

SUPPLEMENTARY MATERIALS

Table S1. Nature-Based Solutions (NBS) units covered in this study and their commonly-used constituent materials, broken down into types (organic, mineral and synthetic) and specifying their circularity aspects and impacts and benefits.

NBS Unit	Material			Material			Material			Output							
	Organic (e.g. plant-based)	CE aspects (recycle, recyclable)	Impacts and benefits (e.g. energy demand, carbon emissions)	Mineral (e.g. based on soil, clay, lime, metals)	CE aspects (recycle, recyclable)	Impacts (e.g. energy demand, carbon emissions)	Synthetic (e.g. plastics)	CE aspects (recycle, recyclable)	Impacts (e.g. energy demand, carbon emissions)								
Ground-based green facade	1# vegetation (ivy, vines, <i>Parthenocisus</i> , wisteria)	1# recyclable (if sustainably managed); locally adapted species and non-invasive	1# water demand; possibility of reuse appropriately treated wastewater (especially grey) and rainwater; carbon capture and sequestration (more sequestration in the soil due to ground based system); improving the thermal performance of the building; microclimate moderation; biodiversity promotion and habitat creation (pollinators, birds etc)	1# metal frame and mechanical connectors for mounting (e.g., steel, aluminium, wires)	1# reuse; partially recyclable (reuse or recycling is labor and energy intensive)	1# highly intensive energy; high carbon emissions	1# plastic frame (e.g. PVC, Polyethylene) and mesh (e.g. Polyester)	1# in general less recycle source material (due to difficulties in processes and waste separation); recyclable (less difficult in terms of waste separation, depending on the type of polymers), take into account the value chain of plastic and ecodesign; not biodegradable	1# needed for specific treatment and disposal; high environmental impact and energy demand/use on the production; plastic is less recyclable than organic material; plastic degradation due to UV exposure and off-gassing	# Support for climate change mitigation and adaptation with organic materials							
	2# wooden frame – durable & resistance (e.g., pine)										2# recycle (sustainable source); recyclable; reuse of elements for the frame	2# soil	2# recycle, recyclable depending on soil quality	2# soil contamination by e.g. pesticides, carbon capture	2# expanded polystyrene as soil layer substrate	2# embodied energy intensive; high environmental impact and energy demand/use on the production	# Enriched soil
	3# substrate component: cork, wood chips as mulch										3# very location depended, recycle, recyclable	3# light weight mineral materials: . expanded clay . expanded vermiculite . perlite . volcanic clay . tuff . pumice	3# potential for recycle and recyclable	3# relatively energy consumption depending on the sourcing			# biomass from pruning
	4# maintenance inputs (time-based): fertilizer, etc. (qty per year, season etc)											3# location dependent; potentially carbon negative (depending of the productive				2# potential reuse but difficult due to soil separation process	# edible plant products

			process); promotion of soil aeration and soil quality							
Wall-based green facade	1# vegetation		1# possibility of using non-climbing plants but limitation on plants requiring large soil volumes	1# larger requirement for metals for planters and supporting structure 2# other mineral substrate rather than local soil		# due to removal of containers the contribution to the building overall thermal performance and energy efficiency	1# larger requirement for plastic both in substrate and supporting system pipes			
Pot-based green facade			# possibility of using non-climbing plants but limitation on plants requiring large soil volumes	# other mineral substrate rather than local soil		# due to removal of the containers the contribution to the building overall thermal performance and energy efficiency				
Vegetated pergola	1# vegetation 2# wood frame	2# in general recycle and recyclable	1# provides shade for occupied areas 2# more material required #foundations required	# metal frame	# in general, recycle and recyclable	# more material required #foundations required				
extensive green roof	1# Drainage layer (cork) 2# Vegetation	1# recyclable recycle 2# recyclable (if sustainably managed); locally adapted species and non-invasive	1&2# Negative carbon 1&2# carbon sink #potential cooling device	1# Substrate (expanded clay) 2# Substrate (compost)	1# recyclable 2# recycle	# reduce the heat load on the roof and on the building	1# Filter layer (textile) 2# Drainage layer (HDPE)	1# recyclable 2# 100% recycled HDPE # extended life of the building due to protection by green layers		# potentially filtered rainwater

Table S2. Material inputs included in Life-Cycle Inventory for green roofs (GR) in previously published Life-Cycle Assessment (LCA) studies.

