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Author(s)	Helena Hanson, Emma Johansson, Sofia Nyrell, Elisabet Ydman, Johanna Alkan Olsson
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Contributors	
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This report is the second deliverable of work package 9 (D9.2 Demonstrator Socio-economics) in the DuneFront project. The overall aim of the project is to enhance coastal protection and safety by improving Dune-Dike hybrid nature-based solutions (DD-hybrid NbS) – a combination of natural elements (dunes) and man-made hard structures (dikes). Within the DuneFront project, data is collected and evaluated from 12 different ‘Demonstrator sites’ spread over six different countries – Sweden, Germany, the Netherlands, Belgium, France and Portugal. The objective of this report is to identify key factors influencing the integration of multifunctional DD-hybrid NbS in coastal protection of sandy coasts.

To achieve the objective, we identified co-benefits delivered by the demonstrators, as well as barriers and enablers influencing the integration of these solutions. The method consisted of field visits combined with semi-structured interviews with key stakeholders of the 12 demonstrators. Because the integration of DD-hybrid NbS for coastal protection is highly influenced by country-specific and site-specific differences, it was necessary to also gather information on the demonstrators’ geographical and organizational conditions.

Results show that many of the demonstrators have delivered additional co-benefits beyond their primary function of coastal protection. Recreation was the most frequently mentioned and most extensively integrated co-benefit across the demonstrators, followed by touristic and biodiversity co-benefits. At many demonstrators, multiple co-benefits were delivered. The planning and implementation of these demonstrators were influenced by various barriers and enabling factors. Overall, the results show that more barriers than enablers were reported. At nearly all demonstrators, there were tensions between different co-benefits, such as between conserving biodiversity and space for recreation. There were also barriers related to the structure of coastal protection work and the question of authority. While working across multiple governance levels was sometimes considered difficult, the most significant enabling factor was an inclusive and structured planning process with broad stakeholder involvement. Communication – both across governance levels and with the public – was another key theme, with investment in communication identified as an important enabler. Additional barriers and enablers were noted in relation to financing, natural resources, risk and uncertainty.

To improve the integration of multifunctional DD-hybrid NbS in planning and implementation process of coastal protection, five key factors should be addressed. (1) Improve the understanding of the boundary conditions, (2) secure capital and sand, (3) manage conflicting needs, (4) respond to changing systems and lastly, (5) mainstream testbeds. This will not be an easy task, but it is needed if DD-hybrid NbS should be a significant part of coastal protection of sandy coasts in the future.

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1. Introduction

Global shorelines are heavily populated. Almost 40% of the global population lives within 100km from the coast (Cosby et al., 2024), and about 10% lives below 10m above sea level (McGranahan et al., 2007). Coastal regions are vulnerable to hazards related to sea-level rise, extreme weather events (e.g. flooding, hurricanes, etc.) and soil erosion, not at least regions with sandy coastlines (Vousdoukas et al., 2020), causing economic damages and severe threats to coastal communities. In the coming decades, coastal hazards are projected to accelerate in the face of climate change (Jevrejeva et al., 2016; Ranasinghe, 2016; Vousdoukas et al., 2018).

Coastal ecosystems, including dunes and beaches, can provide protection against sea level rise, floodings etc., and hence reduce the risk of hazards affecting communities along sandy coastlines (Arkema et al., 2013; Barbier et al., 2011). These ecosystems also provide additional benefits for people and nature, including habitats for plant and animal species, space for recreation and tourism, natural resources and ground water storage (Barbier et al., 2011; Liqueste et al., 2013; Moraes et al., 2022; Renaud et al., 2016; Temmerman et al., 2013).

Historically, coastal protection has been achieved through hard solutions, including the construction of e.g., dikes and seawalls, to protect against erosion and flooding. In recent decades, there has been a growing recognition of the limitations and negative impact of these hard solutions placed for the protection of sandy coastal ecosystems (Cantasano et al., 2022). In parallel, there has been an increasing awareness that nature provide important benefits to counteract societal challenges, not at least the effect of climate change, using a series of related green concepts such as ecosystem services, green infrastructure, ecosystem-based adaption and nature-based solutions (NbS) (Faivre et al., 2017; Hanson et al., 2020; Maes & Jacobs, 2017; Nesshöver et al., 2017). This has led to an increased interest in using nature-based approaches, such as NbS as an alternative and more sustainable way to safeguard vulnerable coastlines (Cantasano et al., 2022).

The NbS concept stress the importance of protecting, restoring and sustainably managing natural and semi-natural ecosystems, and using nature as the inspiration to provide multiple benefits to society (Cohen-Shacham et al., 2016; European Commission: Directorate-General for & Innovation, 2015). Coastal NbS includes different types of protection strategies of sandy ecosystems that are affected by erosion, such as beach nourishment, solely or in combination with traditional hard protection features such as concrete dikes and seawalls (Jordan & Fröhle, 2022; Morris et al., 2018). The effectiveness of dunes and beaches for reducing coastal hazards, including flood events and erosion, has been well documented, showing that they can attenuate and/or dissipate waves and stabilize sediment (Barbier et al., 2011). However, so far, a comprehensive understanding is lacking about whether, and to which extent, different types of coastal NbS provide multiple benefits

(hereafter co-benefits), which is one of the core idea of the NbS concept (Hanson et al., 2020). This includes which types of co-benefits that are covered (biodiversity, environmental, economic and social) as well as how they interact with each other.

