6 ready-to-pack dry grains			GPD = 1.31E4	kg	Mass	100 %	Biopolymers	Agr...\Plant seeds	Legumi puliti nei supersacch
SDC - DGI			GRF*(DUST+GI) = 1.37E3	kg	Mass	0 %	Others	Others	Dust, grass & Insect waste
SDC - MZ			GRF*BP+0.005*GPD = 835	kg	Mass	0 %	Biopolymers	Ag...\Bovine feed	Pulse Waste used as cattle fe
SDC - seeds			Seed*A = 1.3E3	kg	Mass	0 %	Biopolymers	Agr...\Plant seeds	Seeds used
Add									
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add									
Inputs									
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add									
Inputs from technosphere: materials/fuels			Amount	Unit	Distrib	SD2 or 2SD	Min	Max	Comment
SDC - 5 FIBC-packed cleaned dry pulse grains			GPP = 1.5E4	kg					
Add									
Inputs from technosphere: electricity/heat			Amount	Unit	Dis	S	Comment		
Transport, tractor and trailer, agricultural (RoW) transport, tractor and trailer, agricultural Cut-off, S			GRF*(DUST+GI)/1000*4 = 5.4	tkm					TR: AP- field: 4 km
Transport, tractor and trailer, agricultural (RoW) transport, tractor and trailer, agricultural Cut-off, S			(GRF*BP+0.005*GPD)/1000*(1	tkm					TR: AP - Beef cattle farms: 50 km
Outputs to technosphere: Waste and emissions to treatment									
			Amount	Unit	Dis	S			
Waste polyethylene (RoW) treatment of waste polyethylene, municipal incineration Cut-off, S			SS*0.446 = 20	kg					
Waste polyethylene (RoW) treatment of waste polyethylene, sanitary landfill Cut-off, S			SS*0.067 = 3.01	kg					
PE (waste treatment) (GLO) recycling of PE Cut-off, S			SS*0.487 = 21.9	kg					

Table S1.8

Inventory associated with the PP bag production step.

Products									
Outputs to technosphere: Products and co-products		Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment	
SDC- 7 PP bags		1	kg	Mass	100 %	PP	P...\Thermoplasts		
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Inputs									
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Inputs from technosphere: materials/fuels			Amount	Unit	Distrit	SD2 c	Min	Max	Comment
Polypropylene, granulate (GLO) market for polypropylene, granulate Cut-off, S			1/976 = 1.02	kg					Resa: 0.976 kg /kg PP
Inputs from technosphere: electricity/heat					Amount	Unit	Dis	S	Comment
Extrusion, plastic film (RER) extrusion, plastic film Cut-off, S					1/976 = 1.02	kg			
Transport, freight, lorry 16-32 metric ton, EURO5 (RER) transport, freight, lorry 16-32 metric ton, EURO5 Cut-off, S					(1/976)/1000*300 = 0.307	tkm			TR PP Granules Prod Site - Pl: 300 km
Outputs to technosphere: Waste and emissions to treatment						Amount	Unit	Distri	
Waste polypropylene (Europe without Switzerland) market group for waste polypropylene Cut-off, S						0.024	kg	Unde	

Table S1.9

Inventory associated with the cardboard collar production step.

Products										
Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment	
SDC - 8 Cardstock			1	kg	Mass	100 %	not defined	Agr...\Plant seeds		
Add										
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs										
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs from technosphere: materials/fuels			Amount		Unit	Distrib	SD2 or 2SD	Min	Max	Comment
Kraft paper (RER) market for kraft paper Cut-off, S			1		kg	Under				
Add										
Inputs from technosphere: electricity/heat					Amount	Unit	Dis	S	Comment	
Printed paper, offset (RoW) offset printing, per kg printed paper Cut-off, S					1	kg	Un			
Transport, freight, lorry >32 metric ton, EURO5 (RER) transport, freight, lorry >32 metric ton, EURO5 Cut-off, S					(1/1000)*300 = 0.3	tkm			TR Cartoncino PS-Montefiascone: 300 km	

Table S1.10

Inventory associated with the brass rivet production step.

Products									
Outputs to technosphere: Products and co-products		Amount	Unit	Quantit	Allocation %	Waste type		Category	Comment
SDC - 9 - Brass rivets		1	kg	Mass	100 %	Non-ferro		Metals\Non Ferrc	
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Inputs									
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Inputs from technosphere: materials/fuels		Amount		Unit	Distrib	SD2 or 2SD	Min	Max	Comment
Brass (RoW) market for brass Cut-off, S		1		kg	Under				
Inputs from technosphere: electricity/heat				Amount		Unit	Dis	S	Comment
Brass Die-Casting (GLO) die casting, from copper and zinc, primary production production mix, at plant 8.41- 8.86 g/cm3 Pa				1		kg	Un		
Transport, freight, lorry 16-32 metric ton, EURO5 (RER) transport, freight, lorry 16-32 metric ton, EURO5 Cut-off, S				(1/1000)*300 = 0.3		tkm			TR Ottone: PS- Pl: 300 km

Table S1.11

Inventory associated with the adhesive paper label production step.

Products										
Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment	
SDC - 10 Adhesive paper labels			1	kg	Mass	100 %	Paper	...\Graphic paper		
Add										
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs										
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs from technosphere: materials/fuels			Amount	Unit	Distrib	SD2 or 2SD	Min	Max	Comment	
Graphic paper, 100% recycled (GLO) market for graphic paper, 100% recycled Cut-off, S			1	kg	Under					
Add										
Inputs from technosphere: electricity/heat					Amount	Unit	Dis	S	Comment	
Transport, freight, lorry 16-32 metric ton, EURO5 (RER) market for transport, freight, lorry 16-32 metric ton, EURO5 Cut-off, S					(1/1000)*300 = 0.3	tkm			TR Paper x Labels: PS -Montefiascone: 300 km	
Acrylic binder, with water, in 54% solution state (RER) market for acrylic binder, with water, in 54% solution state Cut-off, S					5*1210/(5*1210+600*1000) =	kg				

Table S1.12

Inventory associated with the carton production step (copied from Carton box {EU+EFTA+UK} | Kraft Pulping Process, pulp pressing and drying, box manufacturing | production mix, at plant | 280 g/m², R1=47% | LCI result, EF database 3.1 Corepackage – Sphera).

