SUPPLEMENTAL INFORMATION

SUPPLEMENTAL INFORMATION – TABLE S1. Material and energy inputs and outputs for the annual production in the Baseline scenario.

Input/Output	Type		Detail	Amount	Unit	Life (yrs)	Trans. dist. (km)
Material inputs	Growing media		Peat (Black)	1,952	kg	–	200
			Peat (White)	1,952	kg	–	200
	Seeds		Salad seeds	11.9	kg	–	100
			Filler (Clay)	48	kg	–	100
	Fertilization		Water	59,280	L	–	100
		Fertilizers	Nitrate	8	kg	–	100
			Ammonium	0.7	kg	–	100
			Phosphorus	9.2	kg	–	100
			Potassium	14	kg	–	100
			Sulphur	0.25	kg	–	100
			Boron	3.1	g	–	100
			Copper	1.3	g	–	100
			Iron	0.15	kg	–	100
			Manganese	0.17	kg	–	100
			Molybdenum	0.5	g	–	100
			Zinc	3.1	g	–	100
			Calcium	7.1	kg	–	100
			Magnesium	1.1	kg	–	100
	Carbon supplementation		CO_2	327	kg	–	100
	PH adjust		Phosphoric acid	33	kg	–	100
			Potassium hydroxide	38	kg	–	100
	Cleaner		Hydrogen peroxide	30	kg	–	100
	Packaging		Polyethylene	20	kg	–	100
			Cardboard	40	kg	–	100
Energy	Electricity		LEDs	44,100	kWh	–	–
			Pumps	5,400	kWh	–	–
			Motors/Controls	900	kWh	–	–
			HVAC	39,600	kWh	–	–

SUPPLEMENTAL INFORMATION – TABLE S1. (Continued).

Input/Output	Type		Detail	Amount	Unit	Life (yrs)	Trans. dist. (km)
Infrastructure	Container		Full-Size	1	unit	50	500
			Half-Size	1	unit	50	500
			Steel	20	kg	30	100
			Aluminum	10	kg	30	100
			Wood	20	kg	30	100
	Structure	LEDs	Aluminum	37	kg	6	100
			Steel	2.1	kg	6	100
			Diodes	4.5	kg	6	100
			HDPE	2.1	kg	6	100
			Wire	6.2	kg	6	100
		Structure	Steel	400	kg	40	100
			Plastic (ABS)	10	kg	30	100
		Plug trays	Polypropylene	73	kg	2	100
		Trays	Polyethylene	120	kg	5	100
		Shelves	Polystyrene	160	kg	10	100
		Irrigation	Tubing (PE)	5	kg	10	100
			Tanks (PE)	1.5	kg	10	100
	Electronics	Controls, etc.	Control units	10	kg	10	100
			Pumps	2	unit	10	100
			Other/Sensors	5	kg	10	100
		HVAC system	Air handling unit	1	unit	20	100
			Ducts, etc.	20	kg	40	100
Maintenance		Transport	Car travel	100	km	–	–
		Spare parts	Control units	4	kg	5	100
Main output		Lettuce		5,040	kg	–	–
Waste	Farm-Based	Biowaste		700	kg	–	50
		Plastic waste	Trays	19	kg	–	50
			Packaging	20	kg	–	50
			Other	20	kg	–	50
		Paper waste	Cardboard	40	kg	–	50
		Wastewater		145	L	–	–
	End-of-Life		Cafeteria waste	250	kg	–	50
Transport			Consumables	1,890	tonne-km	–	–
			Infrastructure	10	tonne-km	–	–
			Distribution	–	km	–	–
			Maintenance/Other	100	km	–	–
			Waste handling	53	tonne-km	–	–

Life cycle inventory data

SUPPLEMENTAL INFORMATION – TABLE S2. LCI data employed in the study.