To increase the use of nature-based approaches it is important to mainstream (integrate) these ideas into existing sectoral policies and practices of coastal NbS. One key factor is to increase the understanding of how successful cases can be replicated in other areas. This includes both expanding the knowledge base about implemented cases, including important physical, social and economic boundary conditions, as well as tools and strategies to expand knowledge sharing (Han & Kuhlicke, 2021; Hsiung et al., 2024; Palinkas et al., 2022; Rahman et al., 2023). Expanding the knowledge base about the cases includes identifying barriers and enablers influencing the integration of NbS in planning and implementation including factors related to space constraints, regulations and organizational structures, human and economic resources. Another important factor is involvement of stakeholders, as this is recognized as central part of the NbS concept (Hanson et al., 2020; IUCN, 2020). As NbS is still a relatively new approach within coastal protection, it means that there is limited comprehensive understanding covering multiple cases. A recent study, assessed implemented NbS case studies across European coastal and estuarine areas demonstrating that while the projects provide numerous co-benefits and valuable insights for replication and scaling, progress is hindered by insufficient documentation (Moraes et al., 2022). Increasing the knowledge base is therefore crucial to support the mainstreaming of coastal NbS in a diverse geo-political context such as the European union.

1.1. Objectives and research questions

The objective of this study was to identify key factors influencing the integration of multifunctional Dune-Dike hybrid nature-based solution (DD-hybrid NbS) in coastal protection of sandy coasts. We used field visits and expert interviews to understand the context of 12 implemented DD-hybrid NbS (hereafter demonstrators) in six European countries: Sweden, Germany, The Netherlands, Belgium, France and Portugal (see deliverable 7.1 for an overview of the sites). In this study, we refer to nature-based solutions as solutions that are based on the action of natural processes, either alone or in combination with engineered structures, like dikes, which are used to protect coastal areas against flood events.

To answer our research aim we ask the following research questions:

- (1) What are the geographical and organizational conditions surrounding the demonstrators?
- (2) Which co-benefits are delivered by the demonstrators, and how were they included in the planning and implementation process?

(3) Which are the main enablers and barriers influencing the implementation of the demonstrators?

We define co-benefits as benefits provided by DD-hybrid NbS in addition to the protection of society to coastal flood events. In the discussion section, we reflect on how to handle key factors influencing the integration of DD-hybrid NbS in coastal flood protection of sandy coastlines in Europe in the future.

1.2 Connection to other work packages in DuneFront (WP)

This deliverable (D9.2) forms part of WP9 within the DuneFront project, which focuses on the socio-economic aspects of the demonstrators. It draws extensively on Deliverable D9.1, particularly for the development of interview questions and the analytical framework. Additional input from D16.2, D7.1, and D7.2 supports the understanding of the geographical and organizational context. Furthermore, this deliverable (D9.2) provides input to several DuneFront work packages, including WP13, WP14, WP15 and WP17. It will contribute to a framework for multi-use potential in coastal protection solutions.

2. Methods

To answer our research questions, a field study approach was used. The approach included (1) site visits including guided walks and observations, (2) semi-structured interviews with stakeholders involved in the planning and implementation of the twelve demonstrators.

In this chapter, we first provide details about the twelve demonstrators (section 2.1). We thereafter describe the process of stakeholder selection (section 2.2), the semi-structured interviews (section 2.3), the guided tours of the demonstrators (section 2.4), and the data extraction and analysis (section 2.5). Lastly, we discuss research ethics (section 2.6) and methodological considerations (section 2.7).

2.1 Case study sites

The study is based on the twelve demonstrators included in the DuneFront project (see figure 1 for locations). The demonstrators are spread across six countries: Sweden, Germany, the Netherlands, Belgium, France and Portugal. All demonstrators are situated along sandy coasts, and all include dunes as part of the coastal protection measures. Demonstrator data were mainly collected from other DuneFront projects, specifically deliverables 7.1 (Adeli et al., 2024), 7.2 (Sevindik et al., 2024) and 16.2 (Koedooder et al., 2024). Having this information allowed us to gain a clearer understanding of the demonstrators' physical and social contexts. For an overview of the demonstrators, see Table 1.

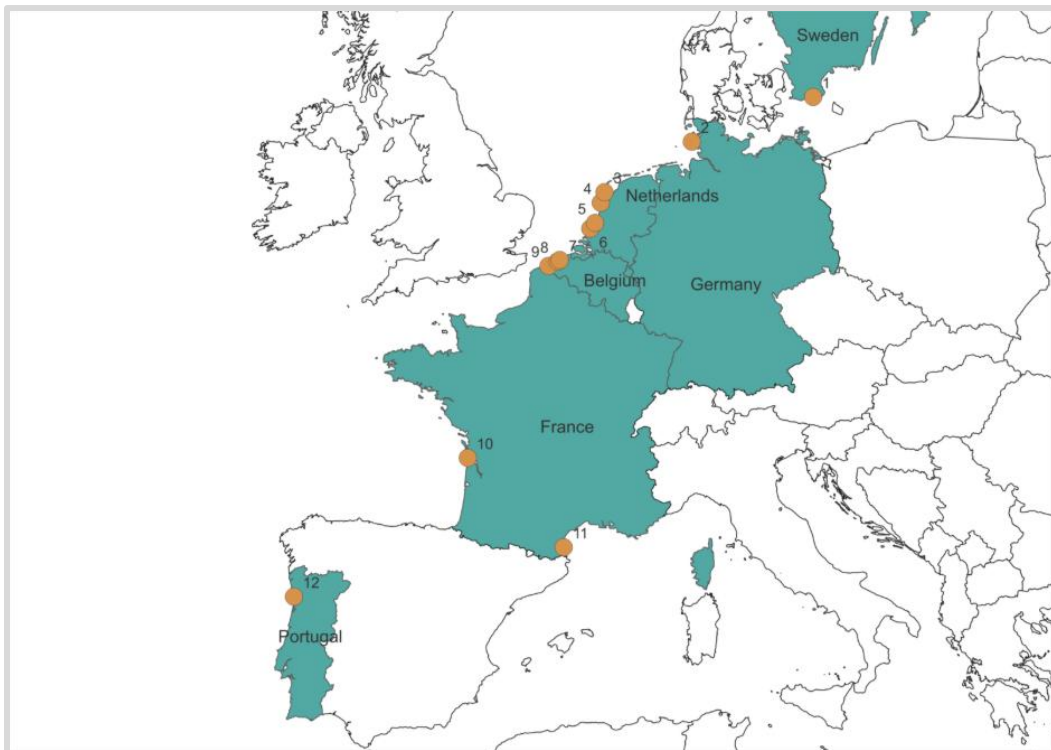


Figure 1 Location of the 12 demonstrators in DuneFront.

