atmosphere

Supplementary Materials

Life Cycle Assessment of a Prospective Technology for Building-Integrated Production of Broccoli Microgreens

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Results are first presented in depth for GWP to more easily depict all major find-ings using a single category only, and to identify the main contributors. Results are shown for both supply scenarios (CS and LS) and the renewable energy variation (PV). Finally, the results of ecotoxicity indicators are presented in Section 3.2. The analysis and explanation of results is included in the Discussion section. (Table S1)

Table S1. Data for GWP

		18.58		22.22							20%	
Impact category	**Reference unit**	**CS**	**CS-PV**	**LS**	**LS-PV**		**CS to PV % change**		**LS to PV % change**		**CS to LS % change**	
Freshwater Ecotoxicity (kg 1,4-DCB)	kg 1,4-DCB	1.59	1.28	3.19	2.89	FE	-19%	123.93	-10%	110.61	101%	49.67
Marine Ecotoxicity (kg 1,4-DCB)	kg 1,4-DCB	2.11	1.74	4.21	3.84	ME	-18%	121.33	-9%	109.63	100%	49.96
Terrestrial Ecotoxicity (kg 1,4-DCB)	kg 1,4-DCB	79.88	89.39	85.53	95.03	TE	12%	89.36	11%	90.00	7%	93.40
Human Toxcity (kg 1,4-DCB)	kg 1,4-DCB	26.46	22.96	60.86	57.36	HT	-13%	115.23	-6%	106.10	130%	43.48

Table S2. Data for Ecotoxicity

	18.58		22.22	
Impact category	**CS**	**CS-PV**	**LS**	**LS-PV**
Freshwater Ecotoxicity	1.59	1.28	3.19	2.89
Marine Ecotoxicity	2.11	1.74	4.21	3.84
Terrestrial Ecotoxicity	79.88	89.39	85.53	95.03
Human Toxcity	26.46	22.96	60.86	57.36

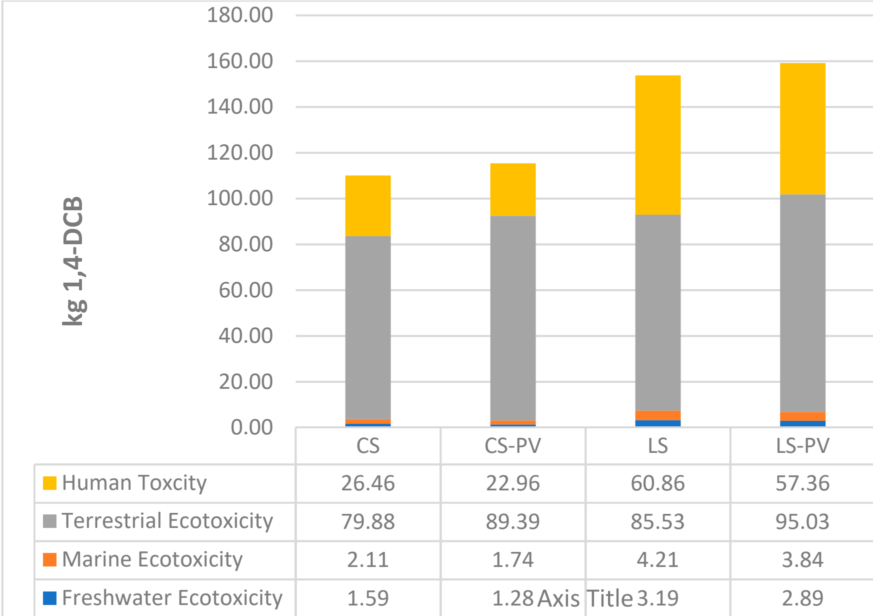

Figure S1. Graph for Ecotoxicity

LCA Inventory

The following are the details of material inputs applied in the Circular and Linear supply chain LCA model developed in OpenLCA.

Includes materials required for all infrastructure related to the installation and integration of the IVF with the building, Technology Infrastructure has a life time of 20 years to produce 54,6 ton of broccoli annually.

Equipment with lifetime of 10 years or 27,3 ton of broccoli; LED, sensors, harvest and trays.

LCI Infrastructure of the building-integrated IVF technology, grouped by equipment types of Indoor Vertical Farm (IVF), hydroponic system, work area, Internet of Things (IoT) and Photovoltaic System (PV), the latter applicable to the renewable energy scenarios only. (More detailed in Table S3)

Table S3. Indoor Vertical Farm Infrastructure.