Reference	GR Type	Related Life Cycle Phase	GR Layer	Input Material	Amount per m ² of GR
[76]	Extensive / Intensive	Manufacturing / Construction	Root barrier	Low density polyethylene (recycled and non-recycled)	0.46 kg / 0.46 kg
			Drainage	Semi-Crystalline polypropylene (recycled and non-recycled)	14.25 kg / 38.0 kg
			Water retention	Polymeric fibers	9.5 kg / 14.25 kg
[92]	Lightweight	Manufacturing / Construction	Protection layer	Nonwoven polypropylene: lighter / heavier	0.3 / 0.5 kg
			Drainage layer	High impact polystyrene: recycled HIPS / virgin HIPS	1.30 kg / 1.30 kg
			Water retention	Recycled textile fibers / Rockwool (Grodan)	1.2 kg / 4.8 kg
			Filter layer	Nonwoven polypropylene: lighter / heavier	0.15 kg / 0.2 kg
			Substrate	Expanded clay (10%) + Crushed brick (80%) + Compost (10%) / Compost (15%) + sand (15%) + pumice (70%)	100 kg / 100 kg
[94]	Extensive/Intensive	Construction	Waterproof membrane	SBS membrane	4.0 kg / 5.0 kg
			Thermal insulation	Foam boards	1.15 kg / 2.88 kg
				Root barrier	0.33 kg / 1.12 kg

				Drainage	2.0 kg / 2.3 kg
				Filter sheet	0.99 kg / 0.99 kg
			Substrate layer	Sand	132.2 kg / 961.2 kg
				Fertilizer	0.99 kg / 1.59 kg
				Pozzolan	56.42 kg / 387.0 kg
				Perlite	28.87 kg / 197.99 kg
[98]	Extensive with shallow coarse aggregate mineral substrate	Construction	Waterproof/root-barrier membrane	Double-bitumen, APP	8 kg
			Protection sheet	Polypropylene	0.50 kg
			Expanded drain membrane	Polystyrene	0.95 kg
			Filtration sheet	Polypropylene PP	0.15 kg
			Coarse substrate	Aggregate substrate 73 x 0.78 m ³	117 kg
			Pipe	Polyethylene pipe Φ16 1400 m	0.186 kg
	Extensive with shallow coarse aggregate mineral substrate	Construction	Waterproof- anti-root membrane	Polyolefin or LDPE	2.20 kg

			Protection sheet	Polypropylene	0.30 kg
			Expanded drain membrane	Polystyrene (Diatherm-60)	0.95 kg
			Filtration sheet	Polypropylene PP	0.15 kg
			Coarse substrate	Aggregate substrate 73 x 0.78 m ³	97.10 kg
			Pipe	Polyethylene pipe Φ 16 1400 m	0.190 kg
	Semi-intensive (at ground floor) and adaptive-extensive (at first floor) with coarse aggregate mineral substrate	Construction	Waterproof/root-barrier membrane	Double-bitumen, APP	8.00 kg
			Protection sheet	Polypropylene	0.50 kg
			Expanded drain membrane	Polystyrene	0.95 kg
			Filtration sheet	Polypropylene PP	0.15 kg
			Coarse substrate	Aggregate substrate 73 x 0.78 m ³	117 kg
			Pipe	Polyethylene pipe Φ 16 1400 m	0.186 kg
	Extensive with a 5-cm rockwool as substrate	Construction	Waterproof- anti-root membrane	Polyolefin or LDPE	2.20 kg
			Protection sheet	Polypropylene	0.30 kg

			Drain membrane	Polypropylene	1.30 kg
			Filtration sheet	Polypropylene PP	0.15 kg
			Rockwool substrate	8 cm deep rockwool substrate	12.00 kg
			Pipe	Polyethylene pipe Φ 16 1400 m	0.186 kg
[30]	Extensive	Construction	SBS membrane	Polyester	0.4 kg
			Thermal insulation	Polystyrene foam slab	0.012 kg
			Root barrier	Polyethylene	0.015 kg
			Drainage layer	Polyethylene	0.089 kg
			Filter sheet	Polypropylene	0.004 kg
			Soil	Solid manure	0.25 kg
			Peat	Peat	0.427 kg
			Pumice	Pumice	0.1 kg
			Fertilizer	Nitrogen fertilizer	0.001 kg
			Vegetation	Sunflower seed	6 plants

