NBS Technological units

This section presents **15 factsheets** related to **NBS Technological units**, highlighting innovative technological solutions integrated into the project regarding **Advanced Ecological Treatments**, **Bioretention Systems**, **Permeable Surfaces, Vertical Greening Systems**, and **Farming Practices.**

ADVANCED ECOLOGICAL TREATMENTS

CARDIMED	SUBSURFACE FLOW CONSTRUCTED WETLAND

Synonyms: Vertical flow treatment wetland; horizontal flow treatment wetland; vertical subsurface flow constructed wetland; horizontal subsurface flow constructed; Constructed wetlands. **Description:** There can be various configurations of Subsurface Flow Constructed Wetlands (SSF CWs). They can be vertical or horizontal and saturated or unsaturated. Typically, saturated SSF CWs are fed continuously and no oxygenation is provided from other sources than plants' roots, while unsaturated SSF CWs are vertical so they can be fed intermittently (fill & drain). During the resting period, air flows through the pores, providing oxygenation to the filter and promoting aerobic biodegradation and nitrification processes. Nowadays CWs are proven to be a robust and reliable technology for addressing all the common parameters: COD, BOD_5, TSS, NH_4^+, NO_3^-, PO^{3-} (partially), at the same level and often with more stable performances than other conventional biological treatment technologies; they are also providing interesting results with the removal of the persistent organic pollutants and most of the CECs in general; they also contribute to disinfection although not sufficiently if the effluents are going to be reused. Properly designed combinations of CWs can operate also with very high loads of biologically treatable compounds, as in some industrial wastewater (food industry, oil sector, chemical sector, and so on). The lifespan when operated properly ranges from 10 to 50 years. Picture source: IRIDRA

Main challenges targeted	Freshwater and groundwater supply and quality, Biodiversity & renaturalization, Sustainable practices, resources recovery & valorization ,
Regulation and Maintenance Services	Reduce water withdrawals, Efficient water treatment, Improve quality of groundwater and surface waters, Improve carbon sequestration, Support pollination, Develop resilience of green spaces, Support free movement of species, Reduce harmful impacts to fauna & flora, Wetland creation and/or restoration, Improve soil fertility / biodiversity, Provide thermal regulation / cooling
Cultural Services	Facilitate education, Support environmental awareness, Health and Well-Being improvement, Promote mental health, Reconnect people with nature, Aesthetic values, Recreation and ecotourism, Social relations.
Provisioning Services	Water reuse, Preserve groundwater and surface waters supply, Nutrient recovery, Produce energy / Reduce energy demand,Provide nutrition sources for birds and insects, Provide raw material, Production of biomass
Other services	Reduced costs in comparison with other solutions, Contribute to local

	employment, Contribute to new or existing business, Favour green economy (reuse of local by-products), Reduced water footprint
Replicability	★★★
Design & planning	**Plants:** *Phragmites Australis, Typha spp., Echinochloa spp., Scirpus Lacustris, Iris Pseudacorus* and other macrophytes. **Media type:** Coarse sand and gravel. **Hydraulic conductivity:** 10^{-3} – 10^{-2} m/s (gravel); 10^{-5} – 10^{-4} m/s (sand). **Media depth:** 70 – 100 cm. **HLR:** <80 (L/m^2-d). **Type of layers:** bed is separated on gravel layers (5 – 10 mm and 16 – 32 mm) in the case of saturated systems, sand layer is also used in the case of intermittently fed vertical SSF CWs (0.5 – 4 mm).
Operation and maintenance	**Operational activities:** Inspection of intermittent loading in the tank before and after each loading, verification of pre-treatment step optimal performance so that suspended solids will not cause clogging of the constructed wetland bed. **Maintenance activities:** Annual removal of invasive plants. Verification of the proper wastewater percolation through the bed Removal of sludge from primary treatment. Occasionally Pruning plants every 2-3 years. **Others**: Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements.Safety protocols and training (to prevent accidents and ensure compliance with safety regulations).Track legal and regulatory compliance.Be prepared to adapt your operation and maintenance practices over time in response to changing environmental conditions, market dynamics, and other factor
Combinations with other NBS	Combinations of different **Treatment Wetland types**, just making use of their different and specific processing capacities depending on the desired targets, are very common in real scale implementations of NBSs. As an example, Vertical flow constructed wetlands are inserted in the combination when there is the need of strong oxidising aerobic environments (nitrification, organics oxidation, etc), while **Free water surface constructed wetland** can be used for a final disinfection or enhanced denitrification (together with HF CWs) as also for CECs removal. **Electroactive constructed wetland** can be used when there is the need to substantially reduce the footprint, up to 5 times in comparison with passive CW types. **Sludge treatment wetlands** can be added to classic activated sludge treatment plants or even for working with primary sludge or faecal sludge, still in combination with **Subsurface flow constructed wetland** (for enhancing treatment efficiency and sustainability). These NBSs can serve as a source of biomass that can be used for **Compost application, mulching application, Agroforestry** (for enhancing sustainability of food production and improving soil quality) This NBS can provide treated water for diverse NBS such as **Agroforestry, Green corridors, urban micro forest (**for enhancing sustainability of water management) **Porous/pervious asphalt, surface unsealing, riparian buffer, bioretention cells (raingarden), bioswale** and **filter drain** (for

	integrated stormwater management).
Supportive units & smart tech	**Advanced water treatments** (filtration membranes, reverse osmosis, biochar or activated carbon filters and oxidation process to enhance pollutant removal). **Rainwater harvesting systems** (for enhanced rainwater management and treatment). **Remote sensing by IoT** (for real-time monitoring of water quality and hydraulic parameters). **Solar panels** (for reducing energy costs and enhancing overall sustainability). **Artificial intelligence** (for predictive modelling and adaptive management, coupled with remote sensing). **Septic tanks, screening, grit removal, detention vaults and tanks** (for increased treatment efficiency and capacity).
Treatment efficiency	**COD: 80-95%; BOD_5: 85-98%; TSS: 80-95%; NH_4^+: 85-99%; NO_3^-: > 80%; TP: 35-75%**
CAPEX	80-200 €/m^2. Main type of costs: Equipment and materials (grid, sedimentation tank, grit chamber, detention vaults and tanks, first flush tank, septic tank, pumps, pipes, geomembranes, filter media, lining materials and monitoring and control devices); Permits, fees and administrative (land acquisition); Labour (soil levelling and land excavation).
OPEX	2-5 €/m^2 y. Main type of costs: Utilities (electricity); Labour (operation and monitoring, sludge removal, reed harvesting, green space maintenance).
By-product(s):	Harvested reeds as biomass (for composting /agricultural uses).

CARDIMED — ELECTROACTIVE CONSTRUCTED WETLAND

Synonyms: Electroactive constructed wetland; Electroconductive wetlands; Electroactive biofilm-based constructed wetland (EABB-CW); Electroactive constructed wetlands; Electroactive wetland. **Description:** Electroactive constructed wetlands are bioelectrochemical systems integrated in constructed wetlands. They accommodate a diverse microbial community in which each microbe sets their own potential to further participate in electron transfer, aided by conductive filling media. In some types of electroactive wetlands artificial electron acceptors are located in the anaerobic regions of the reactor, which accommodate faster microbial metabolism for some pollutants. Further, the electron transfer from anaerobic to aerobic regions through an electrical circuit results in electricity generation, even though with very low yields. By contrast, the electroconductive coke-based CWs are just reducing the treatment volume in comparison with passive systems, making them comparable with Aerated CWs. Picture source: IRIDRA/NTUA/Hydrousa

Main challenges targeted	Freshwater and groundwater supply and quality, Biodiversity & renaturalization, Sustainable practices, resources recovery & valorization
Regulation and Maintenance Services	Reduce water withdrawals, Efficient water treatment, Improve quality of groundwater and surface waters, Improve carbon sequestration,

