DuneFront

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DuneFront

Life Cycle Inventory of Demonstrators

Deliverable 8.3 – D8.3

Deliverable information

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Cover page

This deliverable presents the Life Cycle Inventory (LCI) of selected DuneFront demonstrators and the WP15 De Panne eco-dike prototype. It is prepared within WP8, which develops a blue-infrastructure rating system supported by Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). The role of D8.3 is to compile and harmonize the inventory data required for the later environmental impact assessment and rating-system validation in D8.4.

The inventory covers five European demonstrators: Douro Estuary Sandspit in Portugal, Dunkerque in France, Katwijk and Prins Hendrik Zanddijk/Texel in the Netherlands, and Sankt Peter-Ording in Germany. These demonstrators represent different types of hybrid coastal protection systems, including dike-in-dune, dune-in-front-of-dike, dune-in-between-dikes, and a rubble-mound breakwater in front of a dune/sandspit. The De Panne eco-dike pilot is included as the WP15 prototype.

The inventory is structured by life-cycle modules. The main modules considered are A1-A3 for material production, A4 for transport, A5 for construction and installation, B1 for use-stage processes where physically justified, and B2 for maintenance activities. End-of-life modules are not included because future dismantling, reuse, reinforcement, or adaptation of coastal infrastructure is not consistently documented across the demonstrators.

The available data differ between cases. Katwijk, PHZD/Texel, Dunkerque and Sankt Peter-Ording have detailed inventory data from prior thesis work, along with supporting documentation. Douro has strong contextual and morphodynamic information and provides quantities for sand placement, rock layers, Antifer concrete armour units, and construction equipment. The remaining gaps concern transport distances, material source locations, and possible repair work. For De Panne, preliminary quantities are available for demolition, excavation, geotextile, stone layers, concrete elements, HexaBloom, mini-HARO, setts, concrete piles, and related works.

This deliverable does not present final LCIA results. It provides the inventory basis for the environmental impact assessment, life cycle costing, and blue-infrastructure rating-system validation planned in D8.4.

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List of abbreviations

Abbreviation	Explanation
BIRS	Blue-Infrastructure Rating System
D	Deliverable
DD	Dune-Dike
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NbS	Nature-based Solution
PHZD	Prins Hendrik Zanddijk
SPO	Sankt Peter-Ording
WP	Work Package

1. Introduction

1.1 Project context

DuneFront aims to demonstrate blue-grey coastal and marine infrastructure as a sustainable, inclusive, and aesthetically pleasing approach to coastal safety in the context of climate change. The project focuses on dune-dike hybrid NbS that combine static hard infrastructure with adaptive, dynamic aeolian and vegetated sediments. The broader project ambition is to mainstream biodiversity into marine and coastal hybrid systems while maintaining flood and erosion protection for coastal communities and assets.

Within this context, WP8 develops a blue-infrastructure rating system (BIRS) based on life cycle assessment (LCA) and life cycle cost (LCC) analysis. WP8 is structured as a progression from rating system design (D8.1), translation of dune-dike hybrid NbS parameters into impact categories (D8.2), life cycle inventory compilation (D8.3), and finally LCA/LCC and rating system validation (D8.4).

1.2 Objective of D8.3

The official objective of D8.3 is to report the life-cycle inventory (LCI) for selected demonstrators and prototypes associated with Task 8.3. Task 8.3 requires a full LCI for at least five representative European demonstrators, as well as an LCI for the new WP15 prototype. This report, therefore, does not present final LCIA results; it provides the inventory basis required for subsequent impact assessment and rating-system validation in D8.4.

1.3 Scope of this deliverable

Component	Scope adopted in this report	Status
European demonstrators	Douro Estuary Sandspit, Dunkerque, Katwijk, Prins Hendrik Zanddijk/Texel, Sankt Peter-Ording	Selected by the WP8 preparation discussion.
WP15 prototype	De Panne eco-dike pilot	Included, preliminary quantity estimate available
Life-cycle stages	A1-A3, A4, A5 and selected B modules, with emphasis on B2 maintenance/ nourishment	Aligned with practical LCI needs for coastal demonstrators.
Impact assessment	Not included	To be completed under D8.4

2. Methodology

2.1 LCI system boundary

The inventory is organized by life-cycle stage. The working boundary is cradle-to-operation. End-of-life is documented as a limitation and should only be added in D8.4 if sufficiently robust assumptions are available. This choice reflects the adaptive nature of coastal infrastructure, where future reinforcement, nourishment, and redesign are more reliably modeled through maintenance/ adaptation scenarios than as a single deterministic end-of-life event.