Process	Category	Type	Subtype	Dataset
Material inputs	Growing media	Growing media	Peat	Market for peat moss | peat moss | Cutoff, S
	Seeds	Seeds	Salad seeds	Grass seed production, organic, for sowing | grass seed, organic, for sowing | Cutoff, S
			Filler (Clay)	Market for clay | clay | Cutoff, S
	Water nutrients	Water	Tap water	Market for tap water | tap water | Cutoff, S
		Fertilizers	Nitrate	Market for calcium nitrate | calcium nitrate | Cutoff, S
			Ammonium	Market for ammonium nitrate | ammonium nitrate | Cutoff, S
			P	Market for potash salt | potash salt | Cutoff, S
			K	Market for potassium fertiliser, as K_2O | potassium fertiliser, as K_2O | Cutoff, S
			S	Market for magnesium sulfate | magnesium sulfate | Cutoff, S
			B	Market for boron carbide | boron carbide | Cutoff, S
			Cu	Market for copper carbonate | copper carbonate | Cutoff, S
			Fe	Market for iron sulfate | iron sulfate | Cutoff, S
			Mn	Market for manganese dioxide | manganese dioxide | Cutoff, S
			Mo	Market for molybdenum trioxide | molybdenum trioxide | Cutoff, S
			Zn	Market for zinc oxide | zinc oxide | Cutoff, S
			Ca	Market for calcium nitrate | calcium nitrate | Cutoff, S
			Mg	Market for magnesium sulfate | magnesium sulfate | Cutoff, S
	PH adjust	Acid	Phosphoric acid	Market for phosphoric acid, fertiliser grade, without water, in 70% solution state | Cutoff, S
		Base	Potassium hydroxide	Market for potassium hydroxide | potassium hydroxide | Cutoff, S
	Cleaning agents		Hydrogen peroxide	Market for hydrogen peroxide, without water, in 50% solution state | Cutoff, S
	Packaging		Polyethylene	Market for packaging film, low density polyethylene | packaging film, low density polyethylene | Cutoff, S
			Cardboard	Market for corrugated board box | corrugated board box | Cutoff, S
	Other		Carbon dioxide	Market for carbon dioxide, liquid | carbon dioxide, liquid | Cutoff, S
Energy	Electricity	Swedish		Market for electricity, medium voltage | electricity, medium voltage | Cutoff, S
		Renewable electricity	Wind	Electricity production, wind, >3MW turbine, onshore | electricity, high voltage | Cutoff, S
				Electricity production, wind, 1–3MW turbine, onshore | electricity, high voltage | Cutoff, S
			Renewable mix	Market for electricity, medium voltage, renewable energy products | electricity, medium voltage, renewable energy products | Cutoff, S
		Nordic		Electricity, high voltage, production mix | Nordel-electricity, high voltage | Cutoff, S

SUPPLEMENTAL INFORMATION – TABLE S2. (Continued).