Products									
Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment
SDC - 11 Carton box			1.0	kg	Mass	100 %	Cardboard	Pap...\Packaging	Product flow name: Carton b
Add									
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add									
Inputs									
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Air		in air	5.1649277E1	kg	Undefined				
Inputs from technosphere: electricity/heat					Amount	Unit	Dis	S	Comment
Transport, freight, lorry 16-32 metric ton, EURO5 (RER) transport, freight, lorry 16-32 metric ton, EURO5 Cut-off, S					(1/1000)*300 = 0.3	tkm			TR PS-PG: 300 km

Table S1.13

Inventory associated with the scotch tape production step.

Products										
Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment	
SDC- 12 Scotch			1	kg	Mass	100 %	PP	P...\Thermoplasts		
Add										
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs										
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs from technosphere: materials/fuels			Amount	Unit	Distrib	SD2 c	Min	Max	Comment	
Polypropylene, granulate (GLO) market for polypropylene, granulate Cut-off, S			(1-0.0425)/.976 = 0.981	kg					Resa: 0.976 kg /kg PP	
Add										
Inputs from technosphere: electricity/heat					Amount	Unit	Dis	S	Comment	
Extrusion, plastic film (RER) extrusion, plastic film Cut-off, S					(1-0.0425)/.976 = 0.981	kg				
Transport, freight, lorry 7.5-16 metric ton, EURO5 (RER) transport, freight, lorry 7.5-16 metric ton, EURO5 Cut-off, S					((1-0.0425)/.976+0.0425)/100	tkm			TR PP Granules Prod Site - PI: 300 km	
Acrylic binder, with water, in 54% solution state (RER) market for acrylic binder, with water, in 54% solution state Cut-off, S					10*1210/(10*1210+300*950) :	kg			tape thickness 300 micron (950 kg/m3), acrylic layer 10 micron (1210 kg/m3)	
Outputs to technosphere: Waste and emissions to treatment							Amount		Unit	Distri
Waste polypropylene (Europe without Switzerland) market group for waste polypropylene Cut-off, S							0.024		kg	Unde

Table S1.14

Inventory associated with the PP semi-pallet production step.

Products									
Outputs to technosphere: Products and co-products			Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment
SDC - 13 semipallet			1	kg	Mass	100 %	PP	P...\Thermoplasts	
Add									
Outputs to technosphere: Avoided products			Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add									
Inputs									
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
Add									
Inputs from technosphere: materials/fuels			Amount	Unit	Distrik	SD2 c	Min	Max	Comment
Polypropylene, recycled, pre-consumer (GLO) shredding, pelletizing production mix, at plan			1/98 = 1.02	kg					Resa: 0.98 kg /kg PP
Add									
Inputs from technosphere: electricity/heat					Amount	Unit	Dis	S	Comment
Injection moulding {RER} injection moulding Cut-off, S					1/98 = 1.02	kg			
Transport, freight, lorry 16-32 metric ton, EURO5 (RoW) transport, freight, lorry 16-32 metric ton, EURO5 Cut-off, S					(1/98)/1000*300 = 0.306	tkm			TR PP Granules Prod Site - Pl: 300 km
Outputs to technosphere: Waste and emissions to treatment						Amount	Unit	Distri	
Waste polypropylene (Europe without Switzerland) market group for waste polypropylene Cut-off, S						0.02	kg	Unde	

Inventory associated with the shrink & shrank PE film production step.

Products										
Outputs to technosphere: Products and co-products	Amount	Unit	Quantit	Allocation %	Waste type	Category	Comment			
SDC- 14 PE shrinkable film	1	kg	Mass	100 %	PE	P...\Thermoplasts				
Add										
Outputs to technosphere: Avoided products	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment			
Add										
Inputs										
Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Add										
Inputs from technosphere: materials/fuels	Amount	Unit	Distrib	SD2	Min	Max	Comment			
Polyethylene, low density, granulate (RER) polyethylene production, low density, granulate C	1/976 = 1.02	kg					Resa: 0.976 kg /kg PP			
Add										
Inputs from technosphere: electricity/heat	Amount	Unit	Dis	S	Comment					
Extrusion, plastic film (RER) extrusion, plastic film Cut-off, S	1/976 = 1.02	kg								
Transport, freight, lorry 16-32 metric ton, EURO5 (RER) transport, freight, lorry 16-32 metric ton, EURO5 Cut-off, S	(1/976)/1000*300 = 0.307	tkm			TR PP Granules Prod Site - Pl: 300 km					
Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distri							
Waste polyethylene (ES) market for waste polyethylene Cut-off, S	0.024	kg	Unde							

Table S1.16

Assembly of the primary packaging for dried pulses.