Table 1 Overview of the 12 demonstrators included in the study, based on information from Adeli et al. (2024).

Demonstrator		Country	Coast	NbS type
1	Ystad	Sweden	Baltic coast	Dune-in-front-of-dike
2	Sankt Peter-Ording	Germany	Wadden Sea	Dune-in-front-of-dike
3	Texel Prins Hendrikzanddijk	The Netherlands	Wadden Sea	Dune-in-front-of-dike and dike-in-dune
4	Hondsbossche Duinen	The Netherlands	North Sea	Dune-in-front-of-dike
5	Katwijk	The Netherlands	North Sea	Dike-in-dune
6	Sand Motor (Delflandse kust site)	The Netherlands	Delflandse kust, North Sea	Sand nourishment
7	Living Lab Raversijde	Belgium	The Flemish coast along the North Sea	Dune-in-front-of-dike
8	Middelkerke grass dike	Belgium	The Flemish coast along the North Sea	Dune-in-front-of-dike
9	Dunkerque	France	The North Sea	Dune-in-front-of-dike
10	Soulac	France	The Atlantic	Dune-by-dike
11	Sainte-Marie La Mer	France	The Gulf of Lions, The Mediterranean Sea	Dune-in-front-of-dike
12	Douro estuary sand spit	Portugal	North Atlantic coast	Sandspit and rubble mound breakwaters

2.2 Stakeholder identification and selection

The stakeholder selection was guided by a purposive sampling strategy (Bryman, 2016), meaning that we aimed at identifying stakeholders with knowledge and experience of the planning and implementation of the 12 demonstrators. The entry point of the stakeholder identification was the stakeholder engagement strategy from deliverable 16.2 (Koedooder et al., 2024). The DuneFront project has assigned one contact person for each demonstrator, which either has been directly involved in the demonstrator or has detailed knowledge of it. The contact person provided a list of potential stakeholders, which was scrutinized to better understand each potential respondent's role in the project. Based on this, potential interviewees were contacted by email and/or phone calls. The stakeholders either agreed to participate or directed us to other individuals who they considered more appropriate for the study. In some cases, new potential interviewees were recommended during interviews, leading us to employ a snowball method (Bryman, 2016).

For each demonstrator, the aim was to identify and select 2–4 stakeholders for interviews. While this aim was met in most locations, only one stakeholder was interviewed for the demonstrators in Middelkerke, Soulac and Hondsbossche Dunes, as additional potential interviewees did not respond.

Given the varying approaches to coastal development across different countries, the identified stakeholders differed across the twelve demonstrators, covering a variety of organizations, such as research institutions, municipalities, spatial planning offices, nature conservation agencies, regional and national authorities, and other groups engaged in coastal development.

2.3 Semi-structured interviews

Semi-structured interviews were chosen as an interview approach. Semi-structured interviews give the respondent freedom to share their knowledge and experience in their own manner as the questions are flexible and can come in different orders (Bryman, 2016). Semi-structured interviews are generally organized by themes and guiding questions, and the importance of follow-up questions is emphasized. This type of structure gives the interviewer and respondent more flexibility, which was deemed to be more suitable in this study as the goal was to gather respondents' knowledge and experience of working with these types of coastal protection.

2.3.1 Interview guide

An interview guide was developed (see annex A), based on the literature review conducted in September 2024 (Hanson et al., 2024). From this report, two main themes were identified (1) Co-benefits of coastal zone NbS, focusing on values beyond coastal protection, such as recreation, biodiversity, and tourism, and (2) Barriers and enablers of coastal NbS implementation. To complement the two main themes, two other themes were added, (3) Description of the coastal NbS and (4) Stakeholders involved in the planning and implementation of the coastal NbS. These four themes aimed to get a general overview of the coastal NbS as well as more detailed information about why these types of coastal protection solutions were selected and developed in the way they were based on the respondents' knowledge, experience and perceptions. In relation to these four themes, follow-up questions were developed to support the interviewer when needed.

2.3.2 Conducting the interviews

The interviews were conducted from mid-January to Early October 2025, either at the location of the demonstrator, at the respondent's office or digitally (see Table 2). In total, 21 interviews were conducted with 28 stakeholders. Most interviews were conducted with a single respondent, although in some cases up to three participants attended the interview when they opted to participate as a group. 13 interviews were conducted in person and recorded, and four were conducted digitally and recorded. Four interviews were conducted in the field without being recorded. Instead, extensive field notes were taken. The reason for not recording these interviews was conditional constraints – no indoor facility in the surroundings of the demonstrator, and windy weather conditions, which made outdoor recordings impossible. Two people were present at all these interviews, one focusing on

taking notes and asking questions, and the other observing and taking photos of the surroundings.

Each respondent gave their signed consent to record the interview and to use the material collected in the study. Each consent form was signed either digitally or as a paper form. The interviews took around 50–90 minutes and were performed in Swedish, English or French.

2.4 Guided tours at field sites

To provide a deeper understanding of each demonstrator, a guided tour was planned before, after, or during the interviews with the respondents. A guided tour is a method for studying situated and embodied information, and blends observation and interviews at the field site (Everett & Barrett, 2012; Randall et al., 2007; Thomson, 2018). In nine cases, at least one of the demonstrator's respondents guided the tour (see table 2). In one case, the Sand Motor (Delflandse kust site), a researcher knowledgeable about the demonstrator, but not an identified and selected respondent, guided the tour. In two other cases, Sankt Peter-Ording site and Middelkerke, the site visits were not guided on site, but the respondent's provided guidance in advance regarding where to go and what to observe.

During the guided tours, observations were made of the demonstrator and its surroundings, and the guiding respondent(s) answered questions in relation to the themes of the interview guide (Annex A). The tour included notetaking as well as photographing key features.