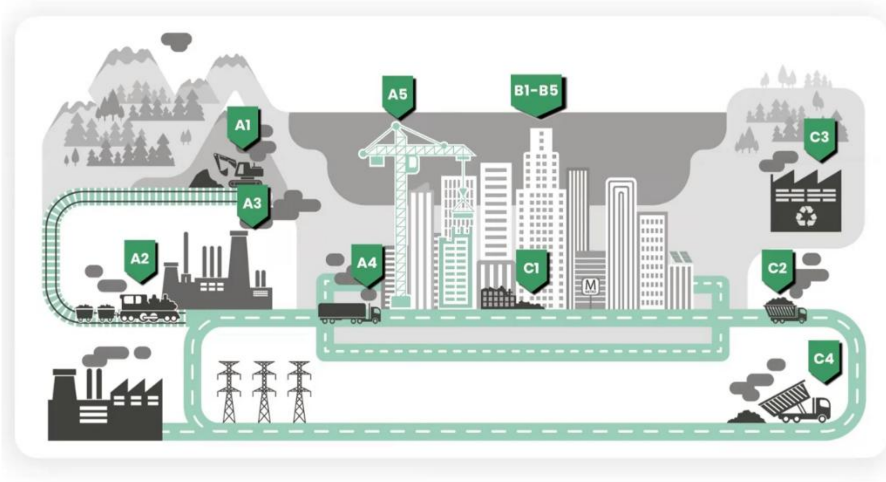

Figure 1: Life-cycle stages

Module	Included inventory flows	Typical coastal processes
A1-A3 Product stage	Material production for sand, rock, concrete, asphalt, steel, geotextiles, vegetation, and other relevant materials	Quarrying and processing: cement/concrete production, asphalt production, steel production, plant materials, where relevant.
A4 Transport	Transport from the source or production location to the site.	Dredging/ pumping distance, vessel transport, road transport, quarry-to-site transport, production-yard-to-site-delivery
A5 Construction/ installation	On-site energy, equipment, and installation processes.	Earthworks, sand placement, pumping, bulldozing, excavation, concrete placement, element installation, temporary works.
B1 Use stage	Only included when physically justified and separately documented	Carbonation of concrete, biogenic carbon uptake by vegetation.
B2 Maintenance	Periodic nourishment, inspection-related works, and vegetation management	Beach-dune nourishment, dredging and pumping, trucking, replacement of damaged elements, and periodic repairs.

B3 Repair	Repair activities after local damage or storm-related impacts, where data are available	Repair of damaged revetment elements, local restoration of dune toe protection, post-storm repair works
B4 Replacement	Replacement of components during the service life, where expected or documented	Replacement of damaged concrete blocks, geotextiles, armour stones, or other revetment elements
B5 Refurbishment	Larger interventions or upgrades that restore or improve the system before end-of-life, where data are available	Major reinforcement, adaptation, redesign, or upgrading of coastal protection elements
C End-of-life	Not included in this report unless case-specific data become available.	Future demolition/reuse/adaptation not yet sufficiently defined for the selected cases.

2.2 Functional unit and reporting unit

Two reporting levels are proposed. First, each demonstrator is reported as the implemented demonstrator system, because this is how the case-specific design and monitoring information is provided. Second, where sufficient geometric information is available, quantities are normalized per meter of protected coastline to improve comparability. For later LCIA in D8.4, the recommended functional framing is: one hybrid dune-dike or dune-related coastal protection system providing flood and erosion protection along a defined coastal section over its operational service life.

2.3 Data quality classification

Because the LCI data originate from different document types and levels of maturity, each input is assigned a data-quality code.

Code	Definition
A- Measured/ reported	Direct value from design report, tender bill, as-built file, official monitoring data, or partner LCI spreadsheet.
B- Calculated	Derived from cross-sections, drawings, geometry, volumes, densities, or recurring maintenance rules
C- Proxy	Representative process or datasets selected because the exact process is unavailable
D- Missing	Required but not yet available

2.4 Harmonized LCI template

To enable comparison across demonstrators with different configurations, data availability, and construction histories, a harmonized LCI template was developed. The template records all available inventory flows by life-cycle module, including material production, transport, construction, use-stage processes, and maintenance. Each flow is reported with its quantity, unit, normalized value, source, data-quality classification, and assumptions. Where values are not available, the field is explicitly marked as "Not Available" and included in the data-gap register.