Input/output	Parameters										
Name			Status			Comment					
SDC - 15 Assembly of Primary Packaging			None								
Materials/Assemblies		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment			
SDC- 7 PP bags		PPBAG = 5	g								
SDC - 8 Cardstock		CAV = 5.8	g								
SDC - 9 - Brass rivets		2*RIV = 0.66	g								
SDC - 10 Adhesive paper labels		ET = 0.323	g								
Add											
Processes		Amount				Unit	D	SD	N	M	Comment
Transport, freight, lorry 7.5-16 metric ton, EURO5 (RER) market for transport, freight, lorry 7.5-16 metric ton, EURO5 Cut-off, S		(PPBAG+2*RIV)/1000*200 = 1.13				kgkm					TR: PI-AP: 200 km
Transport, freight, light commercial vehicle (Europe without Switzerland) market for transport, freight, light commercial vehicle Cut-off, S		(CAV+ET)/1000*30 = 0.184				kgkm					TR: Montefiascone-AP: 30 km
Input/output	Parameters										
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment				
PPBAG	5	Normal	0.3			<input type="checkbox"/>					
CAV	5.8	Normal	0.6			<input type="checkbox"/>					
RIV	0.33	Normal	0.03			<input type="checkbox"/>					
ET	0.323	Normal	0.03			<input type="checkbox"/>					

Table S1.17

Assembly of the secondary packaging for dried pulses.

Input/output	Parameters							
Name		Status		Comment				
SDC - 16 Assembly of Secondary Packaging		None						
Materials/Assemblies	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
SDC - 11 Carton box	CA = 302	g						
SDC - 10 Adhesive paper labels	EC = 2	g						
SDC- 12 Scotch	SC = 4	g						
Add								
Processes		Amount		Unit	D	SD	Min	Comment
Transport, freight, light commercial vehicle [Europe without Switzerland] market for transport, freight, light commercial vehicle Cut-off, S		EC/1000*30 = 0.06		kgkm				TR: Montefiascone - AP: 30 km
Transport, freight, lorry 7.5-16 metric ton, EURO5 [RER] market for transport, freight, lorry 7.5-16 metric ton, EURO5 Cut-off, S		(CA*105+SC*200)/1000 = 32.5		kgkm				TR: PG o PI - AP: 105 o 200 km
Input/output	Parameters							
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment	
CA	302	Normal	3			<input type="checkbox"/>	g	
EC	2.0	Normal	0.2			<input type="checkbox"/>	g	
SC	4	Normal	0.4			<input type="checkbox"/>	g	
Add								

Table S1.18
Assembly of the tertiary packaging for dried pulses.

Input/output	Parameters									
Name		Status		Comment						
SDC - 17 Assembly of Tertiary Packaging		None								
Materials/Assemblies		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
SDC - 13 semipallet		PAL = 5	kg							
Add										
Processes					Amount	Unit	D	N	M	Comment
Transport, freight, lorry 7.5-16 metric ton, EURO5 (RER) market for transport, freight, lorry 7.5-16 metric ton, EURO5 Cut-off, S					(PAL*0.02)*200 = 20	kgkm				TR: PI - AP: 200 km (solo frazione da reintragare: 0.02%)
Input/output		Parameters								
Input parameters		Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment		
PAL		5	Normal	0.1			<input type="checkbox"/>	kg		
Add										

Table S1.19

Assembly of primary and secondary packages for dried pulses.

Input/output	Parameters						
Name		Status		Comment			
SDC - 18 Assembly of I-II packages		None					
Materials/Assemblies	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
SDC - 15 Assembly of Primary Packaging	12	p	Undefined				
SDC - 16 Assembly of Secondary Packaging	1	p	Undefined				
Add							
Processes					Amount	Unit	D N M Comment
Add							

Table S1.20

Assembly of primary, secondary, and tertiary packages for dried pulses.

Input/output	Parameters									
Name				Status		Comment				
SDC - 19 Assembly of I-II-III packages				None						
Materials/Assemblies		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
SDC - 18 Assembly of I-II packages		24	p	Undefined						
SDC- 14 PE shrinkable film		FP = 287	g							
SDC - 10 Adhesive paper labels		EP*2 = 6.22	g							
SDC - 17 Assembly of Tertiary Packaging		1	p	Undefined						
Add										
Processes					Amount	Unit	D	N	M	Comment
Transport, freight, lorry 7.5-16 metric ton, EURO5 {RER} market for transport, freight, lorry 7.5-16 metric ton, EURO5 Cut-off, S					(FP/1000)*200 = 57.4	kgkm				TR: PI - AP: 200 km
Transport, freight, light commercial vehicle {Europe without Switzerland} market for transport, freight, light commercial vehicle C					(EP*2/1000)*30 = 0.187	kgkm				TR: Montefiascone - AP: 30 km
Input/output	Parameters									
Input parameters		Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment		
EP		3.11	Normal	0.3			<input type="checkbox"/>	g		
FP		287	Normal	20			<input type="checkbox"/>	g		

Table S1.21

Assembly of dried pulses (1 Functional Unit).

Input/output		Parameters								
Name		Status		Comment						
SDC - 20 Assembly of Dry Grains		None								
Materials/Assemblies				Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
SDC - 5 FIBC-packed cleaned dry pulse grains				MDP = 0.5	kg					
Nitrogen gas production (EU+EFTA+UK) technology mix production mix, at plant 100% active substance LCI result				N2 = 5	g					
Add										
Processes				Amount	Unit	D	N	M	Comment	
Transport, freight, lorry 7.5-16 metric ton, EURO5 (RER) market for transport, freight, lorry 7.5-16 metric ton, EURO5 Cut-off, S				N2/1000*35 = 0.175	kgkm				TR: Orvieto-AP: 35 km	
Electricity, medium voltage (IT) market for electricity, medium voltage Cut-off, S				EECONS*MDP = 0.33	kWh				EE consumata	
Input/output		Parameters								
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment			
MDP	0.5	Undefined				<input type="checkbox"/>	Dried pulse mass kg]			
N2	5	Normal	0.5			<input type="checkbox"/>	Nitrogen consumed per 0.5-kg dry pulse bag [g]			
EECONS	0.66	Undefined				<input type="checkbox"/>	Electricity consumed [kWh/kg dry pulses]			

Table S1.22

Inventory associated with the use phase.