Table 2 Overview of interviews across demonstrators including date of interview, type of interview (in person, digital), date of guided tour, and number of respondents per interview).

Country	Demonstrator	Date	Type of interview	Recorded	Guided tour	Number of respondents
Sweden	Ystad	22 January	In person	Yes	Yes	1
Sweden	Ystad	22 January	In person	Yes	No	1
Sweden	Ystad	5 February	In person	Yes	No	1
Germany	Sankt Peter Ording	11 March	In person	Yes	No	2
Germany	Sankt Peter Ording	11 March	In person	Yes	No	1
Germany	Sankt Peter Ording	12 March	-	-	Self-guided	-
Netherlands	Texel	27 January	Digital	Yes	No	2
Netherlands	Texel	3 March	In person	Yes	Yes	1
Netherlands	Hondsbossche duinen	4 March	In person	Yes	Yes	1
Netherlands	Katwijk	4 March	In person	Yes	Yes	3

Netherlands	Sandmotor	5 March	In person	Yes	No	1
Netherlands	Sandmotor	5 March	-	-	Yes	-
Netherlands	Sandmotor	6 March	In person	Yes	No	2
Netherlands	Sandmotor	26 March	Digital	Yes	No	1
Belgium	Living Lab Raversijde & Middelkerke	5 March	In person	Yes	No	1
Belgium	Living lab Raversijde	13 March	Digital	Yes	Self-guided	1
France	Dunkerque	6 March	In person	Yes	No	1
France	Dunkerque	7 March	In person	No	Yes	1
France	Soluac	9 May	In person	No	Yes	1
France	Sainte Marie La Mer	12 May	In person	No	Yes	2
Porto	Douro estuary sand spit	15 Sep	In person	No	Yes	2
Porto	Douro estuary sand spit	16 Sep	In person	Yes	No	1
Porto	Douro estuary sand spit	9 Okt	Digital	Yes	No	1

2.5 Data extraction and analysis

After the interviews and field visits, recorded interviews were transcribed, and field notes were transposed from notebooks to digital text. Thereafter, the data was coded, and a thematic analysis was conducted. The thematic analysis consisted of reading and re-reading transcripts and notes to find answers to the research questions (Bryman, 2016). Primarily, a deductive approach was used, meaning that the coding was based on the analytical framework presented in the descriptive literature review (deliverable WP9.1), separated into categories of co-benefits (table 3) and barriers and enablers (table 4). However, the analysis was not limited to the sub-categories, allowing additional sub-categories to emerge inductively from the data. For the co-benefits we assessed their level of integration and delivery on a scale (low-medium-high). High indicates that the co-benefit was deliberately planned for and has been delivered by the implemented demonstrator. Low indicates that the co-benefit was mentioned by the respondents, but it was not considered a major goal in the planning phase of the demonstrator; and sometimes discovered after the demonstrator was implemented.

Table 3 Overarching categories of co-benefits used in the analysis, including a short description of the category.

Co-benefits – overarching categories	Description
Biodiversity	The demonstrator has contributed to increased biodiversity and created space for new nature to develop
Economy	The demonstrator has added economic benefits to the area, such as increased tourism
Social/cultural	The demonstrator has created more or improved social and cultural spaces and values such as recreation and education.

Table 4 Overarching categories of co-benefits used in the analysis, including a short description of the category.

Barriers and enablers – overarching categories	Description
Space and land use	Conflict of interests, e.g. between coastal protection and biodiversity, act as barriers to implementation, while the facilitation of co-existence of co-benefits makes implementation and management easier.
Policy and legal structures	Weak legal regulations and management impede implementation of demonstrators, while established or consistent regulation of NbS enables implementation.
Communication and knowledge	Lack of knowledge and communication hinder implementation, while efforts to increase knowledge and communication facilitate implementation.
Monetary and natural resources	Limited funding and access to natural resources can restrict implementation, while stable financial support and sustainable resource supplies enable implementation.
Uncertainty and risks	High uncertainty and potential risks can hinder implementation, whereas low uncertainty and risk awareness facilitate implementation.

2.6 Research ethics

The research methodology in this report aligns with the ethical requirements specified in the OEI – requirement No1 of the DuneFront project, specifically concerning human participation in research, as well as the handling and storage of personal data. The use of interviews and field visits for data collection made it crucial to handle participants and their personal data thoughtfully and respectfully. Anonymity for the interviewees was a central issue. It involved treating personal data confidentially and using the collected material in a purposeful manner in line with the study's objectives. It was important to accurately represent the interviewees' responses, which is why recording or meticulous notetaking was necessary during the interview process.

Participants have the right to be informed about the purpose of the study and its overall scope (Bryman, 2016). To address this, consent forms containing information about the

study were sent out prior to the interviews, allowing respondents to review the study's purpose and their rights as participants. The consent form provided information about DuneFront and the purpose of the interview study, the rights of the participant, the intended use of the results, and the procedures for processing personal data.

2.7 Method discussion

Reflecting critically on the methodology employed in our study, several key aspects require examination regarding how our chosen methods may have influenced our findings.

The purposive sampling strategy guided by initial contact persons, while effective in identifying knowledgeable stakeholders, may have inadvertently influenced our data sample (Bryman, 2016). By relying on these contacts, we risked filtering our sample towards individuals who may already be proponents of the demonstrators, thus omitting dissenting voices or alternative perspectives within the broader stakeholder community. This could lead to an overly optimistic portrayal of stakeholder engagement and the efficacy of coastal interventions, ultimately affecting the balance of our analysis. Furthermore, stakeholders that were selected might also have felt compelled to present their projects positively, impacting the authenticity of their responses and possibly skewing our understanding of challenges faced in implementing NbS.