	Support pollination, Develop resilience of green spaces, Reduce harmful impacts to fauna & flora, Wetland creation and/or restoration, Provide thermal regulation / cooling, Habitat for species
Cultural Services	Facilitate education, Support environmental awareness, Health and Well-Being improvement, Promote mental health, Reconnect people with nature, Aesthetic values, Recreation and ecotourism.
Provisioning Services	Water reuse, Preserve groundwater and surface waters supply, provide nutrition sources for birds and insects, Nutrient recovery, Produce energy / Reduce energy demand, Provide raw material, Production of biomass
Other Services	Reduced costs in comparison with other solutions, Contribute to local employment, Contribute to new or existing business, Favour green economy (reuse of local by-products), Reduced water footprint.
Replicability	★☆☆
Design & planning	**Plants:** *Phragmites spp.*, *Typha spp*. and *Scirpus spp.* **Type of layer:** Electroconductive filled main layer supported by siliceous gravel on top and bottom. **Total layer:** 100 cm. **Filter media:** Top and bottom layers from siliceous gravel (3-10 mm top; 10-30 bottom). Main filter of electroconductive material (3-10 mm, unsaturated beds; 10-30 mm saturated beds)
Operation and maintenance	Regular documentation of maintenance activities, operational issues, and measurements. **Operational activities:** Inspection of intermittent loading in the tank before and after each loading, Verification of the proper wastewater percolation through the bed. verification of pre-treatment step optimal performance so that suspended solids won't cause clogging. **Maintenance activities:** Annually removal of invasive plants. Occasional pruning plants every 2-3 years. **Others:** Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements.Safety protocols and training (to prevent accidents and ensure compliance with safety regulations).Track legal and regulatory compliance.Be prepared to adapt your operation and maintenance practices over time in response to changing environmental conditions, market dynamics, and other factor
Combinations with other NBS	**Subsurface flow constructed wetland** (for enhancing treatment efficiency and sustainability). These NBSs can serve as a source of biomass that can be used for **Compost application, mulching application, Agroforestry** (for enhancing sustainability of food production and improving soil quality). This NBS can provide treated water for diverse NBS such as **Agroforestry, Green corridors, urban micro forest**, (for enhancing sustainability of water management).
Supportive units & smart tech	**Advanced water treatments** (filtration membranes, reverse osmosis,

	biochar or activated carbon filters and oxidation process to enhance pollutant removal). **Remote sensing** (for real-time monitoring of water quality and hydraulic parameters). **Solar panels** (for reducing energy costs and enhancing overall sustainability). **Artificial intelligence** (for predictive modelling and adaptive management). **Septic tanks, screening, grit removal, detention vaults and tanks** (for increased treatment efficiency and capacity).
Treatment efficiency	**COD: 80-90%; BOD_5: 85-90%; NH_4^+: > 90%**
CAPEX	930 €/m^2. Main type of costs: Equipment and materials (grid, sedimentation tank, grit chamber, detention vaults and tanks, septic tank, pumps, pipes, geomembranes, electrodes or electroconductive media, power supply systems, monitoring and control devices, geomembranes, pipes, electrode supports, filter media and lining materials); Permits, fees and administrative (land acquisition); Labour (soil levelling and land excavation).
OPEX	*not available.* Main type of costs: Utilities (electricity); Labour (operation and monitoring, sludge removal, reed harvesting, green space maintenance).
By-product(s):	Harvested reeds biomass (for composting /agricultural uses).

CARDIMED	**FREE WATER SURFACE CONSTRUCTED WETLAND**

Synonyms: Free water surface treatment wetland; surface flow constructed wetland. **Description:** A free water surface constructed wetland is a type of engineered system designed to mimic natural wetland processes for wastewater and stormwater treatment. They are considered as cost-effective, environmentally friendly, and can be tailored to fit various treatment needs, making them a popular choice for decentralised wastewater treatment applications and sustainable rainwater management. In these systems, wastewater/stormwater flows through shallow ponds or channels with a surface layer of emergent aquatic plants. As the water moves through the wetland, physical, biological, and chemical processes occur, leading to the removal of pollutants such as nutrients, organic matter, and pathogens. Picture source: IRIDRA

Main challenges targeted	Freshwater and groundwater supply and quality, Biodiversity & renaturalization and Rainwater management & flood protection
Regulation and Maintenance Services	Reduce water withdrawals, Efficient water treatment, Improve quality of groundwater and surface waters, Wetland creation and/or restoration, Create or restore habitat, Create or restore fauna, Coastal restoration & protection/ Promote resilience against natural disasters, Reduce sediment flow into drainage systems, Rehabilitate polluted soil, Provide thermal regulation / cooling, Habitat for species Climate regulation
Cultural Services	Facilitate education, Support environmental awareness, Aesthetic values, Recreation and ecotourism, Social relations
Provisioning Services	Water reuse, Preserve groundwater and surface waters supply,

	Nutrient recovery
Replicability	★★☆
Design & planning	**Plants:** *Phragmites Australis, Typha spp., Echinochloa spp.* and other macrophytes. **Required area:** approx. 3.2-4.5 m^2/pe depending on flow rate and quality. **Depth:** 0.5-1 m.
Operation and maintenance	**Maintenance activities:** Monthly cleaning and sampling of manholes. Annually removal of selected plants and/or replanting. Occasionally mosquito management, utilisation of integrated management practices in the event of vector outbreaks. **Others:** Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements.Safety protocols and training (to prevent accidents and ensure compliance with safety regulations).Track legal and regulatory compliance.Be prepared to adapt your operation and maintenance practices over time in response to changing environmental conditions, market dynamics, and other factor .
Combinations with other NBS	**Subsurface flow constructed wetlands , Electroactive constructed wetland, Sludge treatment wetlands, High rate algae pond** (for enhancing treatment efficiency and sustainability). These NBSs can serve as a source of biomass that can be used for **Compost application, mulching application, Agroforestry** (for enhancing sustainability of food production and improving soil quality). as also a CO_2 storage. This NBS can provide treated water for diverse NBS such as **Agroforestry, Green corridors, urban micro forest ,Agroforestry** (for enhancing sustainability of water management) **Porous asphalt, surface unsealing, Riparian buffer, Bioretention cells (rainraden), Bioswale, Filter drain** (for integrated stormwater management). **Aquaculture** (to use treated water).
Supportive units & smart tech	**Advanced water treatments** (filtration membranes, reverse osmosis, biochar or activated carbon filters and oxidation process to enhance pollutant removal). **Remote sensing** (for real-time monitoring of water quality and hydraulic parameters). **Solar panels** (for reducing energy costs and enhancing overall sustainability). **Artificial intelligence** (for predictive modelling and adaptive management). **Septic tanks, screening, grit removal, detention vaults and tanks** (for increased treatment efficiency and capacity). **Flow regulators or diversion structures** (for managing hydraulic loading and maximising treatment efficiency during peak flow events).
Treatment efficiency	**COD: 41- 90%; BOD_5: ~54%; TN: 30- 80%; NH_4-N: ~73%; TP: 27-60%.**
CAPEX	30 - 70 €/m^2. Main type of costs: Equipment and materials (grid, sedimentation tank, grit chamber, detention vaults and tanks, first flush tank, septic tank, pumps, pipes, geomembranes, filter media, lining materials and monitoring and control

	devices); Permits, fees and administrative (land acquisition); Labour (soil levelling and land excavation).
OPEX	0.5 - 2 €/m^2 y. Main type of costs: Utilities (electricity); Labour (operation and monitoring, sludge removal, reed harvesting, green space maintenance).
By-product(s):	Biofuels (biogas, bioethanol, bio oil, biochar, and synthesis gas)

CARDIMED	**SLUDGE TREATMENT WETLAND**

Synonyms: Sludge Drying Reed Beds; Sludge Treatment Reed Beds. **Description:** Sludge treatment wetlands, represent a relatively new approach to sludge treatment inspired by constructed wetlands functioning. Unlike traditional sludge treatment methods that often require chemical or thermal conditioning, sludge treatment wetlands operate without the need for such treatments. Sludge is either directly introduced into the basins from aeration tanks or homogenised in a buffer tank before being discharged into the wetlands. Microbial activity, facilitated breaks down and stabilises organic matter present in the sludge. Additionally, physical processes such as filtration and adsorption further contribute to pollutant removal. Over time, these processes transform the sludge into a stabilised, dewatered by-product that can be safely reused or disposed of. Picture source: Steen Nielsen/WSP