Products										
Outputs to technosphere: Products and co-products		Amount	Unit	Quantit	Allocation %	Category	Comment			
SDC - 21 Use phase		RDP = 1	kg	Mass	100 %	Others				
SDC - Cooked pulses wasted		MPC*CPWASTED = 0.262	kg	Mass	0 %	Others				
Add										
Outputs to technosphere: Avoided products		Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment		
Add										
Inputs										
Inputs from nature		Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment	
Add										
Inputs from technosphere: materials/fuels		Amount			Unit	Distrib	SD2 c	Min	Max	Comment
Tap water {Europe without Switzerland} market for tap water Cut-off, S		(WAM+WAC)*RDP+CONSW*NCL = 15.8			kg					Acqua per amm+ cott + acqua x lavastov
Detergent dish production {EU+EFTA+UK} production mix 1 kg of detergent dish LCI resul		CONSDet*NCL = 7.14			g					Detersivo consumato x lavastoviglie
Add										
Inputs from technosphere: electricity/heat		Amount			Unit	Dis	S	Comment		
Heat, central or small-scale, natural gas {Europe without Switzerland} market for heat, central or small-scale, natural gas Cut-off		ECG*RDP = 1.41			kWh					Consumo Gas nat fornelli a gas
Electricity, low voltage {IT} market for electricity, low voltage Cut-off, S		ECE*RDP+CONSEE*NCL = 0.8			kWh					Consumo EE (fornello+lavastoviglie)
Municipal waste collection service by 21 metric ton lorry {GLO} market for municipal waste collection service by 21 metric ton lor		MPC*CPWASTED*50 = 13.1			kgkm					TR: House-MSWCS: 50 km
Outputs										
Emissions to air		Sub-compartment	Amount	Unit	Distrib	SD2 or	Min	Max	Comment	
Water (evapotranspiration)		low. pop.	WAC*RDP*Wevap = 0.2	kg						
Nitrogen, total		low. pop.	10*RDP = 10	g						
Outputs to technosphere: Waste and emissions to treatment		Amount			Unit	Distrib				
Sludge from pulp and paper production {Europe without Switzerland} treatment of sludge from pulp and paper production, sanitary landfill Cut-off, S		MPC*CPWASTED*.31 = 0.0812			kg					
Raw sewage sludge {RoW} treatment of raw sewage sludge, municipal incineration Cut-off, S		MPC*CPWASTED*.18 = 0.0472			kg					
Biowaste {RoW} treatment of biowaste by anaerobic digestion Cut-off, S		MPC*CPWASTED*.255 = 0.0668			kg					
Biowaste {RoW} treatment of biowaste, industrial composting Cut-off, S		MPC*CPWASTED*.255 = 0.0668			kg					
Wastewater, average {Europe without Switzerland} market for wastewater, average Cut-off, S		(WASTEWAM+WASTEWC)*RDP+CONSW*NCL = 14			l					

Documentation	Input/output	Parameters	System description				
Input parameters	Value	Distribution	SD2 or 2SD	Min	Max	Hide	Comment
RDP	1	Undefined				<input type="checkbox"/>	Dry pulses [kg]
XMDP	0.083	Undefined				<input type="checkbox"/>	Umidità iniziale legumi [g/g]
WAM	4	Undefined				<input type="checkbox"/>	Acqua x ammollo [L/kg dried pulses]
XMAM	0.55	Triangle		0.5	0.6	<input type="checkbox"/>	Umidità legumi post-ammollo [g/g]
WAC	4	Undefined				<input type="checkbox"/>	Acqua x cottura [L/kg dried pulses]
XMC	0.65	Triangle		0.62	0.68	<input type="checkbox"/>	Umidità legumi post-cottura [g/g]
GCH	0.83	Undefined				<input type="checkbox"/>	Frazione dei fornelli a gas
ECH	0.17	Undefined				<input type="checkbox"/>	Frazione dei fornelli elettrici
ETC	1.7	Undefined				<input type="checkbox"/>	Energia totale di cottura [kWh/kg]
CPWASTED	0.1	Triangle		0.08	0.12	<input type="checkbox"/>	Frazione legumi cotti sprecati [g/g]
Portion	50	Undefined				<input type="checkbox"/>	Porzione consumata di legumi secchi [g]
NCOP	28	Undefined				<input type="checkbox"/>	No coperti/ciclo di lavaggio
CONSEE	0.74	Undefined				<input type="checkbox"/>	Cons EE [kWh/ciclo di lavaggio]
CONSW	10.9	Undefined				<input type="checkbox"/>	Cons acqua [L/ciclo di lavaggio]
CONSDDET	10	Undefined				<input type="checkbox"/>	Cons detersivo [g/ciclo di lavaggio]
Wevap	0.05	Undefined				<input type="checkbox"/>	Frazione acqua di cottura evaporata [g/g]
Add							

Calculated parameters	Expression	Comment
MPI	$RDP * (1 - XMDP) / (1 - XMAM) = 2.04$	Massa legumi post-ammollo [kg]
WASTEWAM	$WAM * RDP - (MPI * XMAM - RDP * XMDP) = 2.96$	Acqua da smaltire post-ammollo [kg]
MPC	$RDP * (1 - XMDP) / (1 - XMC) = 2.62$	Massa legumi post-cottura [kg]
WASTEWC	$WAC * RDP - (MPC * XMC - MPI * XMAM) - Wevap * WAC = 3.22$	Acqua da smaltire post-cottura [kg]
ECG	$GCH * ETC * RDP = 1.41$	Energia termica consumata per cuocere RDP kWh]
ECE	$ECH * ETC * RDP = 0.289$	Energia elettrica consumata per cuocere RDP kWh]
NSCOD	$RDP * 1000 / Portion = 20$	No. scodelle utilizzate
NCL	$NSCOD / NCOP = 0.714$	No. cicli di lavaggio in lavastoviglie per consumare RDP

Table S1.23
Waste scenario for plastic packaging wastes (PLW).