The decision to use semi-structured interviews provided flexibility when engaging with respondents (Bryman, 2016). However, this flexibility also creates challenges, particularly by leading to a high level of variation in the responses. Together with the guided walks, the data generated was rich and complex, making data extraction and interpretation of the data challenging. To meet these challenges, careful reading and re-reading of the material as well as discussion between authors was essential. Moreover, the fact that several respondents were present in the interviews may have created an unwanted power balance in the respondent group, influencing the collected data.

Lastly, our ethical considerations – ensuring participant anonymity and informed consent (Bryman, 2016) – were important for building trust and encouraging honest responses. Yet, the constraints associated with informed consent procedures might have affected stakeholders' willingness to share candid critiques or controversial opinions about the demonstrators, further shaping the findings to reflect more favorable views of coastal NbS.

3. Results

The result consists of two parts. The first part (section 3.1 – 3.6) consists of a detailed description of each demonstrator sorted by country using the same template; description of the geographical and organizational conditions surrounding the demonstrator, the aim and included co-benefits, and experienced barriers and enablers in the process of implementing a DD-hybrid NbS. Each country's section starts with a short description of the structure and responsibility of climate adaptation work in the country in relation to coastal protection. The second part (section 3.7) summarizes the results and provides an overview of similarities and differences between the test beds.

3.1 Sweden

In Sweden, coastal protection is primarily assigned to municipalities and private landowners, with support from County Administrative Boards, which oversee climate change adaptation. State authorities provide information, funding, and a regulatory framework, while regions play a role through their responsibility for regional development and emergency preparedness. Although supported by regional and national bodies, a substantial burden still falls on municipalities. This division of responsibility also means that municipalities can only finance climate adaptation solutions that protect public interests on public land. Private properties are not covered, and it is up to individual property owners to protect their own assets. In Sweden, municipalities need to take sea level rises into consideration in the planning and building process, but there are no set national standards that every municipality must follow. In the most southern province Skåne, which is projected to be most affected by sea level rises, the guidelines provided by the County Administrative Board state that new development areas should be able to manage sea level rises of 2–2,5 meters.

3.1.1 Ystad

Geographical and organizational conditions

The demonstrator is located approximately 3 km outside the city center of Ystad, a municipality situated in southern Sweden, on the coast of the Baltic Sea. It is a dune-in-front-of-a-dike solution that has been developed by multiple beach nourishments over several years. The sand from the nourishments is now covering an existing rock revetment. Sand fences and marram grass have been used in different phases to stabilize the dunes. The beach nourishments were implemented in response to beach erosion being observed at several places along the coast, including in front of a spa hotel. Since the municipality owns the land behind the beach, they could implement the nourishments.

The project was initiated by the municipality of Ystad in collaboration with engineering researchers at Lund University. A few municipal employees actively worked to advance the project by engaging with local political decision-makers. The Swedish Geotechnical Institute

(SGI) was also involved in planning the beach nourishment, primarily in coordinating the projects. The beach nourishment was implemented by the municipality.

Aim and included Co-benefits

The aim of the beach nourishment in Ystad has been to preserve the beach, which constitutes the town's most popular **recreation** area. Some locals own beach huts on the beach, and the spa hotel attracts many tourists. One of the interviewees referred to the ideal time for the beach nourishment as a narrow window. They need to avoid beach nourishment during summer, when the beach is most frequently visited, and they also need to take nature values into consideration, such as the timing of fish migration.

At the beginning of the nourishment project, an **education program** was introduced to educate high school students. The program began with a lecture followed by a guided tour of the beach, where students were shown the work that had been done. The students also participated in a workshop where they were tasked with designing a city and developing ideas to protect it. The program is no longer running.

Barriers and enablers in the planning and implementation of the demonstrator

According to the interviewees, the main barrier to implementing beach nourishment in Ystad was, and still is, the **complex and lengthy permit processes**. There are two separate processes: one for sand extraction and another for the locality of the beach nourishment along the coast. Since municipalities are responsible for coastal protection, it places a significant burden on them as they must either possess comprehensive knowledge of the legal processes or rely on consultants for external expertise. One interviewee noted that although the implementation of sand nourishment is strictly regulated, the monitoring and evaluation framework is inadequate and undeveloped in certain areas, which makes municipal responsibility unclear. The intricate legal structure constitutes a major barrier to planning and implementing beach nourishment in Ystad, and in Sweden in general.

Another barrier mentioned was the state authorities' **lack of knowledge** about soft coastal protection measures when the beach nourishment project was developed. At that time, the terminology for soft solutions was new in Sweden, and many state agencies opposed the implementation of beach nourishment in Ystad, as they deemed it an **unproven and temporary method** in comparison to rock revetments. This made it difficult for the project leaders to persuade them to provide support for the beach nourishment. According to one interviewee, knowledge and opinions within state agencies have, however, started to change. The Ystad demonstrator was the first large-scale sand nourishment in Sweden and has served as a testbed and enabler for future work. The implementation of the beach nourishment depended on a few knowledgeable individuals who advocated their use, and the interviewees described the measures in Ystad as examples of learning by doing.

Similarly, local politicians and citizens initially lacked knowledge of soft solutions, causing doubts about their implementation. Many people questioned why funds should be spent on

sand that will disappear. When sand fences were installed, citizens also started using them as firewood. One interviewee reflected that, in hindsight, the behavior was understandable given that many young people gather at the beach on summer nights to make fires. The results show that the **political landscape** began to shift when cost–benefit analyses demonstrated that beach nourishment has **economic benefits**. After the first nourishment, politicians and citizens also witnessed that the solution was effective in protecting the beach. As a result, the local political landscape has become more unified; there is consensus that beach erosion is a problem that can be tackled by soft solutions. In the same way, the public is also now generally positive.

However, **communicating with the public** has also proven to be challenging. Many private property owners affected by coastal erosion want the municipality to cover the cost of coastal protection, and one major challenge is to explain the legal constraints on spending public funds on projects that do not protect common interests. This is not an issue for the demonstrator's location, since most of the area is owned by the municipality, but for other coastal areas in the municipality.