Technology	Process	Input	Amount	Unit
Indoor Vertical Farm (IVF)	Grow Chamber	Polystyrene slab and Aluminum	580.000	Kg
		Cladding, crossbar-pole, aluminum	150.700	m2
	Floor Covering	Epoxy resin insulator, SiO2	123.000	Kg
		Tap Water		
	Trays	PVC, Bulk, polymerized	168.000	kg
		Extrusion of Plastic Sheets		
	Racks	Steel, low-alloyed	280.000	Kg
	Pipes	PVC, Bulk, polymerized plastic Pipes	31.800	Kg
	Clamps	Steel, chromium steel 18/8	3.560	Kg
	Valves	Brass, Tetrafluoroethylene	1.200	Kg
	Cables	cable, three-conductor cable	46.170	m

	Light Emitting Diode (LED)	aluminum, section bar, LED, transformer	251.200	Kg
		Electricity, low voltage	57000.000	MJ
		cable, three-conductor cable	5.300	m
	Assembly	Electricity	106.920	MJ
	Land Use	Occupation, urban built	22.000	M2
	Transport	Freight, lorry 3.5-7.5 metric ton	72.000	t*km
	Climate Control	Air compressor 4kW, Ventilation System, 10 kW / Heat pump, diffusion absorption 4kW	3.000	Item
Hydroponic System	Pipes	PVC, Bulk, polymerized	6.870	Kg
	Clamps	Steel, chromium steel 18/8	17.500	Kg
	Valves	Brass, Tetrafluoroethylene	3.200	Kg
	Water Pump	Water pump 22kW	1.000	Item
Work Area	Work Room	Polystyrene slab and Aluminum	386.000	Kg Kg
		Cladding, crossbar-pole, aluminum	100.000	m2
	Land Use	Occupation, urban built	14.700	M2
	Harvest	electronics equipment	2.200	kg
		metal bench work space	277.185	kg
		polyethylene, plastic equipment	28.245	kg
		chromium steel trolley & trays	277.185	kg
Internet of Things (IoT) Hub	Sensors	Metals, electronic unit, plastics, rubber and coating	1.91547	kg
	Main Hub	Electronics and electrical fuses, switches, meter, circuitary.	136	Item
	Hub Screen and internet	Wifi Router and display interface	2	Item
	Cables	Metals and plastics for cables, ducting and mounting rail	11.016	Kg
Photovoltaic System	Solar Panels	photovoltaic facade installation, 3kWp, multi-Si, panel, mounted, at building	10	Item

Developed based on the integrated controlled environment agriculture system installed within the IVF, the table outlines the primary electronics and communications equipment. This includes all components of the IVF interface panel and materials required to offer a software operated system. The life time assumes is 20 years for replacement.

Sensors were based on Schiender Electric products, 6 Weather station Sensors (KNX - CO^2, Humidity and Temperature substitute for real sensor), 2 Communication Sensors (Harmony Hub), 1 Controlador (M241).

Photovoltaic System

The PV System infrastructure was designed to provide energy for the most demanding period of functioning of the vertical farm, that which LEDs and Climate control are on at the same time. This period corresponds to the period of plant growth and therefore lasts for 12 hours.

During this period the LEDs consume every hour 6,53 kWh and the Climate control 4,47 kWh totalizing 132 kWh/day or (aprox) 4 MWh/month (around 70% of total consumption in Baseline).

Since the photovoltaic production varies throughout the year, it is impossible to full fill this energy requirement without batteries or extreme overproduction. In order to acess the impacts of such a systes it was assumed that the system only had to produce the amount of energy needed for the growing phase as yearly average. In that way there is no energy injected in to the grid and the growing phase is fully fed by photovoltaics.

Using the tool "https://re.jrc.ec.europa.eu/pvg_tools/en/" (accessed on 11 August 2022) it was possible to determine the energy generated monthly with a 1kWp pannel in the worst (winter) and best (summer) case, with an average of 130kWh.

The input from EcoInvent 3.8 "photovoltaic facade installation, 3kWp, multi-Si, panel, mounted, at building" from a global market provider was used to estimate the impacts of building such infrastructure. Its lifetime of 30 years (as in EcoInvent) allows a production of 82,1 tons of brocolee .