[93]	Extensive	Construction	Support layer	Pine wood	25 kg
			Protection layer	Polyethylene	0.76 kg
			Growth substrate layer	Soil and compost	100 kg and 25 kg
			Canopy layer	grass	1 kg
	Intensive	Construction	Anti-root barrier	Recycled LDPE	0.175 kg
			Drainage and filtration	Recycled HIPS	1.252 kg
			Water reserve	Hydrophilic mineral wool	6 kg (dry) 46 kg (saturated)
			Mixture of recycled soil and organic fertilizer	Crushed tile / Poultry manure	200 kg / 50 kg
			Vegetation	Low growth bushes	10 kg
[99]	Extensive	Construction	Roof barrier	PVC	0.016 kg
			Protection layer	Polypropylene sheet	0.30 kg
			Drainage layer	Polystyrene	1.75 kg
			Filter layer	Polypropylene sheet	0.10 kg
			Soil	Gravel / Sand / Kaolin	152.2 kg / 12.8 kg / 51.3 kg
			Plant	Sedums	10 kg

	Intensive	Construction	Roof barrier	HDPE	0.385 kg
			Protection layer	Polypropylene sheet	0.60 kg
			Drainage layer	Gravel / Bentonite / Kaolin	76.1 kg / 20 kg / 25.63 kg
			Filter layer	Polypropylene sheet	0.60 kg
			Soil	Gravel / Sand / Kaolin	1522 kg / 128 kg / 513 kg
			Plant	Up to 3000 mm	30 kg

Table S3. Material inputs included in Life-Cycle Inventory for vertical greening systems (VGS) in previously published Life-Cycle Assessment (LCA) studies.

Reference	VGS Type	Related Life Cycle Phase	VGS Layer	Input Material	Amount per m ² of VGS
[109]	System S1 is made of HDPE modules supported on a steel structure	Production of VGS components	Fastening components	Steel S235	5.21 kg
			Vegetation support elements	HDPE	13.20 kg
			Substrate	Potting soil	75.60 kg
			Vegetation	Pteropsida	8.00 kg
			Irrigation system	PE	0.26 kg
	System S2 consists of modules comprising an underlayer made of alkali-activated precast slab and a top layer of expanded cork	Production of VGS components	Fastening components	Stainless steel	3.20 kg
			Vegetation support elements	Mine waste mud; Milled waste glass; Black cork granules Sodium silicate; Sodium hydroxide; ICB Glue; EPDM	24.40 kg

	agglomerate, fixed to the façade using a stainless-steel structure		Substrate	Light weight substrate	29.70 kg
			Vegetation	<i>Sedum album</i>	5.90 kg
			Irrigation system	PE	0.80 kg
System S3 uses HDPE planter boxes supported on a structure made of stainless steel and galvanized iron	Production of VGS components	Fastening components	Stainless steel; Galvanized iron	40.50 kg	
		Vegetation support elements	HDPE	6.00 kg	
		Substrate	Sandy soil; Expanded clay aggregate	3.60 kg	
		Vegetation	<i>Peperomia claviformis</i>	18.00 kg	
		Irrigation system	PE	0.50 kg	
System S4 consists of plastic modules supported on an aluminium structure and other layers made of polyester and polypropylene	Production of VGS components	Fastening components	Aluminium	0.60 kg	
		Vegetation support elements	Polyester; PP	2.09 kg	
		Substrate	Coconut fibre; Turf; Humus	4.00 kg	
		Vegetation	<i>Hedera helix</i> stems	1.50 kg	

			Irrigation system	PE	0.52 kg
System S5 is based on felt material with gaps, supported on an aluminium structure	Production of VGS components		Fastening components	Aluminium	3.90 kg
			Vegetation support elements	PP; Viscose; Polycarbonate	5.68 kg
			Substrate	Raw soil; SAP; Coco-coir; Peat moss	2.10 kg
			Vegetation	Lonicera n. stems	1.66 kg
			Irrigation system	PE	0.52 kg
[29]	Direct facade greening system + bare wall	Construction/Maintenance/Disposal of 1 m ² facade	Vegetation	<i>Hedera helix</i>	5.5 kg
	Indirect facade greening + bare wall	Construction/Maintenance/Disposal of 1 m ² facade	Structural support	Stainless steel / Stainless steel mesh	0.06 kg / 1.55 kg
			Vegetation	<i>Hedera helix</i>	2.7 kg
	Living wall system (LWS) based on	Construction/Maintenance/Disposal of 1 m ² facade	Structural support	Steel S235	5.205 kg

	planter boxes filled with soil + bare wall		Supporting system	HDPE boxes	13.2 kg
			Growing material	Potting soil	75.6 kg
			Vegetation	Pteropsida	8 kg
			Irrigation system	PE Pipes	0.26 kg
	Living wall system (LWS) based on felt layers + bare wall	Construction/Maintenance/Disposal of 1 m ² facade	Structural support	Steel S235	0.32 kg
			Supporting U section	Steel S235	4.62 kg
			Supporting system	PVC foam plate	7 kg
			White fleece	Polypropylene	0.3 kg
			Wool fleece	Polyamide	0.6 kg
			PE fleece	Polyethylene (LDPE)	0.045 kg
			Black fleece	Polypropylene	0.27 kg
			Vegetation	Pteropsida	7.5 kg