Lastly, there is a **conflict of interest** between recreational/aesthetic values and the conditions necessary for dune development, including impacts on biodiversity. One interviewee explained that the municipality's intensive summer upkeep of the beach for recreation, such as removing seaweed, hinders natural dune growth by disrupting vegetation and sand accumulation.



Figure 2 Ystad (SE) demonstrator: a) dune landscape in front of a conifer forest; b) rock revetment gradually being covered by dunes; c) path between dunes leading to the beach; d) beach viewed from a small dock.

3.2 Germany

Coastal protection in Germany is shared across the federal government, the states, and the municipalities. The federal government develops the overall strategy through several ministries and policies, such as The Federal Climate Adaptation Act and the German Climate Adaptation Strategy from 2024. The coastal states implement policies and coastal protection measures while the local municipalities oversee maintenance and operation of the solutions (Koedooder et al., 2024). At the national level, Germany does not define a fixed sea-level rise that coastal protection measures must meet for safety. In the state of Schleswig-Holstein – where Sankt Peter-Ording is located – the concept of the climate dike was introduced in the coastal protection plan 2022. The concept means that coastal protection solutions in the state should withstand a sea level rise of up to 1 m and hold potential to be adapted to withstand 2 m if needed (Sevindik et al., 2024).

3.2.1 Sankt Peter-Ording

Geographical and organizational conditions

The demonstrator is located in Sankt Peter-Ording, on the North Sea coast of northern Germany, within the Schleswig-Holstein Wadden Sea region. This is both a national park, part of the Natura 2000 network and a UNESCO heritage site. The demonstrator comprises a large natural sand dune area, including a saltmarsh lagoon and an adjacent forest area. The dune area is situated between multiple dikes, which provide coastal protection along the rest of the Schleswig-Holstein coastline. The purpose of the demonstrator is to assess the efficiency of the existing dune system for coastal protection. This work is carried out within the framework of a project called Sandküste. At present, there is no need for sand nourishment in Sankt Peter-Ording, as the area has ample sand reserves. However, such measures may become necessary in the future due to rising sea levels.

The Sandküste project involves multiple organizations and government agencies. The project was initiated by the WWF together with Schutzstation Wattenmeer, an independent association working specifically with the Wadden Sea. They are collaborating with the regional dike and drainage board, who own the land of the area. Other partners are the Schleswig-Holstein Agency for Coastal Protection, the municipality of Sankt Peter-Ording as well as two universities. The project is funded by the German state through the federal agency for nature conservation and will run until 2026.

Aim and included co-benefits

In addition to assessing the efficiency of the dune system for coastal protection, the demonstrator also addresses other co-benefits, including **biodiversity, public awareness, and tourism**. The Wadden Sea area is an important area for bird conservation, but at the demonstrator, there is a focus on plants, invertebrates, and reptiles. A significant part of the Sandküste project concerns the removal of invasive species, such as conifers and cranberry plants, to support native species and biodiversity. Furthermore, enhancing public knowledge

is a key objective of the project. The project partners have carried out a range of communication activities, including online and social media outreach, citizen science initiatives, and guided tours. These efforts not only inform the public about ongoing work but also provide hands-on experiences in nature. Sankt Peter-Ording is a popular tourist destination because of its natural environment, which makes its preservation especially important.

Barriers and enablers in the planning and implementation of the demonstrator

One of the main barriers to retaining the demonstrator area as a soft solution is the **tension between** coastal protection and nature conservation. While the regional dike- and drainage board has preferred hard solutions, such as dikes, due to cost and perceived safety, the area's protected status under Natura 2000 and as a national park has prompted other stakeholders, such as the WWF, to advocate for NbS approaches. Historically, **collaboration** between stakeholders in the area has been challenging. However, the interviewees shared that the Sandküste project has fostered a closer working relationship, contributing to the project's success and increased support for preserving the natural sand dune area for coastal protection.

According to the interviewees, one challenge for the demonstrator is that **legal responsibility** for coastal protection is **unclear** where there is no dike. As it is a natural sand dune area, responsibility for coastal protection is not well-defined. In contrast, dikes have a clearly defined responsible authority. Other federal states in Germany have a definition for dunes that work as a coastal protection measure, but in Schleswig-Holstein there is no such definition.

Another challenge for the demonstrator is the **tension between nature's values and the German legal framework**. Within the Sandküste project, there is an ambition to adopt more nature-friendly methods, such as using sheep and goats for grazing to remove invasive species, rather than excavators. However, German forest law prohibits grazing in certain forest areas. Similarly, as part of the area is designated as a national park, the guiding principle is 'let nature be nature', which, according to one interviewee, makes it difficult to justify the removal of invasive species.

Furthermore, there is also a **conflict** between recreation, coastal protection, and biodiversity **co-benefits**. Activities at the beach – walking, horse riding, kitesurfing, and beach buggy racing – put pressure on the sand. Sankt Peter-Ording is a popular destination for tourists, causing the population to increase drastically during the summer. To protect the dunes, walking within the dune area is prohibited. While most visitors respect these restrictions, interviewees noted that some residents have questioned them, as they have used the area without restrictions for decades. This has made public interaction challenging at times. For instance, some people have expressed confusion about why machinery is allowed to operate in the area while public access remains restricted. One interviewee also

noted that many visitors are unaware that several species in the area, such as conifers, are non-native, which has led to criticism of their removal.

To mitigate misunderstandings, project partners are actively informing the public about ongoing activities and the reasons behind specific measures. They hold regular meetings with as many stakeholders as possible, aiming to provide comprehensive and detailed information. An additional enabling factor in addressing **communication** challenges in Sankt Peter-Ording is the long-term presence of organizations such as Schutzstation Wattenmeer and WWF, which has allowed them to build strong relationships with the local community.