Process	Category	Type	Subtype	Dataset
Infrastructure	Container	Materials	Full size	Market for intermodal shipping container, 40-foot | intermodal shipping container, 40-foot | Cutoff, S
			Half size	Market for intermodal shipping container, 20-foot | intermodal shipping container, 20-foot | Cutoff, S
			Steel	Market for steel, chromium steel 18/8 | steel, chromium steel 18/8 | Cutoff, S
			Aluminum	Market for aluminium alloy, alli | aluminium alloy, alli | Cutoff, S
			Wood	Market for furniture, wooden | furniture, wooden | Cutoff, S
	LED	LEDs	Aluminum	Section bar extrusion, aluminium | section bar extrusion, aluminium | Cutoff, S
				Market for aluminium alloy, alli | aluminium alloy, alli | Cutoff, S
			Steel	Market for steel, chromium steel 18/8 | steel, chromium steel 18/8 | Cutoff, S
			Diodes	Market for light emitting diode | light emitting diode | Cutoff, S
			HDPE	Market for polyethylene, high density, granulate | polyethylene, high density, granulate | Cutoff, S
			Wire	Market for cable, unspecified | cable, unspecified | Cutoff, S
	Growing infrastruc-ture	Structure	Steel	Market for steel, chromium steel 18/8 | steel, chromium steel 18/8 | Cutoff, S
			Plastic (ABS)	Market for polyethylene, high density, granulate | polyethylene, high density, granulate | Cutoff, S
		Plug trays	Polypropylene	Polypropylene production, granulate | polypropylene, granulate | Cutoff, S
		Trays	Polyethylene	Market for polyethylene, high density, granulate | polyethylene, high density, granulate | Cutoff, S
		Benches	Polystyrene	Polystyrene production, high impact | polystyrene, high impact | Cutoff, S
		Irrigation	Tubing (PE)	Polyethylene terephthalate production, granulate, amorphous | Cutoff, S
			Tanks (PE)	Polyethylene terephthalate production, granulate, amorphous | Cutoff, S
			Plastic working	Injection moulding | injection moulding | Cutoff, S
		Controls, etc.	Control units	Market for electronics, for control units | electronics, for control units | Cutoff, S
			Pumps	Pump production, 40W | pump, 40W | Cutoff, S
			Other/Sensors	Market for inductor, miniature radio frequency chip | inductor, miniature radio frequency chip | Cutoff, S
		HVAC system	Air handling unit	Market for blower and heat exchange unit, KWLC 1200 | blower and heat exchange unit, KWLC 1200 | Cutoff, S
			Ducts, etc.	Market for steel, chromium steel 18/8 | steel, chromium steel 18/8 | Cutoff, S
Maintenance			Travel	Market for transport, passenger car, EURO 5 | transport, passenger car, EURO 5 | Cutoff, S
			Control units	Market for electronics, for control units | electronics, for control units | Cutoff, S

Supplemental Information – Table S2. (Continued).

Process	Category	Type	Subtype	Dataset
Waste/ Waste handling	Farm-based	Biowaste	Farm waste	Treatment of biowaste, industrial composting | biowaste | Cutoff, S
		Plastic waste	Trays	Treatment of waste plastic, mixture, municipal incineration | waste plastic, mixture | Cutoff, S
			Packaging	Treatment of waste plastic, mixture, municipal incineration | waste plastic, mixture | Cutoff, S
			Other	Treatment of waste polyethylene, for recycling, unsorted, sorting | waste polyethylene, for recycling, sorted | Cutoff, S
		Cardboard	Paper/Cardboard waste	Treatment of waste paper, unsorted, sorting | waste paper, sorted | Cutoff, S
		Waste water	Waste water	Treatment of wastewater, average, capacity 1.1e10l/year | wastewater, average | Cutoff, S
	End-of-Life		Plant waste (Consumer)	Treatment of municipal solid waste, incineration | municipal solid waste | Cutoff, S
			Plant waste (Digestion)	Treatment of biowaste by anaerobic digestion | biowaste | Cutoff, S
Transport			Consumables	Market for transport, freight, lorry 16–32 metric ton, EURO6 | transport, freight, lorry 16–32 metric ton, EURO6 | Cutoff, S
			Infrastructure	Market for transport, freight, lorry 16–32 metric ton, EURO6 | transport, freight, lorry 16–32 metric ton, EURO6 | Cutoff, S
			Other/Maintenance	Market for transport, passenger car, medium size, petrol, EURO 5 | transport, passenger car, medium size, petrol, EURO 5 | Cutoff, S
			Waste handling	Market for transport, freight, lorry 16–32 metric ton, EURO6 | transport, freight, lorry 16–32 metric ton, EURO6 | Cutoff, S