Products										
Waste specification	Amount	Unit	Category	Comment						
SDC -22 Waste scenario plastic wastes	1	kg	Others							
Inputs										
Inputs from technosphere: materials/fuels			Amount		Unit	Distrib	SD2 c	Min	Max	Comment
Add										
Inputs from technosphere: electricity/heat			Amount		Unit	Dis	S	Comment		
Add										
Outputs										
Materials and/or waste types separated from waste stream			Material / Waste type			Percentage		Comment		
Add										
Waste streams remaining after separation					Percentage		Comment			
Waste plastic, mixture (RoW) treatment of waste plastic, mixture, sanitary landfill Cut-off, S					6.7 %					
Mixed plastics (waste treatment) (GLO) recycling of mixed plastics Cut-off, S					48.7 %					
Waste plastic, mixture (RoW) treatment of waste plastic, mixture, municipal incineration Cut-off, S					44.6 %					

Table S1.24
Waste scenario for cardboard and paper packaging wastes (PCW).

Products									
Waste specification	Amount	Unit	Category	Comment					
SDC -23 Waste scenario Cardboard&paper packagi	1	kg	Others						
Inputs									
Inputs from technosphere: materials/fuels			Amount	Unit	Distrib	SD2 c	Min	Max	Comment
Inputs from technosphere: electricity/heat			Amount	Unit	Dis	S	Comment		
Outputs									
Materials and/or waste types separated from waste stream			Material / Waste type		Percentage	Comment			
Waste streams remaining after separation					Percentage	Comment			
Waste paperboard {RoW} treatment of waste paperboard, sanitary landfill Cut-off, S					5.2 %				
Paper (waste treatment) {GLO} recycling of paper Cut-off, S					87.3 %				
Waste paperboard {RoW} treatment of waste paperboard, municipal incineration Cut-off, S					7.5 %				

Table S1.25
Waste scenario of non-ferrous metal waste (NFMW).

Products										
Waste specification	Amount	Unit	Category	Comment						
SDC -24 Waste scenario non-ferrous metal wastes	1	kg	Others							
Inputs										
Inputs from technosphere: materials/fuels			Amount	Unit	Distrik	SD2	κ	Min	Max	Comment
Inputs from technosphere: electricity/heat			Amount	Unit	Dis	S	Comment			
Outputs										
Materials and/or waste types separated from waste stream			Material / Waste type		Percentage	Comment				
Waste streams remaining after separation					Percentage	Comment				
Waste aluminium {RoW} treatment of waste aluminium, sanitary landfill Cut-off, S					25.4 %					
Aluminium (waste treatment) {GLO} recycling of aluminium Cut-off, S					68.1 %					
Scrap copper {Europe without Switzerland} treatment of scrap copper, municipal incineration Cut-off, S					6.5 %					

Table S1.26
 Disposal scenario of primary packaging material wastes (DS-1pack).

Name		Status	Comment
SDC - 25 Disposal Scenario of Primary Packaging		None	

Referring to assembly	Amount	Unit	Comment
SDC - 15 Assembly of Primary Packaging	1	p	

Processes	Amount	Unit	D	N	M	Comment
Municipal waste collection service by 21 metric ton lorry (GLO) market for municipal waste collection service by 21 metric ton lorry	(11.941/1000)*50 = 0.597	kgkm				TR - Wastes to MSWCS: 50 km

Waste scenarios	Percentage	Comment
SDC -23 Waste scenario Cardboard&paper packaging	55.3 %	
SDC -24 Waste scenario non-ferrous metal wastes	2.8 %	
SDC -22 Waste scenario plastic wastes	41.9 %	

Disassemblies	Percentage	Comment

Reuses	Percentage	Comment

Table S1.27
 Disposal scenario of secondary packaging material wastes (DS-2pack).

Name		Status		Comment	
SDC - 26 Disposal Scenario of Secondary Packaging		None			
Referring to assembly		Amount	Unit	Comment	
SDC - 16 Assembly of Secondary Packaging		1	p		

Processes		Amount	Unit	D	M	M	Comment
Municipal waste collection service by 21 metric ton lorry {GLO} market for municipal waste collection service by 21 metric ton lorry		(308/1000)*50 = 15.4	kgkm				TR - Wastes to MSWCS: 50 km

Waste scenarios		Percentage	Comment	
SDC -23 Waste scenario Cardboard&paper packaging		98.7 %		
SDC -22 Waste scenario plastic wastes		1.3 %		

Disassemblies		Percentage	Comment
Reuses		Percentage	Comment

Table S1.28

Disposal scenario of tertiary packaging material wastes (DS-3pack).

Name		Status	Comment				
SDC - 27 Disposal Scenario of Tertiary Packaging		None					
Referring to assembly	Amount	Unit	Comment				
SDC - 17 Assembly of Tertiary Packaging	1	p					
Processes							
Municipal waste collection service by 21 metric ton lorry (GLO) market for municipal waste collection service by 21 metric ton lorry		Amount	Unit	D	N	N	Comment
		(PAL*.02/1000)*50 = 0.00	tkm				TR - Wastes to MSWCS: 50 km
Add							
Waste scenarios		Percentage	Comment				
SDC - 22 Waste scenario plastic wastes		0.2 %					
Add							
Disassemblies		Percentage	Comment				
Add							
Reuses		Percentage	Comment				
SDC - 29 Semipallet reuse		99.8 %					
Add							

Table S1.29

Disposal scenario of the primary, secondary and tertiary packaging material wastes (DS-1-3pack).