Main challenges targeted	Resources recovery & valorization, Soil restoration & protection, Local Development & Economic Enhancement
Regulation and Maintenance Services	Improve carbon sequestration, Reduce greenhouse gas emissions, Improve soil fertility / biodiversity, Reduce changes on soil characteristics, Stabilise soil / substrate.
Cultural Services	Facilitate education, Support environmental awareness
Provisioning Services	Nutrient recovery, Produce energy / Reduce energy demand, Production of biomass, Material reuse, Habitat for species
Other Services	Reduced costs in comparison with other solutions, Contribute to local employment, Contribute to new or existing business, Favour green economy (reuse of local by-products), Sustainable food production
Replicability	★★☆
Design & planning	**Plants**: *Phragmites Australis*, *Typha spp.*, *Echinochioa spp* and other macrophytes. **Filter media:** upper layer of 10-15 cm sand (0.5-1mm), intermediate layer of 20-30 cm gravel (2-10mm) and drainage layer of 15-20 cm stones (5cm). **Total depth:** 2.4 m (0.6–0.7 m of filter medium and 1.5–1.6 m for sludge accumulation). **Number of beds:** 3-18. **Bed surface:** 4.5- >1000 m^2 **. Feeding period:** 1–2 days (or even 1–2 weeks). **Resting period:** 1–2 months to 1 year. **Surface area required:** 1.5 and 4 pe/m^2.

Operation and maintenance	**Operational activities:** Monitor the performance in terms of sludge dewatering rates, pollutant removal efficiency, and vegetation health. Adjust sludge loading rates to prevent overloading. Adjust flow rates, controlling inlet and outlet structures, and managing sediment accumulation to maximise treatment efficiency and minimise the risk of clogging or overflow. **Maintenance activities:** Controlling invasive species, trimming overgrown vegetation, and periodically replanting. Maintain buffer zones around the wetland to prevent contamination from adjacent land. Periodic removal of accumulated biomass or harvesting of nutrient-rich vegetation for reuse or disposal. **Others:** Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements.Safety protocols and training (to prevent accidents and ensure compliance with safety regulations).
Combinations with other NBS	These NBSs can serve as a source of biomass that can be used for **Compost application, mulching application, Agroforestry** (for enhancing sustainability of food production and improving soil quality)
Supportive units & smart tech	**Advanced water treatments** (oxidation process to enhance pollutant removal). **Remote sensing** (for real-time monitoring of water quality and hydraulic parameters). **Artificial intelligence** (for predictive modelling and adaptive management). **Storage tanks or dewatering facilities** (for providing temporary storage capacity during periods of high loading or maintenance activities).
Treatment efficiency	*not available*
CAPEX	100 - 200 €/m^2. Main type of costs: Equipment and materials (pumps, agitation systems, aeration systems, excavation, canal construction, reservoirs, geotextiles, pipes, support structures; Permits, fees and administrative (land acquisition); Labour (soil levelling and land excavation).
OPEX	2-5 €/m^2 y. Main type of costs: Utilities (electricity); Labour (operation and monitoring, sludge removal, reed harvesting, green space maintenance).
By-product(s):	Treated sludge (for agricultural uses)

CARDIMED

1. HIGH RATE ALGAE PONDS

Synonyms: High-Rate Algal Ponds **Description:** High-Rate Algae Ponds are engineered systems to improve wastewater treatment while concurrently cultivating microalgal biomass. In this method, microalgae absorb nutrients from the wastewater and generate O_2 essential for bacterial activity, facilitating the breakdown of organic matter. This symbiotic relationship between bacteria and microalgae results in the production of clean water suitable for reuse, alongside algal biomass with

potential applications in bioproduct manufacturing. HRAPs demonstrate versatility in treating various wastewater types (industrial effluents, digester discharge, as well as wastewater from agricultural operations such as piggeries and dairy farms). Picture source: UPC/PAVITR	
Main challenges targeted	Sustainable practices, resources recovery & valorization, Freshwater and groundwater supply and quality, Air quality
Regulation and Maintenance Services	Reduce water withdrawals, Efficient water treatment, Improve quality of groundwater and surface waters, Improve carbon sequestration, Reduce greenhouse gas emissions
Cultural Services	Facilitate education, Support environmental awareness, Aesthetic values
Provisioning Services	Water reuse, Preserve groundwater and surface waters supply, Production of biomass, Nutrient recovery, Material reuseFresh water, Food production
Other Services	Reduced costs in comparison with other solutions, Reduced carbon footprint, Reduced water footprint
Replicability	★★☆
Design & planning	**Area requirement:** 3 - 5 pe/m^2. **HRT:** varies seasonally (3 - 4 days in summer and 7 - 9 days in winter). **Depth:** 0.2 - 0.6 m. **Paddle wheel:** mixing (typically 0.15 - 0.30 m/s)
Operation and maintenance	**Operational activities:** Checking of inlet and outlet pumps, as well as proper paddle wheel operation. Measuring the turbidity of the settled effluent. **Maintenance activities:** Checking and maintenance of the probes (weekly cleaning and calibration). **Others:** Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements.Safety protocols and training (to prevent accidents and ensure compliance with safety regulations).Track legal and regulatory compliance.Be prepared to adapt your operation and maintenance practices over time in response to changing environmental conditions, market dynamics, and other factor
Combinations with other NBS	**Photo bio reactors** (for enhancing microalgae cultivation). These NBSs can serve as a source of biomass that can be used for **Compost application, Agroforestry** (for enhancing sustainability and food security). **Free water surface constructed wetland** (for enhancing treatment efficiency and sustainability). **Riparian buffer** (for integrated stormwater management). **Aquaculture** (to use treated water). This NBS can provide treated water for diverse NBS such as **Agroforestry, Green corridors, urban micro forest ,Agroforestry** (for enhancing sustainability of water management)
Supportive units & smartech	**Smart sensors** and **remote sensing** (to monitor biomass density,

	nutrient concentrations and pH for optimising algae growth conditions). **Harvesting systems** (centrifugation, flocculation, or membrane filtration for increasing harvesting efficiency and reducing energy consumption). **Settling tanks or clarifiers** (for optimising algae growth conditions). **Advanced water treatments** (membrane filtration or UV disinfection for polishing treated effluent, making it suitable for reuse in non-potable applications). **Solar panels** (for reducing energy costs and enhancing overall sustainability).
Treatment efficiency	**COD: 40 - 80%; NH_4-N: 80 - 100%; PO_4^{3-}: 30 - 80%**
CAPEX	*not available.* Main type of costs: Equipment and materials (agitators, algae harvesters, control and monitoring devices, building access roads, electrical facilities to power equipment, lighting systems, pumps, pipelines, filtration systems, concrete, geomembranes); Permits, fees and administrative (land acquisition); Labour (soil levelling and land excavation).
OPEX	*not available.* Main type of costs: Utilities (electricity); Labour (replacing parts, repairing leaks, monitoring algae growth, maintaining equipment, cleaning and harvesting algae); Materials and supplies (nutrients supplied for algae); Transportation and delivery (processing facilities).
By-product(s)	Harvested microalgal biomass (for biofuel, animal feed, fertiliser, cosmetics, pharmaceuticals, bioplastics).

CARDIMED

BIOFILTRATION COLUMNS

Picture not available. **Synonyms:** Biofilter; Biofilter column; Stormwater biofilters; Biofiltration systems; Bioretention systems; Biofilter urban stormwater. **Description:** Biofilters provide the combined effects of improving water quality as well as reducing the volume and rate of runoff from impervious surfaces. It can also be used for treating wastewaters. They consist of a vegetated column filled with a filter media and a drainage pipe on the bottom. Stormwater runoff infiltrates, is filtered by the vegetation and filter media, and the treated water is collected in the drainage pipe. Their filter media and vegetation properties enhance pollutant removal efficiency and increase their span life compared to traditional sand or gravel filters.