Table 1: Harmonized demonstrator metadata template

Field	Description
Demonstrator name	Name and country
Configuration	Dike-in-dune, dune-in-front-of-dike, dune-in-between-dikes, breakwater in front of dune/sandspit, prototype zone
Construction / installation period	Year or period of construction
Reporting unit	Whole demonstrator, per meter coastline, per meter dike, per zone, or per element type
Reference period	Service-life or assessment period where available
Main data source	Design report, thesis, Excel, tender, demonstrator sheet, stakeholder input
LCI completeness	High, medium, low, or incomplete
Main gaps	Missing inventory values or assumptions

Table 2: Harmonized inventory-flow template

Module	Inventory Input	Quantity	Unit	Normalized value	Unit per reporting unit	Data quality
A1-A3	Sand		kg or m^3		kg/m or m^3/m	A/B/C/D
A1-A3	Concrete		kg or m^3		kg/m or m^3/m	A/B/C/D
A1-A3	Rock/stone		kg or m^3		kg/m or m^3/m	A/B/C/D
A1-A3	Asphalt		kg or m^3		kg/m or m^3/m	A/B/C/D
A1-A3	Steel		kg		kg/m	A/B/C/D
A1-A3	Geotextile		kg or m^2		kg/m or m^2/m	A/B/C/D
A1-A3	Vegetation		kg, shoots, or area		per m or per area	A/B/C/D
A4	Transport		tkm or km		tkm/m	A/B/C/D

A5	Construction energy		MJ or L diesel		MJ/m or L/m	A/B/C/D
B1	Carbon uptake		kg CO_2		kg CO_2/m	A/B/C/D
B2	Maintenance sand		kg or m³		kg/m/reference period	A/B/C/D
B2	Repairs/replacements		kg, m³, or pieces		per m	A/B/C/D

2.5 Demonstrator selection

Demonstrator	Country	Configuration/context
Douro Estuary Sandspit	Portugal	Rubble-mound breakwater in front of dune/sandspit, no dike, natural barrier protecting inland margins and harbours.
Dunkerque	France	Dune in front of the dike; Digue des Alliés and nourished dune
Katwijk	The Netherlands	Dike-in-dune; hard dike embedded in dune
Prins Hendrik Zanddijk/Texel	The Netherlands	Dune-in-front-of-dike / dike-in-dune, dune landscape as primary protection with ecological goals
Sankt Peter-Ording	Germany	Dune in front of old dike/dune-in-between-dikes, national park/tourism/biodiversity context

2.6 Source documents used

Source group	Documents used	
Demonstrator design	D7.1 Demonstrator design methodologies; D7.2 boundary conditions	Demonstrator typology, design context, and available design information
Boundary conditions	D4.1, D4.2, D4.3	Physical, biological, socio-economic boundary context
Morphodynamics	D6.1, D6.2, D6.3, D11.1	Morphodynamic evolution, vegetation-sediment interaction, model context
Socio-economics	D9.1, D9.2	Multi-use potential, co-benefits, barriers, governance
WP15 prototype	De Panne bestek, stakeholder meeting notes, D15.3	Prototype description and construction-element categories
Case-study LCA material	Thesis documents and Excel files	Available for Katwijk, PHZD, Dunkerque, and Sankt Peter-Ording;

Douro-specific documents	Douro demonstrator sheet, Restinga Douro summary sheet, D11.1	Douro context, morphology, breakwater description, monitoring

3. Demonstrator-specific information

3.1 Douro Estuary Sandspit, Portugal

The Douro Estuary Sandspit is located at Alumiari, Porto, Portugal, with coordinates 41° 8.453'N, 8° 40.055'W. The installation period is reported as 2004–2008. The demonstrator consists of a rubble-mound breakwater located in front of a dune/sandspit system. The sandspit is rooted on the southern bank of the Douro River estuary and is approximately 300 m wide in the east-west direction and 800 m long in the north-south direction. Its eastern part is stabilized by vegetation and connects to the São Paio Bay marshes.

The demonstrator does not include a conventional dike. However, the detached breakwater blocks wave penetration and protects the sandspit from erosion. The combined sandspit and breakwater system provides protective functionality for inland margins and harbours.

Figure 2: Douro Estuary Sandspit (PT) Demonstrator, a rubble mound breakwater in front of a Dune

The Douro sandspit is an important natural coastal defence. Its morphodynamics are controlled by both natural and human processes, including river discharge, ocean waves, tides, aeolian transport, and the influence of the breakwater. The sandspit has shifted inland by approximately 500 m during the past century.

Between 2004 and 2008, a detached breakwater was constructed to stabilize the estuary banks and inlet, improve navigation safety under tide conditions, reduce storm-wave propagation, preserve the sandspit and São Paio Bay nature reserve, and reduce maintenance dredging of the navigation channel. The works included extension of the northern jetty by about 350 m and construction of a 450 m curved breakwater located about 350 m seaward of the sandspit position.

A monitoring programme was established in June 2001 to evaluate sandspit evolution and breakwater efficiency. The programme used DEMs derived from seasonal GPS-based field surveys and later mobile mapping techniques to assess changes in sandspit position, shape, and volume.

D11.1 reports that after completion of the breakwater in 2008, the sandspit grew on average by approximately 68,000 m³ per year, except during some storm-related erosion events. The maximum dune height reaches around 8 m above mean sea level.