Circular scenario

The composition of conventional fertilizers was based on inputs from the producer. In order to understand the amount of fertilizer required, and the potential additional nutrient requirements, it was assumed that the nutrient levels were kept similar. As such, we calculated the demand for different nutrients. As outlined in Strandmark (2019), nitrification will be needed for the digestate-based biofertilizer. As the biofertilizer is in liquid form (20% dry matter (DM) content), derived from the liquid fraction of the it was assumed that this also reduced the water requirements, although additional water may be needed to reach the correct electrical conductivity in the nutrient solution. The modeling of the nutrient demand for the biofertilizer was based on work in Martin et al. (2022). No impacts are allocated to the digestate, which is due to the fact that the biofertilizer currently has no economic benefit for the biogas producer. However, impacts from the intermediate processing of the digestate for its use as a biofertilizer were included. It was assumed that roughly 3–5 kWh m^{-3} of digestate was required for a decanting centrifuge to separate the liquid and solid fractions of the digestate. For the nitrification process, electricity for aeration was also included.

Conventionally sourced lettuce import shares and distances

Based on data from IKEA, conventional lettuce sourcing takes place from several different regions; also varying seasonally. This includes lettuce imports from Spain, Germany, the Netherlands, and domestic production in Sweden. Imports from Germany, in addition to domestic production in Sweden, were assumed to be produced in open fields, greenhouses, and polytunnels, as they are sourced primarily during the summer months from these regions.

During other periods, the lettuce is assumed to be imported from Spain from open field and greenhouse production and the Netherlands from greenhouses. The share of different sources was provided by IKEA for an average year. These are outlined in Supplemental Table S3 below, denoting the country of origin and method of production.

SUPPLEMENTAL INFORMATION – TABLE S3. Share of imported lettuce from different regions during the year.

Country/Method		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ES	OF				20%	10%							
	GH	100%	100%	70%	50%	4%					10%	70%	100%
	PT			30%	30%	6%					10%	30%	
DE	GH					25%				20%	16%		
	OF					25%	40%	40%	40%	20%	24%		
NL	GH					20%					10%		
SE	OF						30%	60%	60%				
	PT					3%	30%						
	GH					7%				60%	30%		

OF: Open field; GH: Greenhouse; PT: Polytunnel; ES: Spain; DE: Germany; NL: The Netherlands; SE: Sweden.

We assumed that the lettuce was transported by refrigerated truck from the different locations to a repackaging and rinsing facility in Helsingborg before being shipped to IKEA. We assumed that roughly 20% of the lettuce is discarded along the supply chain, 10% of which occurring at the farm, 5% during the washing/rinsing phase, and roughly 5% of the lettuce is discarded before being plated. As such, for all imported salad, an extra 20% is required to allow for 1 kg of lettuce to be available for the end user. Supplemental Table S4 provides a review of the country of import and the assumed distances and travel method.

SUPPLEMENTAL INFORMATION – TABLE S4. Import regions, transportation distances and type of vehicle employed for conventionally sourced lettuce and final distribution.

Country of import	Transportation distance	Type of vehicle
Spain (Murcia–Helsingborg)	2,800	Transport, freight, lorry with refrigeration machine, 7.5–16 ton, EURO5, R134a refrigerant, cooling
France (Angers–Helsingborg)	1,600	Transport, freight, lorry with refrigeration machine, 7.5–16 ton, EURO5, R134a refrigerant, cooling
Germany (Baden–Helsingborg)	1,000	Transport, freight, lorry with refrigeration machine, 7.5–16 ton, EURO5, R134a refrigerant, cooling
Netherlands (Arnhem–Helsingborg)	820	Transport, freight, lorry with refrigeration machine, 7.5–16 ton, EURO5, R134a refrigerant, cooling
Sweden (Skåne–Helsingborg)	200	Transport, freight, lorry with refrigeration machine, 7.5–16 ton, EURO5, R134a refrigerant, cooling
Italy (San Marino–Helsingborg)	1,800	Transport, freight, lorry with refrigeration machine, 7.5–16 ton, EURO5, R134a refrigerant, cooling
Final distribution: Helsingborg-Malmö	100	Transport, freight, lorry with refrigeration machine, 7.5–16 ton, EURO5, R134a refrigerant, cooling

At the repackaging and rinsing facility, we assumed that 0.2 L of water and 0.5 kWh of electricity are required for the rinsing and packaging process per kg of lettuce. Furthermore, for the packaging it was assumed that 20 grams of LDPE and 60 grams of cardboard are required for the final packaging per kg of lettuce. All wastes produced in the packaging process are assumed to be sent for anaerobic digestion in a regional biogas plant (BAMA, 2023).