Main challenges targeted	Freshwater and groundwater supply and quality, Rainwater management & flood protection, Sustainable practices, resources recovery & valorization,
Regulation and Maintenance Services	Reduce water withdrawals, Efficient water treatment, Improve quality of groundwater and surface waters, Reduce flood risk, Reduce sediment flow into drainage systems, Reduce urban runoff, Stormwater source control, Habitat for species
Cultural Services	Facilitate education, Support environmental awareness, Aesthetic values
Provisioning Services	Water reuse, Preserve groundwater and surface waters supply, Harvest, store and treat rainwater, Produce energy / Reduce energy demand Fresh water

Other Services	Reduced costs in comparison with other solutions, Reduced water footprint
Replicability	★★☆
Design & planning	**Plants:** Species with thick roots. **Filter media:** Some examples are sand, activated carbon, gravel, peat moss, pumice, expanded clay aggregate, coconut shell, zeolite etc.) upper layer of 300-700 mm sandy-loam; intermediate layer of 70 mm of coarse sand and 70 mm of fine sand; drainage layer of 90 mm of gravel. **Diameter:** 375mm. **Drainage pipe:** 50 mm diameter.
Operation and maintenance	**Operational activities:** Regular monitoring performance of the biofilter system (hydraulics, water quality, plants health). Monitor nutrient levels to maintain optimal conditions for microbial colonisation. This may involve adding supplemental nutrients or adjusting feed rates (in case wastewater is used as water source) to achieve desired nutrient ratios.Maintain appropriate flow rates through the biofilter to ensure adequate contact time. Ensure adequate oxygenation within the biofilter system to support aerobic microbial activity (forced aeration or by maintaining proper flow rates and passive aeration). Avoid disturbances or sudden changes in operating conditions that may disrupt biofilm development. **Maintenance activities:** Regularly inspect the filter media, and replace it if necessary, to prevent clogging. Control pests such as insects, rodents, or algae from colonising the biofilter system. Repair or replace damaged components promptly to prevent water loss and maintain system integrity. **Others:** Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements. Stay informed about emerging technologies and best practices in biofiltration to continually improve system performance.
Combinations with other NBS	These NBSs can serve as a source of biomass that can be used for **Compost application, mulching application, Agroforestry** (for enhancing sustainability of food production and improving soil quality) . **Bioswale** and **bioretention cell (rain garden)** (to enhance and holistic rainwater management). This NBS can provide treated water for diverse NBS such as **Agroforestry, Green corridors, urban micro forest** ,**Agroforestry** (for enhancing sustainability of water management)
Supportive units & smartech	**Smart sensors and remote sensing** (to monitor pH, DO, and pollutant concentrations for enabling automatic system control and optimization). **Flow regulators or diversion structures** (for managing hydraulic loading and maximising treatment efficiency during peak flow events). **Advanced water treatments** (ultrafiltration or nanofiltration to achieve higher water quality standards for reuse; oxidation processes as pre-treatment to enhance the breakdown of recalcitrant pollutants and improves

	overall treatment performance). **Solar panels** (for reducing energy costs and enhancing overall sustainability).
Treatment efficiency	*not available*
CAPEX	*not available.* Main type of costs: Equipment and materials (concrete, steel, composite materials, gravel, sand, activated carbon, pipes, valves, fittings, distribution systems, pumps, blowers, control and monitoring devices); Permits, fees and administrative (land acquisition); Labour (soil levelling and land excavation).
OPEX	*not available.* Main type of costs: Utilities (electricity); Labour (monitoring systems inspections, cleaning, servicing equipment, media replacement, repairing of pumps/valves/piping and replacing parts).
By-product(s):	*Not applicable*

CARDIMED	2. PHOTO BIO REACTOR

Picture not available. **Synonyms:** Microalgae bioreactor; Algae bioreactor; Microalgal photobioreactor; Microalgal cultivation. **Description:** A Photo Bio Reactor (PBR) is a closed or semi-closed system designed to cultivate photosynthetic microorganisms, such as algae or cyanobacteria, under controlled environmental conditions. These reactors utilise light, typically from artificial sources such as LEDs or natural sunlight, to facilitate photosynthesis, wherein microorganisms convert CO_2 and nutrients into biomass and O_2. PBRs are commonly used in various applications, including wastewater treatment, biofuel production, carbon capture, and bioremediation. In wastewater treatment applications, microalgae or other photosynthetic microorganisms cultivated within the PBR utilise nutrients, including nitrogen and phosphorus, as well as CO_2, present in the wastewater as sources for growth.

Main challenges targeted	Freshwater and groundwater supply and quality, Sustainable practices, resources recovery & valorization, Air quality,
Regulation and Maintenance Services	Reduce water withdrawals, Efficient water treatment, Improve quality of groundwater and surface waters, Improve carbon sequestration, reduce greenhouse gas emissions.
Cultural Services	Facilitate education, Support environmental awareness.
Provisioning Services	Water reuse, Preserve groundwater and surface waters supply, Production of biomass, Nutrient recovery, Material reuse Fresh water, Food production
Other Services	Contribute to local employment, Reduced costs in comparison with other solutions, Reduced water footprint, Reduced carbon footprint
Replicability	★★☆
Design & planning	**Species:** Microalgae and cyanobacteria. **Requirements conditions: pH:** 7 - 8, **DO:** 0.2 - 0.5 mgO_2/L, **COD:** 5, **TN:** 0.3, **Bacterial product:** Maximum 2.5 at **OLR** of 5 g/L/d COD biomass. For outdoor Photobioreactor the implementation of a buffered medium or

	installation of a pHstat system in conjunction with PBRs is recommended to mitigate the inhibition of cell growth rates caused by seasonal variations, T fluctuations, and light intensity.
Operation and maintenance	**Operational activities:** Monitoring key parameters such as T, pH, DO, nutrient concentrations (e.g., nitrogen and phosphorus), biomass density, and light intensity (to ensure optimal growth conditions and early detection of any deviations or issues). **Maintenance activities:** Regular biomass harvesting (to prevent biomass accumulation and maintain optimal growth conditions). Repair or replace damaged components promptly to prevent water loss, contamination, or operational disruptions **Others**: Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements.Safety protocols and training (to prevent accidents and ensure compliance with safety regulations).Track legal and regulatory compliance.Be prepared to adapt your operation and maintenance practices over time in response to changing environmental conditions, market dynamics, and other factor
Combinations with other NBS	**Subsurface flow constructed wetlands, electroactive wetlands, biofiltration columns, free water surface constructed wetlands** and **high rate algae ponds** (for synergistic approach for wastewater treatment). **Bioretention cells (rain gardens) and bioswale** (for the treatment of captured stormwater) and **Aquaculture** (Microalgae biomass harvested can serve as a nutritious feed source for species such as fish, shrimp, or shellfish).This NBS can provide treated water for diverse NBS such as **Agroforestry, Green corridors, urban micro forest**, **Agroforestry** (for enhancing sustainability of water management)
Supportive units & smartech	**Smart sensors** and **remote sensing** (to monitor pH, DO and pollutant concentrations, enabling automatic system control and optimization). **Artificial intelligence** (for predictive modelling and adaptive management). **Solar panels** (for reducing energy costs and enhancing overall sustainability). **Anaerobic digesters or microbial fuel cells** (for integrated bioprocesses for wastewater treatment, bioenergy production, and resource recovery). **Advanced water treatments** (membrane filtration, UV disinfection, or electrocoagulation to enhance effluent quality and pathogen removal for potable water production or wastewater reuse).
Treatment efficiency	*not available.*
CAPEX	*not available.* Main type of costs: Equipment and materials (pumps, pipes, sensors, lighting systems, valves, fittings, distribution systems photobioreactor modules, glass, acrylic, polyethylene, LEDs/fluorescent lamps, lighting fixtures, control and monitoring devices, mixing systems, aeration devices, nutrient dosing systems, harvesting equipment); Permits, fees and administrative (land acquisition); Labour (soil levelling and land excavation).

OPEX	*not available.* Main type of costs: Utilities (electricity); Labour (replacing parts, repairing leaks, monitoring algae growth, maintaining equipment, harvesting algae and cleaning); Materials and supplies (nutrients supplied for algae); Transportation and delivery (processing facilities).
By-product(s):	Harvested biomass can be processed for various applications such as biofuel production, animal feed supplements, nutritional supplements, or bioplastics. Microalgae produce a wide range of bioactive compounds, pigments, antioxidants, and other high-value chemicals with pharmaceutical, nutraceutical, or cosmetic applications.