Due to seasonal variation in weather and its impact on energy generation, a PV system in reality could not fulfill the total energy demand without batteries or extreme over production. To address this, we assumed the monthly electricity demand as a fixed amount of 4620 kWh with no excess electricity stored or transferred into the energy grid. The size of the PV infrastructure required was determined using the Photovoltaic Geographical Information System [55]. According to this tool, monthly solar in-plane irradiation of the region in Lisbon varies between 116 kWh/m^2 in winter and 222 kWh/m^2 in summer. The tool then calculated that a 3-kWh solar installation without shadowing enables the monthly production of 313 kWh in winter and 555 kWh in summer. The average of these values was applied to estimate the monthly production of a 3-kWh installation as 463 kWh. Covering the fixed electricity demand of 4620 kWh thus required 10 items (PV panels) (Table S4).

Table S4. Calculation of the number of 3kWp panels needed.

Growing Consume per day (kwh)	Summer Produce per day (kwh)	Winter Produce per day (kwh)
132	180/30 *3 = 18	100/30 *3 = 10
Consume per month (kwh)	Panels	Panels
3 960	132/18=7.3333	132/10=13.2

Processes

LCI of the processes applied for IVF operations with the system boundary 6 processes: Seeding, Growing, Harvest, Packaging, and Delivery are provided with material inputs. Units describe the total volume of inputs per kilograms of fresh weight (kg/kg FW), electricity is measure in mega-joules per fresh weight (MJ/kg FW), water in liters (L/kg FW) and kilometers for transportation (km/kg FW). (More detailed in Table S6)

Table S5. Process (All units per Function unit of 1 kg of Fresh Weight).

Process	Input	Amount	Unit
Seeding	Polyethylene (from Trays)	2,31	g / kg FW
	Extrusion of plastic Sheet		
	Coconut fiber	3,456	Kg / kg FW
	Cauliflower Seeds	0,070	Kg / kg FW
Growing	Tap water	17	L / kg FW
	NPK (15-15-15) fertilizer	21,42	g / kg FW
	Electricity (LEDs)	37,63	MJ / kg FW
	Sensors	1 / LT	Group
	Electricity (Equipment)	48	MJ / kg FW
Harvest	Equipment	1 / LT	Group
	Compost	3.456	Kg
Cleaning	cleaning consumables, without water, in 13.6% solution state	0,751	kg / kg FW
	Electricity	0,0922	MJ / kg FW
	Water	150	L / kg FW
	Soap	1,9	g / kg FW
	polyethylene terephthalate, granulate, amorphous	0,94	g / kg FW
	Tissue Paper	5,7	g / kg FW
	Clothes	1/LT	Group
Compost			
Packaging	1-propanol	0.0048	kg
	diesel	2.00E-04	kg
	ethanol, without water, in 99.7% solution state, from ethylene	0.0055	kg
	ethyl acetate	0.0012	kg
	polyethylene, high density, granulate	0.0276	kg
	polyethylene, low density, granulate	0.0324	kg
	toluene, liquid	0.0017	Kg
	ethanol, without water, in 99.7% solution state, from ethylene	0.0055	kg
	ethyl acetate	0.0012	kg
	polyethylene, high density, granulate	0.0276	kg
	polyethylene, low density, granulate	0.0324	kg
	toluene, liquid	0.0017	Kg
Labels	stretch blow moulding	2.34E-02	kg
	polypropylene, granulate	1.38E-02	kg
	polyethylene terephthalate, granulate, bottle grade	9.60E-03	kg
	electricity, low voltage	9.18E-03	MJ

Collapsed version

Table S6. IVF Operating Processes.

Process	Input	Amount	Unit
Seeding	Trays (Polyethylene)	2.31	g / kg FW
	Extrusion of plastic Sheet		
	Substrate (Coconut fiber)	3	Kg / kg FW
	Seeds	0.07	Kg / kg FW
Growing	Tap water	17	L / kg FW
	NPK (15-15-15) fertilizer	21.42	g / kg FW
	Electricity (LEDs)	37.63	MJ / kg FW
	Sensors	1 / LT	Group
	Electricity (Equipment)	48	MJ / kg FW
Harvest	Equipment	1 / LT	Group
	Compost	3.456	Kg
Cleaning	Dry cleaning consumables, plastics, and tissue papers	7.391	kg / kg FW
	Electricity	0.0922	MJ / kg FW
	Water	150	L / kg FW
	Soap	1.9	g / kg FW
	Clothes	1/LT	Group
Packaging	Electricity (lighting)	0.09216	MJ / kg FW
	Electricity (sealing bags)	0.030732	MJ / kg FW
	Plastic bags	10	Items / kg FW
	Labels	10	Items / kg FW
	Cardboard box	0.186667	kg / kg FW
Delivery	Truck with refrigeration machine	12.7007	kg*km / kg FW