Conventionally sourced LCI data

Based on data from imported lettuce as outlined above, for the conventional supplies, data for the production of lettuce in Italian greenhouses was taken from Fusi et al. (2016), while data for lettuce from Spanish open-field production was taken from Casey et al. (2022). The aforementioned sources and methods were remodeled based on inventory data available in order to provide results that were comparable and employed the same LCIA methods and associated impact categories. This included only the production of the lettuce and not subsequent logistics for its availability for Swedish consumers, which is modeled as an additional process. We assumed that similar conditions were in place in Spain and Italy. As such, the data from Fusi et al. (2016) was also used to model a Spanish GH, and data from Casey et al. (2022) was used to model open-field production for the different regions (except for Sweden). For this, the input datasets which are regionally specific (e.g., the electricity) were changed to the local mix. For production from greenhouses in the Netherlands, data from Blom et al. (2022) was employed.

No data for Swedish lettuce production is available in the literature. As such, it was assumed that the lettuce is produced similarly to that in open-field and under polytunnels in France based on data from Agribalyse v 3.0. These datasets included *Lettuce, open field, conventional, at farm gate kg^{-1}* and the dataset *Lettuce, autumn under tunnel, conventional, at farm gate kg^{-1}*, respectively. Finally, a Swedish greenhouse was also modeled based on the Fusi et al. (2016) study, where again the regional input datasets were changed to Swedish datasets (i.e., the electricity).

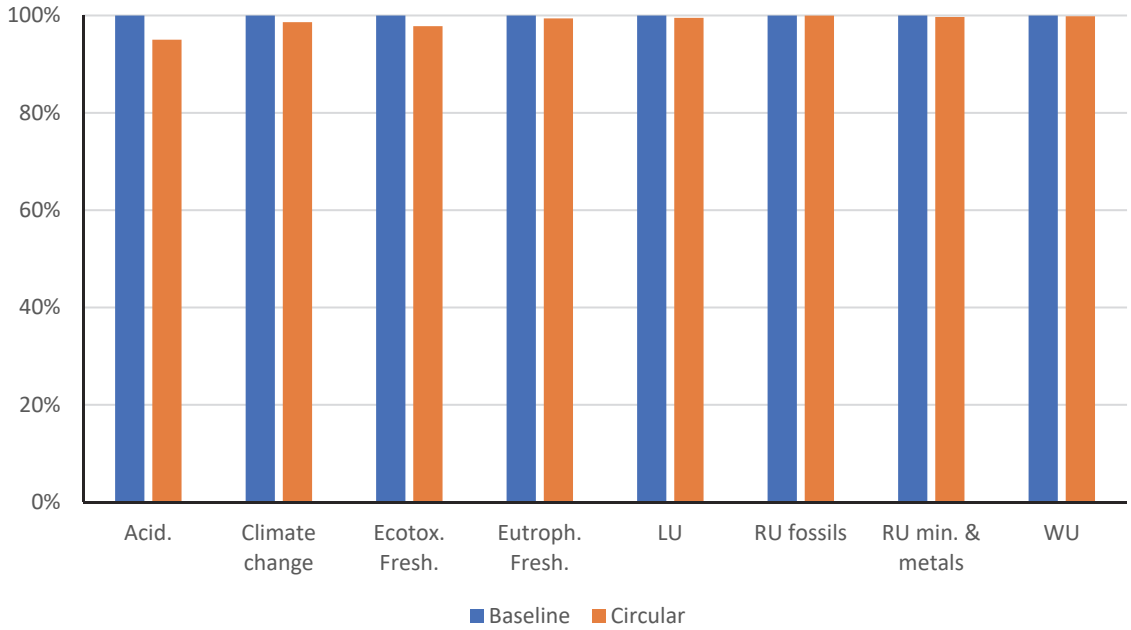
SUPPLEMENTAL INFORMATION – TABLE S5. LCI data employed for modeling 1 kg of Spanish open-field produced lettuce based on Casey et al. (2022).