			Irrigation system	PE Pipes	0.09 kg
[88]	Living wall system based on planter boxes	Manufacture construction and maintenance	External finishing layer	Polyester	0.25 kg
			Bearing structure	Polypropylene boxes	1.34 kg
			Hydrophilic layer	Polyester	0.25 kg
			Growing medium	Coconut fibre, turf and hummus	4 kg
			Closing layer	Polyester	0.25 kg
			Hooking system	Aluminium	0.6 kg
			Vegetation layer	<i>Hedera helix</i> stems	1.5 kg
	Living wall system made with felt layers	Manufacture construction and maintenance	External finishing layer	Polypropylene fibre and non-woven geotextile	0.53 kg
			Bearing structure	Aluminium alloy	3.9 kg
			Hydrophilic layer	Non-woven viscose fabrics	1.15 kg
			Growing medium containment layer	Polypropylene monofilament geomat-grid	2 kg
			Growing medium	50% of raw soil; 30% of SAP; 15% of coco-coir; 5% of peat moss	2.1 kg
			Closing layer	Alveolar polycarbonate in Lexan resin	2 kg
			Vegetation layer	Lonicera n. stems	1.66 kg
[89]	The trellis system is composed of evergreen climbing plants and a stainless steel frame	Manufacturing, constructing, maintaining and disposing of 1 m ² living walls	Structural support	Stainless steel/Stainless steel mesh	0.06 kg / 1.55 kg
			Vegetation	<i>Hedera helix</i>	2.7 kg

	The planter box living wall system	Manufacturing, constructing, maintaining and disposing of 1 m ² living walls	Structural support	Stainless steel	5.205 kg
			Planter boxes	HDPE	13.2 kg
			Growing material	Potting soil	75.6 kg
			Vegetation	Pteropsida	8 kg
			Watering system	PE	0.26 kg
	The felt layer living wall system	Manufacturing, constructing, maintaining and disposing of 1 m ² living walls	Structural support	Stainless steel	4.94 kg
			Foam plate	PVC	7 kg
			White/Black fleece	Polypropylene	0.3 kg / 0.27 kg
			Wool fleece	Polyamide	0.6 kg
			PE fleece	Polyethylene	0.045 kg
			Vegetation	Pteropsida	7.5 kg
			Watering system	PE	0.09 kg
[90]	Living wall system (LWS) based on felt layers	Manufacture, transportation, use, and disposal of 1 m ² living walls	Felt pockets & root wrappers	Recycled PET bottles	2.3 kg
			Backing board	HDPE	4.1 kg
			Screws & washers	Stainless steel	0.128 kg
			Plants	<i>Liriope muscari</i>	17 kg
[100]	Vertical Greenery System (VGS)	Raw material depletion and transportation, operation, recycling and disposal of 1 m ² VGS	Planter boxes	HDPE	6.0 kg
			Growing materials	Sandy soil & Expanded clay aggregate	1.8 kg + 1.8 kg = 3.6 kg
			Vegetation	<i>Peperomia claviformis</i>	18.0 kg

			Bolts & Angle bars	Stainless steel	10.5 kg
			Square tubes	Galvanized iron	30.0 kg
[95]	Geogreen modular system	Transport, production, construction and use	Watering system tubes & Drip lines	Polyethylene (LDPE)	0.5 kg
			Support	Alkaline activated board: Panasqueira mine waste mud Milled waste glass Black cork granules Sodium silicate Sodium hydroxide	10.5 kg 1.7 kg 0.7 kg 2.7 kg 1.7 kg
				Expanded black cork board: Expanded cork board Fixing glue: Neoprene glue Fastening: Stainless steel anchorage HILTY HUB-H8 + 47 mm circular face stainless steel plate	6.5 kg 0.5 kg 3.2 kg
			Greening	Substrate: Light weight substrate (Sirorooft) Plants: Sedum album Waterproofing: EPDM membrane (2 layers) Irrigation system: Polyethylene tubes	29.7 kg 5.9 kg 0.1 kg 0.8 kg