BIORETENTION SYSTEMS

CARDIMED	BIORETENTION CELL (RAIN GARDEN)

Synonyms: rain garden, Bioretention facility; Bioretention cell; Pluvial beds; Infiltration/stormwater planters; Biofilter; Infiltration garden; Rainfall garden; Water control garden; Floodable garden; Bioretention filter; Bioretention area. **Description:** Bioretention cells (rain gardens), are shallow, vegetated depressions designed to capture, store, filter, and treat stormwater runoff from impervious surfaces like driveways. By reducing the volume and speed of runoff, they minimise erosion and flood risks. While often associated with urban areas, rain gardens can be adapted to various environments, including rural settings. In rural areas, they can be strategically placed along drainage ditches, field edges, or at the base of slopes to capture sediment, nutrients, and pollutants from agricultural runoff, thereby enhancing water quality and safeguarding downstream ecosystems. Furthermore, rain gardens are integral components of innovative design approaches that enable the onsite reuse of treated water, promoting sustainability and resource efficiency. Picture source: Fondation Engie France

Main challenges targeted	Rainwater management & flood protection, Biodiversity & renaturalization, Freshwater and groundwater supply and quality
Regulation and Maintenance Services	Reduce water withdrawals, Efficient water treatment, Improve quality of groundwater and surface waters, Reduce flood risk, Reduce sediment flow into drainage systems, Reduce combined sewer overflows, Reduce urban/agricultural runoff, Stormwater source control, Permeability restoration, Mitigate desertification, Create or restore flora, Support pollination, Develop resilience of green spaces, Coastal restoration & protection/ Promote resilience against natural disasters, Enhance and stabilise water retention, Reduce CO_2 emissions, Provide thermal regulation / cooling, Habitat for species
Cultural Services	Health and Well-Being improvement, Increase aesthetic and patrimonial or cultural value,Facilitate education, Support environmental awareness Increase stakeholder engagement, Aesthetic values, Social relations
Provisioning Services	Water reuse, Preserve groundwater and surface waters supply,

	Harvest, store and treat rainwater, Provide nutrition sources for birds and insects,Production of biomass
Other Services	Contribute to local employment, Increase land/property monetary value, Increase tourism, Contribute to new or existing business, Reduced costs in comparison with other solutions, Reduced water footprint, Sustainable food production
Replicability	★★★
Design & planning	Native **plant** species are chosen for their resilience to occasional flooding, serving not only to enhance biodiversity but also to aid in water filtration and erosion control. This selection ensures the bio retention cell's ability to thrive within its environment. Additionally, the versatility of these cells makes them suitable for **small-scale installations**, whether in private gardens or public spaces, offering an effective solution for stormwater management in various urban settings. Incorporating a gentle **slope** into the design further enhances its performance by facilitating water infiltration and retention. This slope promotes efficient drainage and groundwater recharge, minimising runoff and reducing the risk of flooding and soil erosion. Ensuring easy **access** for maintenance and management activities is essential for the sustained effectiveness of the bio retention cell.
Operation and maintenance	**Operational activities:** Watering is essential, particularly during dry periods, to sustain the health of the native plant species. In this sense, periodic reviews of the irrigation system are crucial to identify and address any issues promptly, ensuring efficient water distribution. **Maintenance activities:** Pruning and pollarding help manage plant growth and promote a tidy appearance, while also encouraging healthy root development. Substituting mulching as needed aids in moisture retention and weed suppression, contributing to overall plant vitality and ecosystem balance. Weed control and fertilisation are carried out as necessary to maintain plant health and minimise competition for resources. **Others:** Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements.Safety protocols and training (to prevent accidents and ensure compliance with safety regulations).Track legal and regulatory compliance.Be prepared to adapt your operation and maintenance practices over time in response to changing environmental conditions, market dynamics, and other factor
Combinations with other NBS	**Mulching application, Compost application, Surface unsealing** (for improving soil quality, reduction of erosion, water and moisture retention, and suppressing weeds). **Green corridors, Urban micro forest, Terracing, Restoring native vegetation, Riparian buffer, Bioswales and Filter drains** (for an integrated rainwater management with a positive impact on biodiversity)

Supportive units & smart tech	**Rainwater harvesting systems** (for using collected rainwater for irrigation). **Smart irrigation systems** (for optimising water usage). **Smart sensors** (to monitor humidity, T and air quality, rainfall measurements for assessing the impact of environmental conditions, detecting anomalies and optimising maintenance).
Treatment efficiency	**NH_3: 84,6%; Cd: 80-90%; Cu: 80-90%; Pb: 80-90%; Zn: 80-90%; PAHs: 70-90%.**
CAPEX	100-300 €/m^2 Main types of costs: Equipment and materials (containers or sealed and unsealed surfaces, rainwater barrels, fibreglass pots along with wooden lamellas, bench and hydrophytic plants), Labour (irrigation and monitoring system installation, information board installation).
OPEX	2-5 €/m^2 y Main types of costs: Labour (removing litter, maintaining vegetation, weeding, removing sediment, clearing inlets and outlets, inspections, flushing out drainage, minor repairs and infiltration test).
By-product(s)	Pruned plant material or harvested plants can be used for onsite and production of organic fertilisers (for agricultural uses), edible goods and pharmaceuticals (for local consumption or sales).

CARDIMED	BIOSWALE

Synonyms: Swale; Green drainage corridor; Vegetative filter; Vegetated bioswale, grassed swales, vegetated swale. **Description:** A bioswale is a vegetated, linear, and gently sloped pit commonly established in urban areas near or between roads to reduce flood risk during heavy rain events. They absorb, store, and convey surface water runoff, removing pollutants and sediments as water filters through the vegetation and soil layer. While typically found in urban settings, bioswales can also be effective in rural areas. In both settings, they capture and treat stormwater runoff from roads, agricultural fields, and other surfaces. Some bioswales include dams or similar structures to support water infiltration. Picture source: SIARE naturalwalkingcities

Main challenges targeted	Rainwater management & flood protection, Air quality
Regulation and Maintenance Services	Reduce water withdrawals, Efficient water treatment, Improve quality of groundwater and surface waters, Reduce flood risk, Reduce sediment flow into drainage systems, Stormwater source control, Permeability restoration, Create or restore habitat, Mitigate desertification, Create or restore fauna, Create or restore flora, Support pollination, Reduce harmful impacts to fauna & flora, Develop resilience of green spaces, Coastal restoration & protection/ Promote resilience against natural disasters,Reduce sediment flow in the river, Reduce sediments deposition in river beds, Enhance and stabilise water retention, Improve carbon sequestration, Reduce CO2 emissions, Provide thermal regulation / cooling ,Reduce risk of pest and diseases, Habitat for species

Cultural Services	Health and Well-Being improvement, Increase recreational and socialisation value, Increase aesthetic and patrimonial or cultural value, Ensure accessibility to green spaces, Facilitate education, Support environmental awareness, Increase stakeholder engagement, Aesthetic values
Provisioning Services	Water reuse, Preserve groundwater and surface waters supply Not applicable, Harvest, store and treat rainwater, Production of biomass, Nutrient recovery, Produce energy / Reduce energy demand, Material reuse
Other Services	Contribute to local employment, Increase land/property monetary value Contribute to new or existing business, Reduced costs in comparison with other solutions, Favour green economy (reuse of local by-products), Reduced carbon footprint, Reduced water footprint, Sustainable food production
Replicability	★★☆
Design & planning	The native deep-rooted **plants** are selected to withstand occasional flooding (often grass, + other plants for esthetic reasons). The **slope** typically ranges from 1% to 4%, facilitating efficient drainage and erosion prevention. Bioswales vary in **length** from 10 to 30 m and may include **elements** like forebays, berms and internal water storage for enhanced performance in capturing sediment and reducing flow velocities. Integrating these elements ensures bioswales effectively manage stormwater runoff, promoting improved water quality and sustainable urban development.
Operation and maintenance	**Operational activities:** Inspection and correction of erosion, vegetation damage, sediment, and debris accumulation. It is essential to ensure uniformity in cross-section and longitudinal slope, as well as monitor vegetation on side slopes to prevent erosion and the formation of rills or gullies. Identify any pools of standing water, which should be promptly dewatered and discharged into a sanitary sewer. Swale inlets and outlets, such as curb cuts and pipes, are also inspected for signs of erosion or blockage to ensure continued functionality. **Maintenance activities:** Regular mowing and trimming of vegetation are conducted to maintain safety, aesthetics, and proper swale operation, as well as to suppress weeds and invasive species. **Others:** Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements.Safety protocols and training (to prevent accidents and ensure compliance with safety regulations).Track legal and regulatory compliance.Be prepared to adapt your operation and maintenance practices over time in response to changing environmental conditions, market dynamics, and other