During construction, approximately 200,000 m³ of sand was dredged and placed on the sandspit. The detached breakwater includes approximately 15,882 m³ of rock for the berm layers and toe protection. The armour layer consists of high-density concrete Antifer blocks, including 8,880 units of 80 kN and 2,841 units of 102 kN. The reported concrete density for the Antifer blocks is 3.2 t/m³. No geotextile or vegetation quantities were reported. The breakwater was constructed as a rubble-mound breakwater with a crest around +6 m chart datum, using a rock core/intermediate rock layers and an armour layer of high-density concrete Antifer blocks. Two cranes were used to place the Antifer blocks and rockfill: a Manitowoc 4000, a 140-ton crane, and a Manitowoc 2250, a 300-ton crane. No regular sand nourishment was reported after construction.

Table 3: LCI relevant information

LCI element	Available status	Data quality
Main structure	Rubble-mound detached breakwater	A
Natural component	Sandspit / dune with sparse vegetation	A
Construction period	2004–2008	A
Breakwater length	450 m curved breakwater reported	A
Jetty extension	About 350 m reported	A
Sand dredged and placed on sandspit	200,000 m³	A
Rock for berm layers and toe protection	15,882 m³	A
Armour units	Antifer blocks: 8,880 units of 80 kN + 2,841 units of 102 kN	A
Concrete density	3.2 t/m³	A
Breakwater crest	Around +6 m chart datum	A
Construction equipment	Manitowoc 4000, 140-ton crane; Manitowoc 2250, 300-ton crane	A
Vegetation	NA	D
Transport distance	NA	D
Maintenance sand nourishment	Not applicable after construction, except for construction-stage sand placement	A
Monitoring data	Available as DEM/GPS/mobile mapping context	A

Table 4: Douro harmonized LCI input

Module	Inventory Input	Quantity	Unit	Normalized value	Unit	Data quality
A1-A3 / A5	Sand dredged and placed on sandspit	200,000	m³	444.44	m³/m breakwater	A
A1-A3	Sand mass equivalent	3.30E+08	kg	7.33E+05	kg/m breakwater	B
A1-A3	Rock for berm layers and toe protection	15,882	m³	35.29	m³/m breakwater	A
A1-A3	Rock mass equivalent	4.21E+07	kg	9.36E+04	kg/m breakwater	C
A1-A3	Antifer blocks, 80 kN	8,880	units	19.73	units/m breakwater	A
A1-A3	Antifer blocks, 102 kN	2,841	units	6.31	units/m breakwater	A
A1-A3	Antifer concrete mass	1.02E+08	kg	2.27E+05	kg/m breakwater	B
A1-A3	Antifer concrete volume	31,861	m³	70.80	m³/m breakwater	B
A4	Transport of sand, rock, and Antifer blocks	Not Available	tkm	Not Available	tkm/m breakwater	D
A5	Crane placement of rockfill and Antifer blocks	2 cranes	equipment type	2 cranes	—	A
B2	Sand nourishment after construction	Not applicable	—	—	—	A
B2	Repair/maintenance works	Not Available	—	Not Available	—	D

Normalized values for Douro were calculated per meter of detached breakwater using the reported breakwater length of 450 m. The sand mass equivalent was calculated using an assumed density of 1,650 kg/m³, consistent with the other demonstrator inventories. The rock mass equivalent was calculated using an assumed density of 2,650 kg/m³ and is therefore marked as proxy-based. Antifer concrete mass was calculated from the reported unit weights of 80 kN and 102 kN, and Antifer concrete volume was calculated using the reported density of 3.2 t/m³.

3.2 Dunkerque, France

D7.1 identifies Dunkerque as a dune-in-front-of-dike demonstrator. The demonstrator has a dike safety function, and design reports, extreme boundary conditions, and an official safety assessment methodology are available. D7.1 also reports that Dunkerque has a comprehensive monitoring and maintenance plan involving biannual monitoring of the beach and dune, including DTMs, drone surveys, and surficial grain-size analysis.

Figure 3: Dunkerque (FR) Demonstrator, at three key locations: Malo les Bains (West and East sections of the Digue des Alliés) and Digue du Break

The Digue des Alliés demonstrator includes a sand dune and a dike component. The dune was constructed in 2020 by accumulating sand on the seaward side of the dike. The resulting dune is 600 m long, 20–30 m wide, and approximately 3 m high. It was planted with marram grass at 10 shoots/m² to stabilize the dune and reduce sand transfer from the beach to the canal.

A separate LCI was developed for the dune and the dike. Where exact quantities were unavailable, material volumes and weights were estimated from design drawings or calculated using assumptions from literature. The dune length used for normalization is 600 m, while the dike length is 900 m.