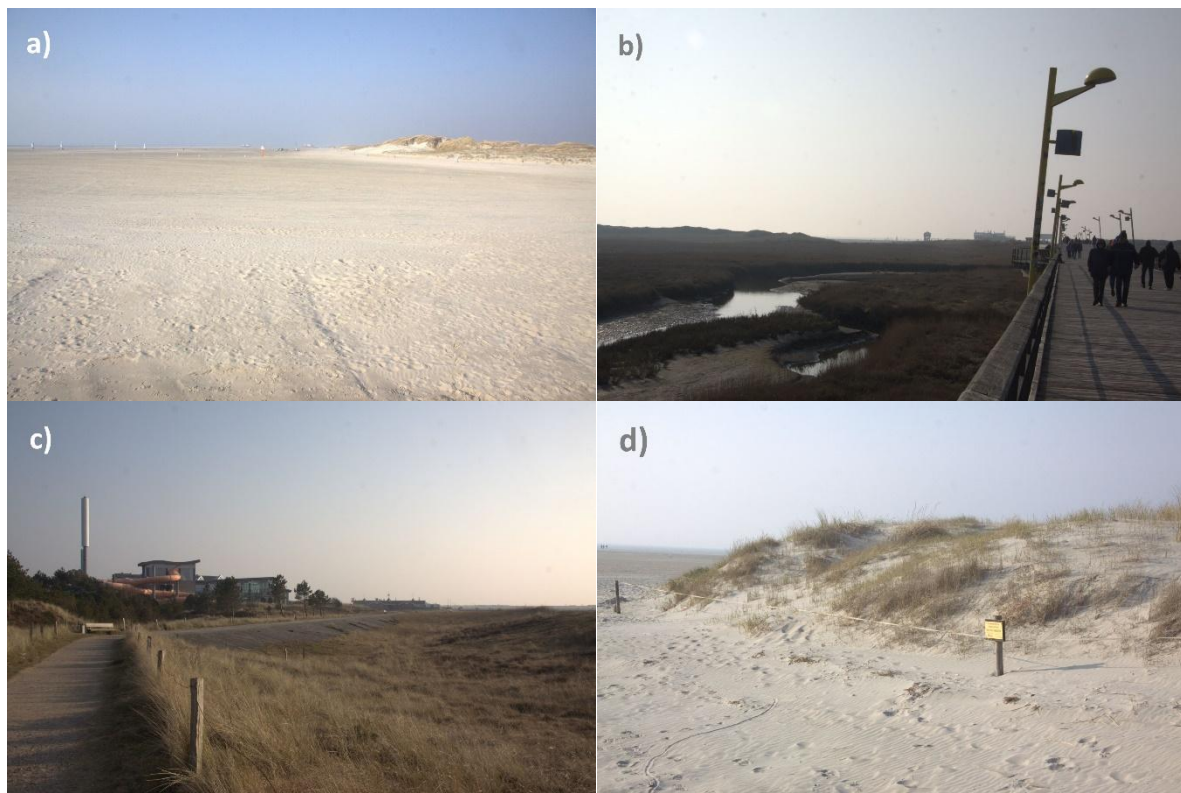


Figure 3 Sankt Peter-Ording (DE) demonstrator: a) wide beach area with dunes in the background; b) wetland area adjacent to a recreational path; c) section of the dike system with a walking path on top; d) protected dune zone – access restricted to the public.

3.3 The Netherlands

Coastal protection in the Netherlands is a clearly defined national task that is executed by Rijkswaterstaat – the Dutch governmental agency responsible for primary flood defenses. The maintenance of coastal flood protection solutions is overseen by 21 regional water boards. Rijkswaterstaat and the water boards collaborate on long-term water safety and climate resilience through the Delta Program, launched in 2008. The Delta Program has promoted the principle ‘soft where possible, hard where necessary’, prioritizing natural defenses like dunes and sand nourishment but using engineered structures like dikes and storm-surge barriers when necessary. The Netherlands plans for coastal protection to withstand sea level rise of up to 1.3 m by 2100 and prepare for a 2–4 m rise by 2200. Compared with other DuneFront countries and Europe more broadly, Dutch coastal-protection measures stand out for their exceptionally large scale and high cost (Koedooder et al., 2024).

3.3.1 Prins Hendrik Sand Dike

Geographical and organizational conditions

The demonstrator is located on the eastern side of Texel Island, within the Wadden Sea. The previous coastal protection consisted of a vegetated dike, which needed to be renewed to increase coastal protection and to counteract saltwater seepage into the hinterlands. Instead of strengthening the dike, a new sand dune landscape was built in front of the vegetated dike. The dune landscape, which is a nature reserve, now serves as the primary coastal protection measure.

The project was initiated by the Hoogheemraadschap Hollands Noorderkwartier – the water authority (board) for the province of Noord-Holland. The local branch of Staatsbosbeheer (the Netherlands’ State Forestry Service) were thereafter involved. The local government and a Dutch technical network for coastal and hydraulic specialists also participated in planning the project. Furthermore, an ecological design bureau was involved in making drawings of the plan including both water safety and biodiversity aspects. The Jan De Nul Group – a construction and dredging company – was responsible for the construction of the dune landscape.

Aim and included co-benefits

Besides coastal protection, the most important co-benefits that were addressed in the planning and implementation of the demonstrator were **biodiversity** and **nature conservation**. Half of the cost of the project was funded by the nature restoration fund Waddenfonds, which required that the area would become a nature reserve. One of the goals was to provide a habitat for birds, particularly terns. The efforts were effective – Prince Hendrik Sand dike has become one of the largest tern colonies in the Netherlands.

Recreational values were addressed when locals protested about the future restrictions on public access to the area as it was converted into a nature reserve. This led to two

compromises being made – a bike lane was established on top of the dune-landscape, and one part of the beach remained open to the public.

Barriers and enablers in the planning and implementation of the demonstrator

According to the interviewees, **community engagement** was an important enabling factor for the implementation of the dune landscape. Farmers were particularly supportive of NbS instead of reinforcing the existing dike, which was the initial plan by the project team. Strengthening the dike would have meant increasing its width, which would have resulted in the loss of farmland.