Name		Status		Comment		
SDC - 28 Disposal Scenario of I-II-III Packaging		None				
Referring to assembly		Amount	Unit	Comment		
SDC - 19 Assembly of I-II-III packages		1	p			
Processes						
Municipal waste collection service by 21 metric ton lorry (GLO) market for municipal waste collection service by 21 metric ton lorry Cut-off, S		Amount	Unit	D	I	Comment
		(0.294)*50 = 14.7	kgkm			TR - Paper & Plastic Wastes in a pallet to MSWCS: 5
Waste scenarios		Percentage		Comment		
SDC -22 Waste scenario plastic wastes		19.845 %				
SDC -23 Waste scenario Cardboard&paper packaging		79.331 %				
SDC -24 Waste scenario non-ferrous metal wastes		0.824 %				
Disassemblies		Percentage		Comment		
Reuses		Percentage		Comment		

Table S1.30
Reuse phase of the PP semi-pallet.

Input/output		Parameters	
Name		Status	Comment
SDC - 29 Semipallet reuse		None	
Referring to assembly		Amount	Unit
SDC - 17 Assembly of Tertiary Packaging		1	p
			Comment
Processes		Amount	Unit
Transport, freight, light commercial vehicle (Europe without Switzerland) market for transport, freight, light commercial vehicle Cut-off, S		(PAL*.998)/1000*1	tkm
Input/output		Parameters	
Input parameters		Value	Distribution
PAL		5	Normal
		SD2 or 2SD	Min
		Max	Hide
			Comment
			Mass of semipallet PE [kg]

Table S1.31
 Life cycle of dried pulses (LC-DP).

Input/output

Parameters

Name

Status

Comment

SDC - 30 Life cycle of Dried Pulses

None

Assembly

Amount

Unit

Distribution

SD2 or 2SD

Min

Max

Comment

SDC - 20 Assembly of Dry Grains

2

p

Undefined

Two 500-g bags

Processes

Amount

Unit

Dis

N

Comment

Transport, freight, light commercial vehicle {Europe without Switzerland} | market for transport, freight, light commercial vehicle | Cut-off, S

(PPDP/MDP*1)*150 = 168

kgkm

TR - Dried Pulses - Points of Sale: 150 km

SDC - 21 Use phase

1

kg

Ur

Waste/Disposal scenario

Comment

Additional life cycles

Number

Distribution

SD2 or 2SD

Min

Max

Comment

SDC -31 Life Cycle of I-II-III packaging

1/144 = 0.00694

Input/output

Parameters

Input parameters

Value

Distribution

SD2 or 2SD

Min

Max

Hide

Comment

PPDP

161.42

Undefined

☐

Mass del Semipallet carico [kg]

MDP

144

Undefined

☐

Massa di Legumi secchi nel semipallet [kg]

Table S1.32

Life cycle of the primary, secondary, and tertiary packaging materials (LC-1-3pack).

Input/output	Parameters						
Name		Status		Comment			
SDC -31 Life Cycle of I-II-III packaging		None					
Assembly	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
SDC - 19 Assembly of I-II-III packages	1	p	Undefined				
Processes		Add		Amount	Unit	Dis	Comment
Waste/Disposal scenario				Comment			
SDC - 28 Disposal Scenario of I-II-III Packaging							
Additional life cycles		Number	Distribution	SD2 or 2SD	Min	Max	Comment
SDC -32 Life Cycle of III packaging		1	Undefined				
Add							

Table S1.33
Life cycle of the PP semi-pallet (LC-3pack).

Input/output	Parameters						
Name		Status		Comment			
SDC -32 Life Cycle of III packaging		None					
Assembly	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment
SDC - 17 Assembly of Tertiary Packaging	1	p	Undefined				
Processes							Amount
Add							Unit
Waste/Disposal scenario							Disposal
SDC - 27 Disposal Scenario of Tertiary Packaging							Comment
Additional life cycles		Number	Distribution	SD2 or 2SD	Min	Max	Comment
Add							

A comprehensive study from cradle-to-grave on the environmental profile of malted legumes

Mauro Moresi and Alessio Cimini

SUPPLEMENTARY MATERIAL S2

Table S2.1 Input/output data for the conventional cultivation of the 3 varieties of legumes examined here (SDC, GPB, LO), as referred to a nominal land area of 1 ha. Air and water emissions were estimated according to the IPCC [45] and EPD® [46] guidelines.