Table 5: LCI relevant interpretation

LCI element	Available status
Configuration	Dune-in-front-of-dike
Construction years	2015 and 2020 sections reported
Major nourishment	2014 beach nourishment reported
Dike safety function	Available
Design documents	Available according to D7.1

Table 6: Dunkerque dune LCI inputs

Module	**Inventory input**	**Total quantity**	**Unit**	**Normalized value**	**Unit**	**Data quality**
A1-A3 / A5	Sand	2.90E+09	kg	4.84E+06	kg/m dune	B
B2	Sand maintenance	6.53E+09	kg	1.09E+07	kg/m dune	B
B1	Marram grass	1.00E+00	kg model flow	1.67E-03	kg/m dune	C

Table 7: Dunkerque dike LCI inputs

Module	**Inventory input**	**Total quantity**	**Unit**	**Normalized value**	**Unit**	**Data quality**
A1-A3	Sand	4.88E+08	kg	5.42E+05	kg/m dike	B
A1-A3	Clayey gravel	1.12E+07	kg	1.24E+04	kg/m dike	B/C
A1-A3	Marl	2.87E+07	kg	3.19E+04	kg/m dike	B/C
A1-A3	Masonry	2.50E+07	kg	2.78E+04	kg/m dike	B/C
A1-A3	Steel 1949	5.30E+06	kg	5.89E+03	kg/m dike	B/C

A1-A3	Unreinforced concrete 1949	6.05E+07	kg	6.72E+04	kg/m dike	B/C
A1-A3	Reinforced concrete 1949	2.10E+07	kg	2.33E+04	kg/m dike	B/C
A1-A3	Reinforced concrete 2018	1.56E+06	kg	1.73E+03	kg/m dike	B/C
A1-A3	Micro piles	2.85E+04	kg	3.17E+01	kg/m dike	B/C
A1-A3	Granular filtration/drainage layer	9.65E+06	kg	1.07E+04	kg/m dike	B/C
A1-A3	Steel 2018	9.00E+05	kg	1.00E+03	kg/m dike	B/C

Marram grass is reported as a model flow used for carbon uptake modelling and should not be interpreted as the full physical vegetation biomass.

3.3 Katwijk, The Netherlands

D7.1 identifies Katwijk as a dike-in-dune demonstrator. It has a dike safety function, design report availability, design/extreme boundary condition availability, and official safety assessment methodology availability.

Katwijk was assessed using LCA with a cradle-to-use scope covering A1–B2 and a functional unit of one meter of dike over a 100-year protection period. The LCI was compiled from work plans, technical drawings, and supplier data. Where direct quantities were missing, volumes and weights were estimated from scaled drawings or calculated using standard material densities. The total assessed dike length, including the discharge channel, is 1,466 m.

Katwijk dune-dike structure includes basalt blocks, basalt split, granite aggregate, sand, geotextile, concrete revetments with steel reinforcement, limestone riprap, and marram grass.

Figure 4: Katwijk (NL) Demonstrator, Dike-in-Dune

Table 8: LCI relevant interpretation

LCI element	Available status
Configuration	Dike-in-dune
Functional unit	1 m over 100 years
Boundary	A1–B2 available
Data sources	Contractor data, technical drawings, supplementary documentation
Maintenance	Sand nourishment identified as important

Table 9: Katwijk LCI inputs

Module	Inventory input	Total quantity	Unit	Normalized value	Unit	Data quality
A5 / construction	Sand	2.81E+09	kg	1.91E+06	kg/m dike	A/B
B2	Sand maintenance	8.25E+09	kg	5.62E+06	kg/m dike / 100 years	B
A1-A3	Granite aggregate	2.04E+07	kg	1.39E+04	kg/m dike	A/B
A1-A3	Crushed limestone riprap	2.14E+07	kg	1.46E+04	kg/m dike	A/B

A1-A3	Basalt blocks	2.29E+07	kg	1.56E+04	kg/m dike	A/B
A1-A3	Basalt split	3.54E+06	kg	2.41E+03	kg/m dike	A/B
A1-A3	Concrete revetments	1.58E+06	kg	1.08E+03	kg/m dike	A/B
A1-A3	Geotextile	1.63E+04	kg	1.11E+01	kg/m dike	A/B
B1	Marram grass	1.00E+00	kg model flow	6.82E-04	kg/m dike	C

For sand, A1-A3 were not modelled separately because the sand was extracted directly from a nearby seabed and did not undergo industrial processing. The environmental burdens were instead included under A5, where dredging, pumping, and placement were modelled based on diesel use and equipment activity. Sand was dredged from offshore borrow area Q13K, located 18.5 km from the site.

3.4 Prins Hendrik Zanddijk/Texel, The Netherlands

D7.1 identifies Texel / Prins Hendrik Zanddijk as a dune-in-front-of-dike demonstrator. The overview table reports that design reports, design/extreme boundary conditions, and official safety assessment methodology are available.