Input/Emission	Description	Unit	Amount	LCI Dataset
Fertilisers	Nitrogen	kg	0.013	Market for nitrogen fertiliser. as N | nitrogen fertiliser. as N | Cutoff. S
	Phosphorus	kg	0.01	Market for phosphate fertiliser. as P_2O_5 | phosphate fertiliser. as P_2O_5 | Cutoff. S
Other inputs	Electricity	kWh	0.059	Market for electricity, medium voltage, ES
	Diesel	kg	0.006	Market for diesel, Europe
	Pesticide	kg	0.0003	Market for pesticide, unspecified | pesticide, unspecified | Cutoff, S
	Water	L	58.2	Tap water production, conventional treatment | tap water | Cutoff, S
Field emissions	N_2O to air	kg	0.0001	Nitrous oxide
	NH_3 to air	kg	0.002	Ammonia
	CO_2 to air	kg	0.008	Carbon dioxide
	P to water	kg	0.0001	Phosphorus
	N to water	kg	0.001	Nitrogen

SUPPLEMENTAL INFORMATION – TABLE S6. LCI data employed for modeling 1 kg of Italian greenhouse produced lettuce based on Fusi et al. (2016).

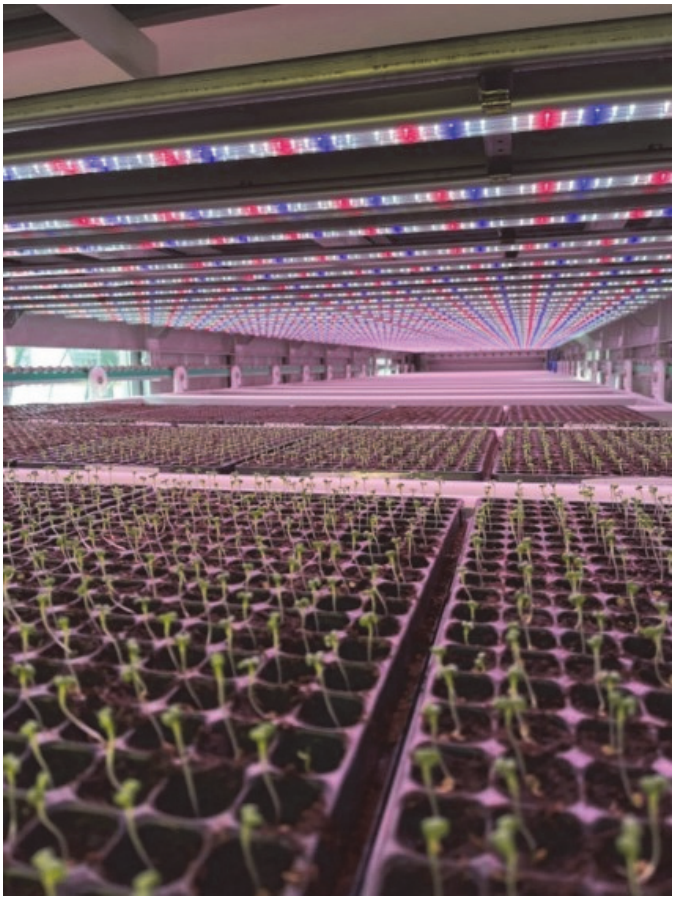
Input/Emission	Description	Units	Value kg^{-1}	LCI dataset
Seeds	–	mg	2,522.9	Market for grass seed, Swiss integrated production, at farm | grass seed, Swiss integrated production, at farm | Cutoff, S - GLO
Compost from cow and horse manure	Organic fertilizer	g	275.2	Market for compost | compost | Cutoff, S - GLO
Fosetyl-Al	Pesticide	mg	169.5	Market for fosetyl-Al | fosetyl-Al | Cutoff, S - GLO
[Thio] carbamate-compounds (Propamocarb)	Pesticide	mg	289.7	Market for [thio]carbamate-compound | [thio]carbamate-compound | Cutoff, S - GLO
[Sulfonyl]urea-compounds (Benfluralin)	Pesticide	mg	344.0	Market for [sulfonyl]urea-compound | [sulfonyl]urea-compound | Cutoff, S - GLO
Diesel fuel	Fuel	g	35.7	Market for diesel | diesel | Cutoff, S - Europe without Switzerland
Water	–	L	164.4	Market for tap water | tap water | Cutoff, S - Europe without Switzerland
Electricity for irrigation	–	kWh	0.2	Market for electricity, medium voltage | electricity, medium voltage | Cutoff, S - IT
LDPE film (greenhouse)	–	mg	281.4	Market for packaging film, low density polyethylene | packaging film, low density polyethylene | Cutoff, S - GLO