Input/Output Parameter	Legume	SDC	GPB	OL	Unit
Nominal non-irrigated land used (S)		1	1	1	ha
Input					
NPK Fertilizer		100.0	100.0	20.0	kg/(ha yr)
N		20.0	20.0	4.0	kg/(ha yr)
P		8.7	8.7	1.7	kg/(ha yr)
K		16.6	16.6	3.3	kg/(ha yr)
Poultry Manure		200.0	200.0	200.0	kg/(ha yr)
N		8.0	8.0	8.0	kg/(ha yr)
P		3.5	3.5	3.5	kg/(ha yr)
K		6.6	6.6	6.6	kg/(ha yr)
Output					
Fresh grain yield		1.71	1.26	1.26	Mg/(ha yr)
Average dry matter in grains harvested		0.88	0.88	0.88	g/g
Harvested annual dry matter grain yield		1.505	1.109	1.109	Mg/(ha yr)
Above ground biomass (AGR)		2.55	2.10	2.10	Mg/(ha yr)
Ratio of above-ground residues dry matter to harvested crop yield		2.1	2.1	2.1	g/g
Ratio of below-ground biomass to above-ground biomass (R _{BG-BIO})		0.19	0.19	0.19	g/g
N content of above-ground residues (N _{AG})		0.008	0.008	0.008	g/g
N content of below-ground residues (N _{BG})		0.008	0.008	0.008	g/g
Fraction of above-ground residues removed (Frac _{Removed})		0			%
Fraction of total area under crop annually renewed (Frac _{Renew})		1			-
Below-ground residues (BG)		770.5	610.2	610.2	kg ss/(ha yr)
Nitrogen in crop residues (F _{CR})		26.57	21.71	21.71	kg N/(ha yr)
Fraction of synthetic N fertilizer volatilized as NH ₃ + NO _x (Frac _{GASF})		0.11 (0.02-0.33)			(kg NH ₃ -N+NO _x -N)/(kg N)
Fraction of organic N fertilizer volatilized as NH ₃ + NO (Frac _{GASM})		0.21 (0.0-0.31)			(kg NH ₃ -N+NO _x -N)/(kg N)
Fraction of all N added lost through leaching off and runoff (Frac _{LEACH})		0.24 (0.01-0.73)			kg N/(kg N)
N ₂ O-N emissions per unit mass of N fertilizer added (EF ₁)		0.01 (0.001-0.018)			kg N ₂ O-N/(kg N)
N ₂ O-N emissions per unit mass of NH ₃ and NO _x emitted (EF ₄)		0.01 (0.002-0.018)			kg N ₂ O-N/(kg NH ₃ -N+kg NO _x -N)
N ₂ O-N emissions per unit mass of N leached off (EF ₅)		0.011 (0.0-0.020)			kg N ₂ O-N/(kg N lisc/dilavato)
Direct N ₂ O emissions F _{N2ODIR} [(F _S +F _{CR}) · EF ₁ · 44/28]		0.857	0.781	0.530	kg N ₂ O/(ha yr)
NH ₃ +NO _x		3.88	3.88	2.12	kg (NH ₃ -N+NO _x -N)/(ha yr)
F _{NH3-NOX}		0.061	0.061	0.033	kg N ₂ O/(ha yr)

Nitrate emissions in water [NO ₃ ⁻]	13.10	11.93	8.09	kg NO ₃ ⁻ -N/(ha yr)
F _{NO3-}	0.226	0.206	0.140	kg N ₂ O/(ha yr)
Indirect N ₂ O emissions (F _{N2OI} IND)	0.287	0.267	0.173	kg N ₂ O/(ha a)
N ₂ O emissions from managed soils (F _{N2O} = F _{N2ODIR} + F _{N2OI} IND)	1.145	1.048	0.703	kg N ₂ O/(ha a)
P emissions in water [0.05 kg P/ kg P applied] [46]	0.61	0.61	0.26	kg P/(ha a)
NO emissions in air [46]	0.731	0.731	0.178	kg NO-N/(ha a)

Table S2.2

Overall material balance of the fumigation process, cleaning/optical selection of harvested legumes, and storage of cleaned grains shown in Fig. 2, as related to the average yield of harvested fresh grain pulses. All symbols used to identify the various stream flows are given in the Nomenclature section.

Legume	S	GRs	GR	AIP		PH₃	GRF	SP	GP	RP	PO+ER	SS		GPP	H₂O_v
	ha	kg/ha	kg	Comp.	g	g	kg	kg	kg	kg	kg	No.	kg	kg	kg
SDC	10	1710	17100	85.5	256.5	85.5	17100.2	2137.7	14962.5	769.5	1368.2	15.0	44.9	15007.4	598.5
GPB	8.5	1260	10710	53.6	160.7	53.6	10710.1	1338.9	9371.3	482.0	856.9	9.4	28.1	9399.4	374.85
LO	30	1260	37800	189.0	567.0	189.0	37800.4	12285.4	25515.0	4725.0	7560.4	25.5	76.5	25591.5	1020.6

Legume	GPPD	Seeds	GPD	SGP	MZ	SSU	SSU	RPS
	kg	kg	kg	kg	kg	No	kg	kg
SDC	14364.0	1300.0	13064.0	65.3	834.8	0.8	2.5	837.3
GPB	8996.4	850.0	8146.4	40.7	522.7	0.5	1.6	524.3
LO	24494.4	3000.0	21494.4	107.5	4832.5	4.8	14.5	4847.0

Table S2.3

Selling prices (sp) for the cleaned and selected grains of the legumes examined (SDC, GPD, LO) and by-products designated for animal husbandry (MZ) along with the total revenue, and allocation percentage of by-products (ALL_{MZ}). All symbols used are given in the Nomenclature section.

Legume	sp_{GPD}	sp_{MZ}	MZ	GPD	Total revenue	ALL_{MZ}
	[€/kg]	[€/kg]	[kg]	[kg]	[€]	[%]
SDC	3.6	0.1	834.8	13064	47113.9	0.18%
GPB	6.0	0.1	522.7	8146.4	48930.7	0.11%
LO	5.0	0.1	4832.5	21494.4	107955.2	0.45%

Table S2.4

Percentage fraction of the process and packaging materials discarded, as collected in the dry legume factory examined in this work.

Processing and Packaging Materials discarded	Discarded Fraction (%)
PE super-sacks	0
Dry legumes	0.5
<i>Primary packaging</i>	
PP bags	2.5
Paper label	0.5
Cardbord collar	0.5
Brass rivets	0.5
<i>Secondary packaging</i>	
Cartons (CAW)	1.0
Carton labels	0.3
Scotch tape	0.3
<i>Tertiary packaging</i>	
Damaged PP semi-pallet	0.2
Pallet adhesive label	0.5
Stretch & shrink film	0.5

Table S2.5

Overall material balance of the packaging process of cleaned pulse grains and its waste management process., as referred to the block diagram in Fig. 3. All symbols used to identify the various stream flows are given in the Nomenclature section.