Figure 5: Texel, Prins Hendrik Zanddijk (NL) Demonstrator, Dune-in-front-of-Dike

The PHZD LCI was compiled from material specifications derived from contractor Jan De Nul data. The total length used for normalization is 3,200 m. The main materials included in the inventory are sand, concrete, marram grass, and basalt. Certain minor materials were excluded from the environmental impact calculation because of their negligible contribution or because they served functions outside the core infrastructure assessment.

Table 10: LCI relevant interpretation

LCI element	Available status
Configuration	Dune-in-front-of-dike / sand-dike context
Functional unit	1 m over 100 years available
Boundary	A1–B2 available
Data sources	Contractor data, drawings, supplementary documentation
Maintenance	Sand nourishment identified as important

Table 11: PHZD/Texel LCI inputs

Module	Inventory input	Total quantity	Unit	Normalized value	Unit	Data quality
A5 / construction	Sand	9.00E+09	kg	2.81E+06	kg/m dike	A
B2	Sand maintenance	1.65E+09	kg	5.16E+05	kg/m dike / 100 years	B
A1-A3	Concrete	6.28E+06	kg	1.96E+03	kg/m dike	A
B1	Marram grass	1.00E+00	kg model flow	3.13E-04	kg/m dike	C
A1-A3	Basalt	2.04E+06	kg	6.38E+02	kg/m dike	A

For PHZD, A1-A3 were not modeled for sand. As in Katwijk, the sand was considered an unprocessed extracted material, and its environmental burdens were included under A5, where dredging, transport, pumping, and placement were modeled using diesel use and equipment activity. Sand was sourced from borrow areas Q2N and L15, located 36 km and 73 km from Texel, respectively. The total sand volume was 5,455,680 m³, corresponding to approximately 9.00E+09 kg using a density of 1,650 kg/m³. The weighted average sailing distance was calculated as approximately 39.6 km.

3.5 Sankt Peter-Ording, Germany

D7.1 identifies Sankt Peter-Ording as a dune-in-between-dikes demonstrator. The overview table reports that the dike has a safety function and that design reports, design/extreme boundary conditions, and official safety assessment methodology are available.

D11.1 includes Sankt Peter-Ording as one of the selected demonstrators for numerical morphodynamic modelling. WP11 focuses on setting up XBeach and AeoLiS models to investigate morphodynamic functioning, using input from D6.1 and D6.2.

Figure 6: Sankt Peter-Ording (DE) Demonstrator, Dune-in-between-Dikes

Table 12: LCI relevant interpretation

LCI element	Available status
Configuration	Dune-in-between-dikes
Dike safety function	Available
Design reports	Available according to D7.1
Boundary conditions	Available according to D7.1
Morphodynamic model context	Available

The Sankt Peter-Ording system consists of two engineered dikes and two dune systems: the northern coastal protection dike, the southern regional dike, a foredune system, and the dune Maleens Knoll. A separate LCI was developed only for the two engineered dikes, because the dunes consist of natural sediment bodies. This avoids assigning construction burdens to naturally developed dunes.

Where exact quantities were unavailable, material volumes and weights were estimated from design drawings or calculated using general assumptions from literature. Both dikes extend over a length of 1,900 m.

Table 13: Sankt Peter-Ording LCI inputs for engineered dikes

Module	Inventory input	Total quantity	Unit	Normalized value	Unit	Data quality
A1-A3	Sand	8.53E+08	kg	4.49E+05	kg/m dike	B
A1-A3	Mastic asphalt	2.02E+07	kg	1.06E+04	kg/m dike	B/C
A1-A3	Stone mastic asphalt	1.54E+07	kg	8.09E+03	kg/m dike	B/C
A1-A3	Hot bitumen sand	1.05E+07	kg	5.53E+03	kg/m dike	B/C
A1-A3	Rockfill	1.82E+06	kg	9.60E+02	kg/m dike	B
A1-A3	Concrete	2.19E+05	kg	1.15E+02	kg/m dike	B
A1-A3	Asphalt concrete	1.68E+07	kg	8.86E+03	kg/m dike	B/C

The natural dunes should remain excluded from construction burdens unless specific human construction or nourishment interventions are documented.

3.6 WP15 prototype: De Panne Eco-Dike

The De Panne eco-dike pilot is the WP15 prototype included in the D8.3 inventory scope. WP15 focuses on the co-creation, design, construction and monitoring of a new DD-hybrid NbS prototype at the Belgian coast. The prototype is located at the existing dune-foot reinforcement in De Panne, between Westerpunt and the beach access road from Dynastielaan. This location was selected because the existing concrete dune reinforcement is reaching the end of its operational life and needs to be replaced. The current structure consists of a hardened concrete dune reinforcement with a slope of approximately 45°, with the top functioning as a hardened walking and cycling path. The slope consists of gabions and/or rockfill, partly penetrated with concrete, and the landward dune body is bordered in some areas by a concrete storm wall of approximately 1 m height.