Land	–	m^2	1.8	Land use change, annual crop | land use change, annual crop | Cutoff, S - IT
Salad	–	g	1,000.0	
Carbon dioxide	From diesel fuel	g	134.1	Carbon dioxide (emission to air, unspecified)
Carbon monoxide	From diesel fuel	mg	690.0	Carbon monoxide (emission to air, unspecified)
Nitrogen oxides	From diesel fuel	mg	1,184.6	Nitrogen oxides (emission to air, high population density)
Particulate	From diesel fuel	mg	102.9	Particulates (emission to air, unspecified)
Hydrocarbons	From diesel fuel	mg	135.3	Hydrocarbons, unspecified (emission to air, indoor)
Dinitrogen monoxide	From fertilizer	mg	77.0	Dinitrogen monoxide (emission to air, unspecified)
Ammonia	From fertilizer	mg	835.5	Ammonia (emission to air, unspecified)
Benfluralin	From herbicide	mg	34.4	Benfluralin (emission to air, unspecified)
Fosetyl-Al	From fungicide	mg	16.9	Fosetyl-aluminium (emission to air, unspecified)
Propamocarb	From fungicide	mg	29.0	Propamocarb (emission to air, unspecified)
Benfluralin	From herbicide	mg	34.4	Benfluralin (emission to water, unspecified)
Fosetyl-Al	From fungicide	mg	16.9	Fosetyl-aluminium (emission to water, unspecified)
Propamocarb	From fungicide	mg	29.0	Propamocarb (emission to water, unspecified)
Benfluralin	From herbicide	mg	258.0	Benfluralin (emission to soil, agricultural)
Fosetyl-Al	From fungicide	mg	127.8	Fosetyl-aluminium (emission to soil, agricultural)
Propamocarb	From fungicide	mg	217.3	Propamocarb (emission to soil, agricultural)

Further results



SUPPLEMENTAL INFORMATION – FIGURE S1. Comparison of the environmental impacts between the Baseline and Circular scenarios (Acid.: Acidification; Ecotox. Fresh.: Ecotoxicity freshwater; Eutroph. Fresh.: Eutrophication freshwater; LU: Land use; RU fossils: Resource use fossils; RU min. & metals: Resource use-minerals and metals; WU: Water use).

Depiction of container



SUPPLEMENTAL INFORMATION – FIGURE S2. Depiction of the lettuce in the container as seedlings (Source: IKEA).

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