Legume	GPD	SGP	Bags	PP	N ₂	CAV	RO	ET	SPP	SCAV	SRO	SET
	[kg]	[kg]	No.	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]	[kg]
SDC	13064.0	65.3	25997.4	133.2	130.0	151.5	8.7	21.1	3.2	0.754	0.043	12.7
GPB	8146.4	40.7	16211.3	83.1	81.1	94.5	5.4	13.2	2.0	0.470	0.027	7.9
LO	21494.4	107.5	42773.9	219.2	213.9	249.3	14.3	34.7	5.3	1.240	0.071	20.9
Legume	LCI		CA		SCA		EC	SEC	SC	SSC		
	[kg]		No.	[kg]	[kg]		[kg]	[kg]	[kg]	[kg]		
SDC	13426.5		2166.4	660.8	6.5		4.3	0.01	8.7	0.03		
GPB	8372.5		1350.9	412.1	4.1		2.7	0.01	5.4	0.02		
LO	22090.8		3564.5	1087.2	10.8		7.2	0.02	14.3	0.04		
Legume	LCII		PAL		SPAL		EP	SEP	FP	SFP	LCIII	
	[kg]		no.	[kg]	[kg]		[kg]	[kg]	[kg]	[kg]	[kg]	
SDC	14093.8		90.3	452.2	0.9		0.6	0.003	26.1	0.13	14571.6	
GPB	8788.5		56.3	282.0	0.6		0.4	0.002	16.3	0.08	9086.5	
LO	23188.7		148.5	744.1	1.5		0.9	0.005	42.9	0.21	23974.9	
Legume	RPL'		RCC'		RM'			MZ		PO+E		
	[kg]		[kg]		[kg]			[kg]		[kg]		
SDC	49.2		20.0		0.043			834.8		1368.2		
GPB	30.8		12.5		0.027			522.7		856.9		
LO	83.6		32.9		0.071			4832.5		7560.4		

Table S2.6

Overall material balance of the malting, cleaning, dehulling and packaging processes of cleaned pulse grains and their waste management process, as referred to the block diagrams in Figures S1 and 3. All symbols used to identify the various stream flows are given in the Nomenclature section.

Legume	GPD			MP				PCR				MPC								
	[kg]			[kg]				[kg]				[kg]								
SDC	13064.0			13064.0				1920.4				11143.6								
GPB	8146.4			8146.4				1197.5				6948.9								
LO	21494.4			21494.4				3159.7				18334.7								
Legume	SMP		PP		N ₂		CAV		RO		ET	SPP	SCAV		SRO		SET		MPCI	
	[kg]		No.		[kg]		[kg]		[kg]		[kg]	[kg]	[kg]		[kg]		[kg]		[kg]	
SDC	55.7		22175.7		113.7		110.9		129.3		7.4		18.0	2.8	0.643		0.037		10.8	11452.8
GPB	34.7		13828.3		70.9		69.1		80.6		4.6		11.2	1.7	0.401		0.023		6.8	7141.7
LO	91.7		36486.1		187.0		182.4		212.7		12.2		29.6	4.6	1.058		0.061		17.8	18843.5
Legume	CA		SCA	EC	SEC	SC		SSC	MPCII	PAL		SPAL	EP	SEP	FP	SFP	MPCIII			
	No.		[kg]	[kg]	[kg]	[kg]		[kg]	[kg]	No.		[kg]	[kg]	[kg]	[kg]	[kg]	[kg]			
SDC	954.4		291.1	2.9	1.9	0.01		3.8	0.01	11746.8	77.0	385.8	0.8	0.5	0.002	22.2	0.11	12154.4		
GPB	595.1		181.5	1.8	1.2	0.00		2.4	0.01	7325.0	48.0	240.6	0.5	0.3	0.001	13.9	0.07	7579.2		
LO	1570.3		479.0	4.7	3.2	0.01		6.3	0.02	19327.1	126.7	634.7	1.3	0.8	0.004	36.6	0.18	19997.8		
Legume	RPL'				RCC'				RM'			MZ			PO+E					
	[kg]				[kg]				[kg]			[kg]			[kg]					
SDC	48.6				14.4				0.037			2745.6			1368.2					
GPB	30.4				9.0				0.023			1714.2			856.9					
LO	82.6				23.6				0.061			7976.4			7560.4					

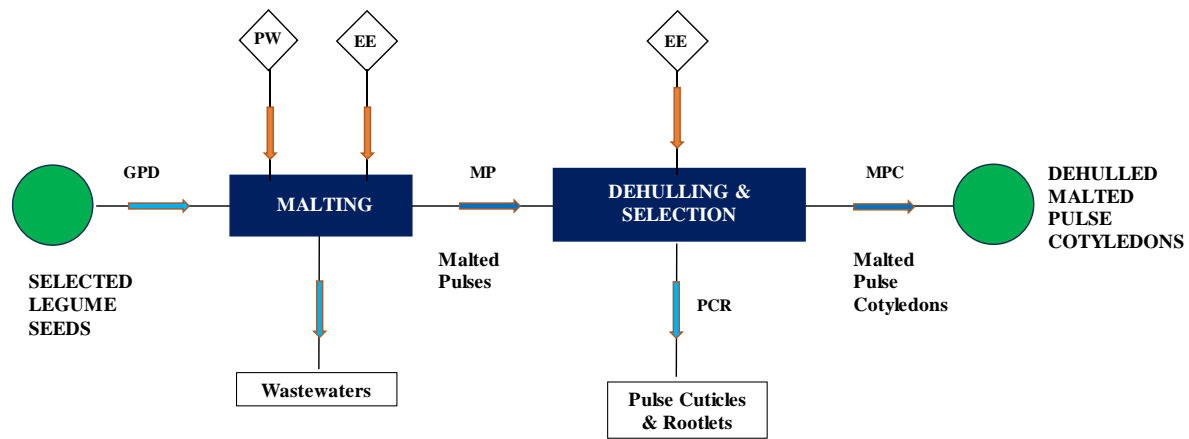


Figure S2.1. Block diagram of the malting, dehulling and selection process of selected legume seeds. For all symbols refer to the Nomenclature section.