Process Assumptions

Cauli Flower Seeds

Our function for broclee seeds was a copied from Agribalyse "Cauliflower seed, conventional, at production site/FR U" that has an output of 190 kg. It was made two alterations so it could be replicated in EcoInvent. Firstly, since cauliflower seeds function has dependency on seeds, and the seeds have dependency on seeds, there was an input loop). To solve that, inputs from seedlings and seeds were combined and transferred to EcoInvent based on a solution of the 2-variable system, writing the Seeds function without dependency on seedlings. This function had the output slightly less than 190kg. The, the input amount were calculated for 1kg of seed with unit conversion when it was necessary (conversion factors in table). The function is sent separated

Coconut Fiber

The function that produces Coconut fiber has the same inputs as Agribalyse "Coconut fiber, at regional storehouse/kg". The only difference is that in Agribalyse the Coconut dehusked had "0" amount. From literature we have chosen the ratio between Coco Fiber and Coco Deshusked to be 75%. Then it is necessary 1,33 kg of coconut husk to produce 1 kg of coco FIbre.

Table S7. Coconut fiber.

Flow	Unit	Amount
Coconut dehusked, coconut husk	kg	1,33333
electricity, high voltage	MJ	0,406799675
extrusion, plastic film	kg	0,045

polyethylene, low density, granulate	kg	0,045
transport, freight, lorry 16-32 metric ton, EURO5	t*km	0,035
transport, freight, lorry >32 metric ton, EURO5	t*km	0,26
transport, freight, sea, container ship	t*km	11,2

Table S8. Equipment for Processes. Clothes (lifetime 1 year).

Equipment	Input	Amount	Unit
Clothes	textile, woven cotton	0,7	Kg
Glasses	polyurethane, flexible foam	0,02	Kg
	Polycarbonate	0,08	
Hair net	textile, nonwoven polypropylene	0,05	Kg
Gloves	Nylon 6	0,006	Kg

Packaging

We assumed each plastic bag has an area of 20x20 cm^2 and its empty weight is 6 grams. To package 1kg of broccoli divided in 100 grams bags we need 10 bags and so 10 labels. Regarding the electricity needed for the sealing process, from the literature we chose as referential data 6.3 kW for conducting 3 cycles in 1 min, from which we obtained 0.8537 Wh/ bag as our electricity input.

Assumption on carton box total capacity is of 10 kg and, from measurements, a similar box empty weight is 0.70 kg. To cover the total amount of daily bags used we need two of them, thus 1.4 kg.

Table S9. Plastic bags (x10).

Inputs	Unit	Amount
1-propanol	0.0048	kg
diesel	2.00E-04	kg
ethanol, without water, in 99.7% solution state, from ethylene	0.0055	kg
ethyl acetate	0.0012	kg
polyethylene, high density, granulate	0.0276	kg
polyethylene, low density, granulate	0.0324	kg
toluene, liquid	0.0017	kg

Labels production

For the “Labels production” process, we decided to copy only those inputs which are applied to each plastic bag.

Table S10. Labels (x10).

Inputs	Unit	Amount
stretch blow moulding	2.34E-02	kg
polypropylene, granulate	1.38E-02	kg
polyethylene terephthalate, granulate, bottle grade	9.60E-03	kg
electricity, low voltage	9.18E-03	MJ

Delivery assumptions

We are assuming the total packaged broccoli weight is made of:

- Broccoli leaves = 1 kg
- LDPE + HDPE + Carton box from Packaging = 0.24667 kg
- Polypropylene + PET from Labels = 0.0234

Total = 1.27007 kg

The distance taking into account is of 10 kms radius.

To model the vehicle used, the process '*transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO6, R134a refrigerant, cooling*' was selected from the EcoInvent database. It was assumed the vehicle was made after 2015, and as such, adheres to the Euro 6 European emission standard (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32007R0715) (Accessed on 11 August 2022).

The refrigerant chosen for the cooling cycle is R134a, as it is more commonly used than CO2 for this application in Portugal.