	factor
Combinations with other NBS	**Green corridors, Urban micro forest, Terracing, Restoring native vegetation, Bioretention cells (rain gardens), Riparian buffer, Filter drains** and **permeable surfaces** (for an integrated rainwater management with a positive impact on biodiversity). **Cover crop** (to improve soil quality, control erosion, increase biodiversity, and suppress weeds)
Supportive units & smart tech	**Rainwater harvesting systems** (for using collected rainwater for irrigation). **Smart irrigation systems** (for optimising water usage). **Smart sensors** (to monitor humidity, T and air quality, rainfall measurements for assessing the impact of environmental conditions, detecting anomalies and optimising maintenance).
Treatment efficiency	**TSS: 63-85% ; TN:46-67% ; TP: 40-99%**
CAPEX	13 - 122 €/m^2. Main types of cost: Design and development infrastructure; Equipment and materials (salvaged topsoil, seed and mulch and sod); Labour (clearing, grubbing, excavation, level and till).
OPEX	1 - 5 €/m^2 y. Main types of cost: Labour (grass mowing, general grass care, swale debris and litter, removal grass, reseeding with mulch and fertiliser and swale inspection)
By-product(s)	Pruned plant material or harvested plants can be used for onsite and production of organic fertilisers (for agricultural uses)

CARDIMED

FILTER DRAIN

Synonyms: Filter trench; Surface sand filter; Customised drain, Subsurface rainwater collector, Gravel filter drain; Runoff collection filter drain; Rainwater filter drain. **Description:** Filter drains are shallow excavations filled with stone or gravel, designed to provide temporary subsurface storage for attenuating, conveying, and filtering surface water runoff, including rainwater. These drains play a crucial role in managing stormwater in various environments, including urban, peri-urban, and rural areas. By capturing and temporarily storing runoff, filter drains help reduce the volume and velocity of water entering downstream water bodies, minimising the risk of erosion and flooding. Additionally, the bottom of filter drains can be also impermeable/permeable allowing for controlled drainage while retaining captured water. This design feature enhances their effectiveness in treating runoff and facilitates onsite reuse for purposes such as irrigation for agricultural lands, landscaping, or other non-potable water uses, contributing to water conservation efforts and promoting sustainable water management practices. Picture source: Travauxbricolage.fr

Main challenges targeted	Rainwater management & flood protection, Freshwater and groundwater supply and quality, Sustainable practices, resources recovery & valorization

Regulation and Maintenance Services	Reduce water withdrawals, Efficient water treatment, Improve quality of groundwater and surface waters, Reduce flood risk, Reduce sediment flow into drainage systems, Reduce agricultural runoff, Stormwater source control, Permeability restoration, Mitigate desertification, Create or restore fauna, Connect blue and green spaces, Develop resilience of green spaces Coastal restoration & protection/ Promote resilience against natural disasters, Improve carbon sequestration, Reduce greenhouse emissions, Provide thermal regulation / cooling, Reduce risk of pest and diseases
Cultural Services	Health and Well-Being improvement, Facilitate education, Support environmental awareness, Increase stakeholder engagement.
Provisioning Services	Water reuse, Preserve groundwater and surface waters supply, Harvest, store and treat rainwater, Nutrient recovery, Produce energy / Reduce energy demand, Material reuse Fresh water
Other Services	Contribute to local employment, Contribute to new or existing business, Reduced costs in comparison with other solutions, Favour green economy (reuse of local by-products), Reduced carbon footprint, Reduced water footprint.
Replicability	★★☆
Design & planning	The main types of **filter media** include gravel, washed gravel, and stones. It is designed with a minimum **length** of 5 m and a minimum **depth** of 1 m to effectively filter water and manage drainage. The **width** of the filter drain should be triple the diameter of the incoming pipe, including bedding and surround, ensuring proper installation and functionality. Additionally, to maintain optimal performance, there should be a minimum distance of 500 mm between any pipework and the bed of the filter trench, preventing interference with the drainage system
Operation and maintenance	**Operational activities:** Regular inspections are conducted to detect signs of clogging, which may impede the drain's function. **Maintenance activities:** Sediment accumulated in the pre-treatment system is removed to prevent blockages and maintain efficient water flow. Additionally, the surface layer of gravel is intermittently cleaned or replaced, typically every five to ten years, to optimise filtration performance. Cleaning and replacing gravel are preferred over disposal, as it is a more sustainable option, contributing to the long-term viability and environmental friendliness of the filter drain system. **Others:** Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements.Safety protocols and training (to prevent accidents and ensure compliance with safety regulations).Track legal and regulatory compliance.Be prepared to adapt your operation and maintenance practices over time in response to changing environmental conditions, market

	dynamics, and other factor
Combinations with other NBS	**Bioretention cells (rain gardens), bioswales and riparian buffer** (for an integrated rainwater management).
Supportive units & smart tech	**Rainwater harvesting systems** (for using collected rainwater for irrigation), **Smart sensors** (to monitor humidity, T and air quality for assessing the impact of environmental conditions, detecting anomalies and optimising maintenance).
Treatment efficiency	**30-50 % TSS**
CAPEX	80 - 200 €/m^2. Main types of costs: Equipment and materials: pipes, gravel, stones, geotextiles, excavators and trucks); Labour (excavation, placement of materials, soil compaction, and other related tasks).
OPEX	0.5-3 €/m^2 y. Main types of costs: Labour (cleaning, repairs and replacement of parts, inspections, monitoring and controlling the operation of the filter drain).
By-product(s):	*Not applicable*

PERMEABLE SURFACES

CARDIMED	POROUS ASPHALT

Synonyms: Hard drainage pavements, pervious asphalt, pervious pavement, porous pavement, permeable pavements; modular permeable paving, grass reinforcement, resin bound gravel, porous concrete. **Description:** Porous asphalt is a permeable paving system designed to absorb stormwater, thereby reducing surface water runoff. Similar to permeable or pervious concrete, porous asphalt allows water to pass through its surface. Unlike regular asphalt, porous asphalt is composed of larger stones and different asphalt binders, facilitating water permeability. Beneath the porous asphalt layer lies an open-graded stone bed, which further aids in water drainage. Common application areas for porous asphalt include parking lots, streets, driveways, and other surfaces where stormwater management is essential. Picture source: Veronique Masotti

Main challenges targeted	Rainwater management & flood protection, Freshwater and groundwater supply and quality
Regulation and Maintenance Services	Improve quality of groundwater and surface waters, Reduce flood risk, Reduce sediment flow into drainage systems, Reduce combined sewer overflows, Reduce urban runoff, Stormwater source control, Permeability restoration, Stabilise soil / substrate, Enhance and stabilise water retention Provide thermal regulation / cooling
Cultural Services	Facilitate education, Support environmental awareness