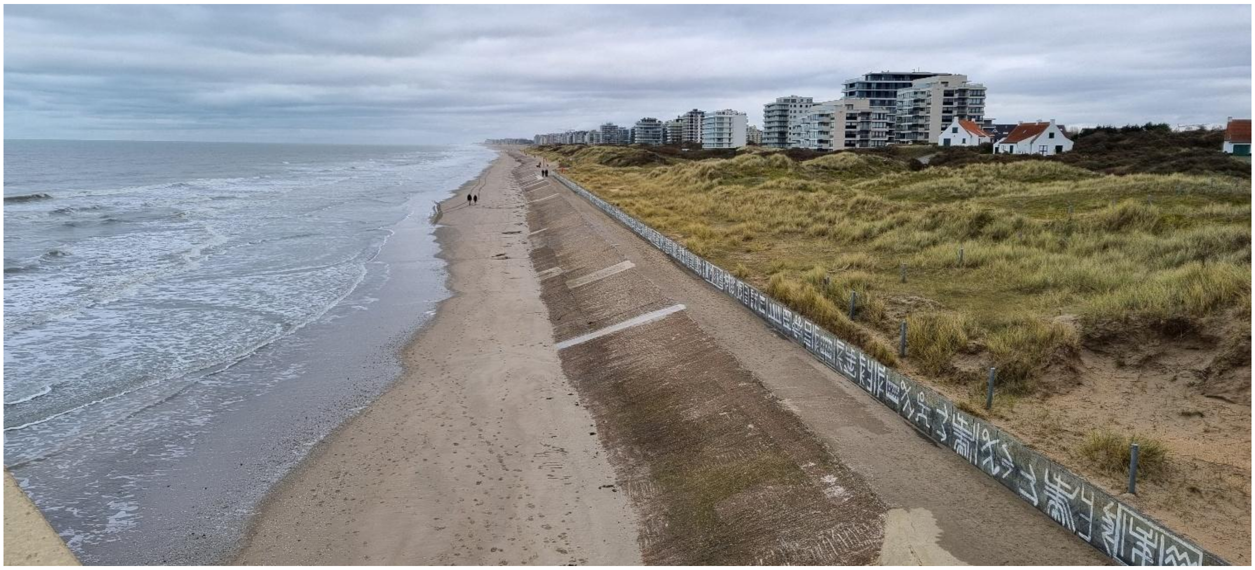

Figure 7: De Panne demonstrator, Belgium

The project location is situated in a transitional coastal zone where natural beach-dune dynamics, ecological values, recreational use, and hard coastal protection meet. It lies between the more natural Westhoek Reserve near the French border and the more urbanized and erosion-sensitive beach zone near the centre of De Panne. The site also overlaps with protected nature designations, including Natura 2000, VEN, and areas protected under the Dunes Decree. This means the pilot must integrate coastal safety, ecological connectivity, and recreational accessibility.

The design of the pilot was developed through a co-creation process involving DuneFront partners, MDK, Arcadis, WL, UGent, VLIZ, and stakeholders from public authorities, recreation and tourism, nature conservation, the local community, culture and heritage, academic and research sectors, and the maritime sector. Across this process, three guiding ambitions were defined: safety, nature, and recreation. Safety remains the primary requirement, while nature provides direction through ecological connectivity and habitat development, and recreation is considered a connecting function through walking and cycling access.

The pilot aims to test different forms of ecological dune-foot reinforcement. Following the market study and further design development, it was adjusted to four test zones of approximately 38 m each, resulting in a total pilot length of approximately 154 m. Each test zone will contain a different dike revetment type, allowing comparison of form, material, ecological potential, opening ratio, sand-trapping capacity and practical implementation. The four concrete cover elements are:

1. Ecoblock Forte or equivalent

2. Basalton Quattroblock or equivalent
3. Mini-HARO block
4. 3D-printed HexaBloom

For D8.3, the De Panne pilot is included as a prototype inventory based on the available tender information, co-creation documents, and preliminary quantity estimate. Remaining assumptions mainly concern transport distances, exact production locations, repair quantities, and the monitoring plan.

Table 14: LCI relevant interpretation

LCI element	Available status
Prototype location	De Panne, Belgium, between Westerpunt and Dynastielaan beach access
Prototype purpose	Replacement/testing of ecological dune-foot reinforcement
Existing structure	Concrete dune-foot reinforcement with hardened walking/cycling path
Existing path width	Approximately 3 m walking/cycling path
Existing slope	Approximately 45° concrete dune reinforcement
Strategic ambitions	Safety, nature and recreation
Pilot layout	Four test zones of approximately 38 m each
Total pilot length	Approximately 154 m
Cover elements	Betonzuil, zetsteen, mini-HARO, HexaBloom
HexaBloom geometry	Diameter 1350 mm, height 600 mm, rotation 15°
Sand filling	Internal cavities/openings to be filled with sand where applicable
Monitoring	Monitoring plan to be developed in T15.4

The tender also lists works including partial demolition of existing dune-foot protection, construction of new dune-foot protection and concrete path, production, delivery, and placement of HexaBloom.