Supporting Services	Erosion regulation, Enhance and stabilise water retention
Provisioning Services	Preserve groundwater supply
Replicability	★★★
Design & planning	The porous/previous asphalt incorporates various **materials** and equipment for construction. Materials typically include larger stones, asphalt binders such as epoxy resin, grass, gravel-grass, plastic grass slabs, concrete grass slabs, gravel and geotextiles. The **equipment** required for installation is standard, similar to that used for building regular asphalt roads. One key aspect of the design is the **depth** of the stone bed, which typically ranges from 0.5 to 1 m. This depth is crucial for proper water filtration and drainage through the porous asphalt surface.
Operation and maintenance	**Operational activities:** Annual inspections are conducted to assess the surface for signs of deterioration. Additionally, the exfiltration capability of the pavement is evaluated at least once a year. **Maintenance activities:** Surface cleaning is performed using a power washer to dislodge trapped particles, followed by vacuum sweeping to remove debris. **Others:** Regular documentation of maintenance activities, operational issues, and measurements. Safety protocols and training (to prevent accidents and ensure compliance with safety regulations.
Combinations with other NBS	**Bioretention cell (rain garden), Bioswale and filter drain** (for reducing the runoff going to these systems, improving stormwater source control and enhancing overall biodiversity of the approach - an integrated rainwater management strategy). **Terracing** (for enhancing slope stability and maximising the available land for water infiltration).
Supportive units & smart tech	**Smart sensors** (to monitor water flow, T, and pavement condition for assessing the impact of environmental conditions, detecting anomalies, and optimising maintenance). **Subsurface drainage systems** (for channelling the water captured for a proper disposal).
CAPEX	45-120 €/m^2. Main type of costs: Equipment and materials (porous concrete, gravel and geotextiles); Labour (excavation, soil levelling, pervious pavement installation, pouring and laying porous concrete)
OPEX	0.5-65 €/m^2 y. Main type of costs: Labour (removing litter, surface vacuum, restriping, replacing pavers, cleaning out pipes, replacing joint and rehabilitation).
By-product(s):	*Not applicable*

VERTICAL GREENING SYSTEMS

CARDIMED	WALL-BASED GREEN FACADE

Synonyms: Hydroponic green facade; Facadebound greening; Facade bound green, wall; living wall; Continuous green, wall; Plant wall system; Green façade with vertical panels; Greening vertical panel; Vertical greening pane, Planter green wall; Planter green facade; Planter boxes; Planter pots; Planter-based green wall; **Description:** This NBS is a greening vertical panel that is fixed onto walls (in building facade or other types of walls). The panels allow the placement of plants and substrate on the entire surface. In contrast to green façades, this NBS can support a wider variety of plant species (e.g. shrubs, grasses and several perennials). The panels can be continuous or modular. Continuous panels are lightweight and permeable screens in which plants are inserted individually. A frame is fixed to the wall to support the panel, normally leaving a gap between the system and the surface. Modular panels can have several elements with specific dimensions (e.g.trays, vessels, pots, planter tiles, flexible bags). These elements can include the growing media or be soilless/hydroponics. These elements together can create modular sections that are supported by a complementary structure or fixed directly on the vertical surface. Some systems allow the removal of panels during wintertime (adapted from Castellar et al., 2021) IRIDRA Srl (Courtesy prof. Prof. Yaser Abunnasr)

Main challenges targeted	Thermal regulation, Air quality, Biodiversity & renaturalization,
Regulation and Maintenance Services	Reduce water withdrawals and Efficient water treatment (only in the case this NBS is used to treat and reuse wastewater) ,Create or restore habitat Mitigate desertification, Create or restore flora, Support pollination, Develop resilience of green spaces, Provide nesting and breeding habitat, Improve carbon sequestration, Reduce greenhouse emissions, Enhance dry deposition of aerosol particles, Provide thermal regulation / cooling, Provide thermal isolation
Cultural Services	Health and Well-Being improvement, Increase recreational and socialisation value, Increase aesthetic and patrimonial or cultural value, Facilitate education, Support social cohesion and justice, Support environmental awareness, Increase stakeholder engagement, Enhance acoustic comfort, Promote physical and mental health, Reconnect people with nature
Provisioning Services	Water reuse, Provide nutrition sources for birds and insects, Production of biomass, Nutrient recoveryFood production, Biochemical, natural medicines and pharmaceuticals,
Other Services	Contribute to local employment, Increase land/property monetary value, Increase tourism, Contribute to new or existing business, Reduced costs in comparison with other solutions, Favour green economy (reuse of local by-products), Reduced water footprint
Replicability	★☆☆
Design & planning	The most common **plants** used are shrubs, herbs, and grasses, but edible plants can also be used. They are selected based on local climate conditions such as sunlight exposure and rainfall. It's advisable to incorporate a diverse range of 10-15 plant species to

	bolster resilience against pests, diseases, and environmental factors, while also ensuring visual appeal. **Panel sizes** typically fall within the range of 0.5 to 1.0 m2. The materials used for the panels should be resistant to the elements and also comply with local safety regulations (for example: resistance to fire, etc.). **Automatic irrigation systems** with perforated pipes or drippers are commonly employed, although drippers may not be suitable for wastewater treatment due to potential clogging issues. The **substrate** used is usually lightweight and mineral-based, such as perlite or expanded clay pellets, occasionally supplemented with organic materials like coconut fibre or peat moss. However, soilless systems/hydroponics can also be implemented.
Operation and maintenance	**Operation activities:** Regular inspection of irrigation systems to ensure proper functioning in line with plants needs, monitoring plant health and addressing any signs of pests or diseases promptly, adjusting irrigation schedules based on seasonal changes in environmental conditions, regular inspection of structural integrity to ensure stability and safety. **Maintenance activitie**s: pruning and trimming of plants to maintain desired aesthetics and prevent overgrowth, monitoring nutrients demand, periodic cleaning of modular components to remove dust, debris, or algae buildup. **Others:** Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements. Safety protocols and training (to prevent accidents and ensure compliance with safety regulations).Track legal and regulatory compliance.
Combinations with other NBS	**Green corridors** as an element (for maximising thermal regulation and biodiversity enhancement), **Bioretention cells (rain gardens)** and **Bioswales** (for reducing the runoff going to these systems).
Supportive units and smart tech	**Rainwater harvesting systems** (for using collected rainwater for irrigation). **Solar panels** (for reducing energy costs and enhancing overall sustainability). **Smart irrigation systems** (for optimising water usage). **Smart sensors** (to monitor humidity, T and air quality for assessing the impact of environmental conditions, detecting anomalies and optimising maintenance) and pretreatment, advanced water treatments and storage tanks (for treating wastewater).
CAPEX	1000-1200 €/m^2 Main type of costs: Site preparation; Equipment and materials (panels, irrigation systems, growing medium, plant-, structural support - frames, brackets, fasteners -, tools and machinery); Labour (irrigation system installation and other tasks); Transportation and delivery; Permits, fees and administrative; Design and development infrastructure (engineering services); Unforeseen expenses or project contingencies.
OPEX	10-70 €/m^2 y Main type of costs: Utilities (water and electricity); Permits, fees and administrative (municipal water fees, periodic inspections, water treatment if using recycled water, fertilisers, nutrients, or soil amendment, documentation and reporting for compliance or regulatory purposes); Labour (cleaning and aesthetic upkeep, record-keeping, pruning, pest control, prevent or treat plant diseases and infestations, replacement plants, periodic inspections, training staff, cleaning and

	aesthetic upkeep and record-keeping); Materials and supplies (pest management or treat plant diseases and infestations products); Other (Water quality analytics for compliance with current local regulations for water reuse are essential).
By-product(s):	Organic biomass from trimming, pruning, clippings and fallen leaves (for mulching, soil amendments, composting, organic fertilisers, energy production and biofuel). Edible goods and pharmaceuticals (for local consumption or sales).

CARDIMED	VEGETATED PERGOLA

Synonyms: Green pergola; Greened pergola; Green mattresses; Green shady structures; Green shade, Eco-friendly pergola; Plant-filled pergola; Living pergola. **Description:** It is an architectural structure crafted to offer shade while supporting climbing plants, enhancing outdoor living spaces with a blend of functionality and visual appeal. Typically, they utilise pillars, beams, stretched textile structures, and lattices made of various materials to provide a framework for vegetation growth and shaded areas. These structures may incorporate inert substrates onto which seeds can be spread. Vegetated pergolas can be installed fixed to building facades, along streets, or supported by posts anchored to sidewalks. Picture source: NATURE4CITIES

Main challenges targeted	Biodiversity & Renaturalization, Thermal regulation, Air quality
Regulation and Maintenance Services	Habitat for species, Create or restore habitat, Mitigate desertification, Create or restore fauna, Create or restore flora, Support pollination, Connect green spaces, Develop resilience of green spaces, Support free movement of species, Provide nesting and breeding habitat, Promote resilience against natural disasters, Enhance and stabilise water retention, Improve carbon sequestration, Reduce greenhouse emissions, Enhance dry deposition of aerosol particles, Provide thermal regulation / cooling, Reduce risk of pest and diseases
Cultural Services	Health and Well-Being improvement, Increase recreational and socialisation value, Increase aesthetic and patrimonial or cultural value, Preserve cultural and historic heritage, Facilitate education, Support social cohesion and justice, Support environmental awareness, Increase stakeholder engagement, Enhance acoustic comfort, Increase physical and mental health, Reconnect people with nature, Promote health habits
Provisioning Services	Provide nutrition sources for birds and insects, Production of biomass, food production
Other g Services	Contribute to local employment, Increase land/property monetary value, Increase tourism, Contribute to new or existing business, Reduced costs in comparison with other solutions, Favour green economy (reuse of local by-products), Reduced carbon footprint

	Sustainable food production
Replicability	★★★
Design & planning	**Plants:** Usual plants are climbing vines, creepers, but also edible species can be used**.** Consider factors such as climate suitability, growth habits, maintenance requirements, aesthetics, and desired functions (e.g., shade, privacy). **Support systems:** Prioritise durability, aesthetics, plant support, functionality, maintenance ease, cost-effectiveness, environmental friendliness, and adaptability.
Operation and maintenance	**Operational activities:** Structural integrity checks, safety measures. **Maintenance activities:** Regular pruning to maintain structure and health, and timely harvesting for fruit-bearing plants. Additionally, consider fertilisation, pest and disease management. **Others:** Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements. Safety protocols and training (to prevent accidents and ensure compliance with safety regulations).Track legal and regulatory compliance.
Combinations with other NBS	**Wall-based green facade** (for enhancing aesthetics appeal and providing additional habitat for pollinators and other wildlife). **Compost application, Mulching application** (for optimising the maintenance or as end for produced biomass).
Supportive units & smart tech	**Rainwater harvesting systems** (for using collected rainwater for irrigation). **Smart irrigation systems** (for optimising water usage). **Smart sensors** (to monitor humidity, T and air quality for assessing the impact of environmental conditions, detecting anomalies and optimising maintenance). **Additional features or amenities** (chairs, tables, bicycle racks to create inviting spaces). **Solar panels** (for reducing energy costs and enhancing overall sustainability).
CAPEX	*not available.* Main types of costs: Equipment and materials (pergola structure, climbing vines, creepers or other suitable plants, irrigation systems, trellises, wire mesh, netting, lighting fixtures, pathways, seating areas, seating, benches, tables and decorative elements); Labour (construction, installation, and landscaping work and irrigation system installation); Permits, fees and administrative (architectural and engineering fees, and permit acquisition).
OPEX	*not available.* Main types of costs: Utilities (water and electricity); Permits, fees and administrative (insurance); Labour (pruning, trimming, weeding, and replacing vegetation, removing debris, sweeping pathways, washing surfaces, repairing and replacing damaged or worn-out components of the pergola structure, pest control and training staff); Materials and supplies (fertilisers, compost, mulch, or other soil amendments.
By-product(s):	Harvested edible plants (for local consumption or sale). Organic biomass from trimming, pruning, clippings and fallen leaves (for mulching, soil amendments, composting, organic fertilisers, energy production and biofuel). Harvested flowers and ornamentals (for decorative purposes). Woody biomass (for biofuel).

FARMING PRACTICES

CARDIMED	AQUACULTURE

Synonyms: Mariculture; Aquafarming; Flow-through fish farm; Recirculating Aquaculture Systems (RAS); Integrated multi trophic aquaculture (IMTA); Open-net pens or cages. **Description:** Aquaculture is the farming of aquatic organisms, including fish, molluscs (like mussels), crustaceans, and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. Aquaculture includes flow-through fish farms as well as recirculating aquaculture systems (RAS). Aquaculture has potential for providing lower priced fish, enhancing nutritional security and contributing to local employment. Urban aquaculture can decrease the distance between farm and plate, generate income, use less resources, and serve as a community-building tool. Picture source: Wikimedia Commons

Main challenges targeted	Biodiversity & renaturalization and Local Development & Economic Enhancement
Regulation and Maintenance Services	Create or restore fauna, Connect blue and green spaces, Refuge for farm and wild animals, Restore aquatic habitats, Improve carbon sequestration, Provide thermal regulation / cooling
Cultural Services	Facilitate education, Support environmental awareness, Recreation and ecotourism
Provisioning Services	Provide nutrition sources for birds and insects, Sustainable food production
Other services	Contribute to local employment, Increase land/property monetary value
Replicability	★☆☆

Design & planning	**Objective setting**: Define the specific goals of the aquaculture operation, including the type of species to be farmed, production goals, and market targets. **Species selection:** Fish: salmon, tilapia, catfish, carp, trout, barramundi; Crustaceans: shrimp, prawns, crayfish; Mollusks: oysters, mussels, clams; Seaweeds: kelp, nori; Other aquatic plants: spirulina. **Site selection**: Choose a suitable location based on water source availability, environmental conditions, accessibility, and regulatory constraints. **Environmental impact assessment**: Conduct an assessment to evaluate the potential impacts of the aquaculture system on the local environment and comply with all regulatory requirements. **System design**: Choose the appropriate aquaculture system (e.g., open ponds, RAS, cage systems) based on the species, scale, environmental factors, and economic considerations. **Water source and quality analysis**: Analyse the quality of the available water sources and design water treatment systems if necessary to ensure optimal water conditions for aquaculture. I**nfrastructure planning**: Plan and design the necessary infrastructure, including tanks, cages, water supply systems, feed systems, waste management, and other facilities. **Biosecurity measures**: Design biosecurity measures to prevent the introduction and spread of diseases within the farm. **Technology and equipment selection**: Select appropriate technology and equipment for feeding, monitoring, and managing the aquatic environment. **Financial planning**: Develop a detailed business and financial plan including budgeting, expected revenue, and profitability analysis. **Operational planning**: Establish protocols for daily operations, including feeding, monitoring, harvesting, and staff management. **Marketing strategy**: Develop a marketing strategy to position and sell the aquaculture products effectively in the targeted markets.
Operation and maintenance	**Operational activities:** Monitor water quality regularly, manage feeding carefully to avoid overfeeding, ensure proper water exchange for filtration, implement biosecurity measures, maintain appropriate stocking densities, regular health checks for stock, monitor weather conditions to mitigate potential stressors, develop emergency response plans, energy efficiency measures **Maintenance activities:**Clean and maintain equipment routinely, algae control, predator control, and waste management. **Others:** Training to staff and volunteers responsible for the operation and maintenance. Regular documentation of maintenance activities, operational issues, and measurements.Safety protocols and training (to prevent accidents and ensure compliance with safety regulations).Track legal and regulatory compliance.Be prepared to adapt your operation and maintenance practices over time in response to changing environmental conditions, market dynamics, and other factor

Combinations with other NBS	**Riparian Buffer, Subsurface flow constructed wetland, Electrowetland , Free water surface constructed wetland** and **High rate algae pond** (for improving the influent and effluent of the system).
Supportive units & smart tech	**Smart sensors** (to monitor water quality, T and feeding regimes for optimising production processes and maintenance, detecting anomalies and managing feeding). **Artificial intelligence, computer vision** and **machine learning** (for predictive modelling and adaptive management).
[1]CAPEX	10,000.00 - 20.00,000.00 €. Main type of costs: Equipment and materials (aquatic species, hatchery and broodstock and other construction equipment and materials); Permits, fees and administrative (land acquisition and other permits); Labour (hatchery and broodstock installation); Unforeseen expenses or project contingencies.
[2]OPEX	5,000.00 - 5,000,000.00 €/y. Main type of costs: Utilities (water and electricity); Materials and supplies (feed and nutrition); Labour (water and waste management, veterinary care, maintenance and repairs); Permits, fees and administrative (insurance); Marketing and sales.
By-product(s):	Fishmeal and fish oil (for livestock feed), Organic Fertilizer from sludge (for agriculture), biogas from organic waste (for heating, electricity, vehicle fuel), Shellfish Shells (for agriculture), Fish Skin and Scales (for cosmetics, pharmaceuticals, or dietary supplements)

[1] The total costs depend on several factors such as the scale of operation, type of aquaculture system, species cultivated, geographic location and market conditions

[2] The total costs depend on several factors such as the scale of operation, type of aquaculture system, species cultivated, geographic location and market conditions