The De Panne tender includes LCI-relevant items for HexaBloom, such as prefabrication, delivery, loading, transport, processing, placement, and filling internal cavities and spaces between blocks with sand.

The HexaBloom element is a modular hexagonal unit designed for nature-inclusive coastal structures, such as hybrid dune dikes. It uses extrusion-based 3D concrete printing to enable complex geometries and optimized material distribution. The design objectives include structural stability under coastal conditions, reduced material use, high bioreceptivity for dune vegetation, increased openings for sand trapping and vegetation growth, and modular assembly.

Table 15: De Panne preliminary LCI quantities

LCI element	Quantity	Unit
Unreinforced concrete pavement + foundation to remove	470	m^2
Excavation for reuse on site	1,635.08	m^3
Reuse/backfill with excavated soil	1,635.08	m^3
Demolition/removal of ground berm + beach levelling	4,716.24	m^3
Removal/sieving of excavated soil	1,635.08	m^3
Stone-like foreign material removal	9	ton
Other foreign material removal	9	ton
Crushed stone foundation, type II, 30 cm	470	m^2
New concrete pavement, 20 cm	470	m^2
Longreach excavator	120	hours
Unreinforced concrete demolition	2,860.34	ton
Reinforced concrete demolition	3,360.34	ton
Rubble/rockfill demolition	1,000	ton
Geotextile separation layer	1,797.95	m^2
Recycled concrete aggregate 20/40 for L-wall foundation	62.83	ton
Profiling layer below geotextile, site sand	202.87	m^3
New CP45/125 armour stone, supply	387.61	ton

New CP45/125 armour stone, transport/placement	387.61	ton
HexaBloom blocks prefabrication	209	pieces
HexaBloom blocks delivery	209	pieces
HexaBloom blocks placement	182	pieces
Sand filling for HexaBloom cavities/openings	27.76	m^3
Mini-HARO blocks prefabrication	270	pieces
Mini-HARO blocks delivery	270	pieces
Mini-HARO blocks placement	270	pieces
Sand filling for mini-HARO cavities/openings	35.86	m^3
Zetstenen purchase/delivery	318.27	m^2
Zetstenen placement	318.27	m^2
Basalt split top layer surcharge	318.27	m^2
Saw cut for lower row of zetstenen	38.3	m
Jointing/inwash material 4–32 mm	13.29	ton
Filter material 16–32 mm	161.46	ton
Betonzuilen purchase/delivery	314.74	m^2
Betonzuilen placement	314.74	m^2
Mini-HARO moulds	7	pieces
Print-concrete test cubes for HexaBloom	3	pieces
In-situ unreinforced concrete C35/45 EE4 LA	62.71	m^3
Prefabricated reinforced concrete C60/75 lower L-wall	40.04	m^3
Prefabricated reinforced concrete C60/75 upper L-wall	15.4	m^3

Based on feedback from the De Panne project team, transport distances and exact production locations are not yet finalized and will need to be assumed for the LCI. The revetment elements are expected to be produced in concrete factories and transported to the site. Therefore, the A4 transport stage should be modelled using assumed factory-to-site transport distances, clearly marked as assumptions.

For the construction stage, the following equipment and activities are expected:

- two cranes during demolition works: one crane for demolition and one crane for excavation of the dike toe and loading material into trucks;
- trucks for the removal of demolished material and the delivery of new materials;
- one crane for unloading trucks and installing the new revetment elements;
- mixer truck for the concrete used for the pathway.

No regular maintenance is currently scheduled. The dike will be inspected periodically and after severe storm-surge events. If damage is observed, repair works will be carried out, but the frequency and quantity of such repairs cannot currently be predicted. A monitoring plan has not yet been prepared.

4. Conclusion

This deliverable compiles the available Life Cycle Inventory data for five European DuneFront demonstrators and the WP15 De Panne eco-dike prototype. A harmonized LCI template was developed to report all available flows by life-cycle module, quantity, unit, normalized value, source, and data-quality classification.

The most complete LCI datasets are available for Katwijk, PHZD/Texel, Dunkerque, and Sankt Peter-Ording.

For Douro, the inventory was substantially improved through newly received construction information, including sand dredged and placed on the sandspit, rock quantities for berm layers and toe protection, Antifer concrete armour units, and construction equipment. The remaining gaps mainly concern transport distances, transport modes, source locations, and possible repair work. For De Panne, the preliminary quantity estimate substantially improves the prototype inventory, although transport distances, production locations, repair works, and the monitoring plan still require assumptions or further confirmation.

The compiled inventory provides the basis for the next WP8 step, D8.4, where LCIA, LCC, and validation of the blue-infrastructure rating system will be performed.