The building of a dune landscape in front of the old dike, however, could cause saltwater seepage into the farmlands during the construction period, causing crop damage. To prevent this, extensive monitoring systems were established to collect data of salinity and water levels, which was used to determine whether the construction could proceed without additional measures. Citizens who were interested could follow the monitoring which was available online.

One challenge with the demonstrator is **sand drift**, which affects areas behind the dike, such as farmland, houses, and gardens, causing inconvenience for the owners. To prevent and decrease the sand drift, marram grass and other species have been planted to stabilize the sand dunes. Although the vegetation has been successful in reducing sand drift, according to the interviewees, it is inevitable to avoid it completely. Mitigation measures include removing accumulated sand from the grass dike and deploying cleaning staff to remove sand from windows of the affected houses.

Another challenge was to handle and **communicate restrictions** on public access to the area. When the nature reserve was closed for public access, there were initial issues with trespassing, including vandalism of the fences. Part of the solution was the compromise on public access – the construction of a bike path and leaving part of the beach open for public access. A few cameras were also put up, which further decreased trespassing. The restriction of public access also applies to kitesurfing, a popular activity at Texel. The area where the Prins Hendrik sand dike was constructed is one of the island's best kitesurfing spots, and some kitesurfing schools run their activities there. Since the access restrictions, kitesurfers have been redirected to a surfing beach further north, where conditions are less suitable. One interviewee noted that it is positive that the surfers were offered an alternative location; however, it is debatable whether this constituted a genuine alternative. Although kitesurfing is no longer permitted in Prins Hendrik, some kitesurfers continue to use the area. One of the interviewees noted that there has not yet been political consensus to act on the issue. However, the situation has improved somewhat as kitesurfers have become more aware of the bird breeding season and now avoid the most sensitive areas.

One of the respondents explained that communication challenges could have been mitigated through better timing and the inclusion of a broader range of stakeholders in the

planning stages of the demonstrator. For example, by actively involving people who use the area for recreation and sport activities.

An important enabler for the project, and for coastal protection in general in the Netherlands, is the **trust in the governmental institutions** among citizens. According to one of the interviewees, the Netherlands represent a special case, as the country has a long-standing tradition of combatting the water. The system of waterboards is robust, and trust in them is part of the culture, because as she reasoned, if you cannot trust them, it will be impossible to live in the country.

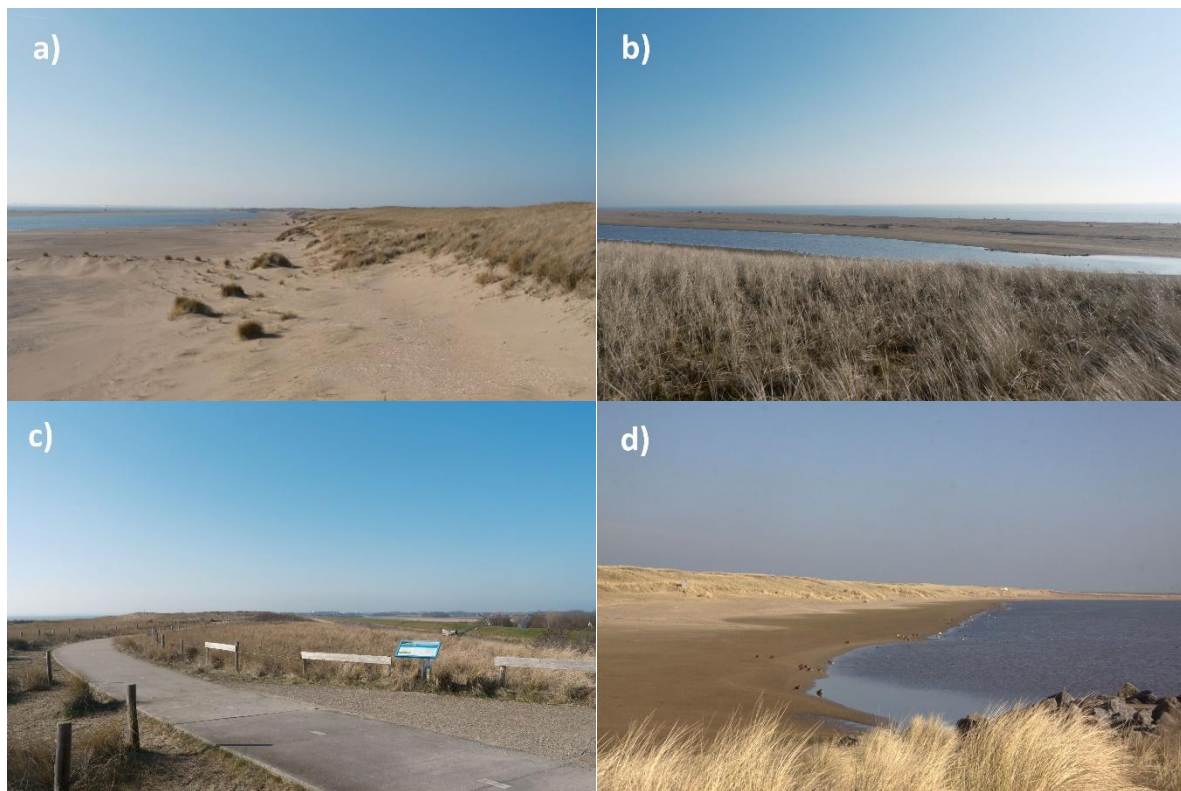


Figure 4 Prins Hendrik Sand Dike (NL) demonstrator – a) dune landscape in front of the vegetated dike; b) view of the demonstrator from the dike crest; c) bicycle lane on top of dike; d) birds at the waterfront.

3.3.2 Hondsbossche dunes

Geographical and organizational conditions

The demonstrator, located on the Dutch North Sea coast between Petten and Camperduin, consists of a dune landscape formed through a large-scale sand nourishment in front of an existing dike. A lagoon was also part of the construction, with the idea that the sand of the lagoon would erode and feed sediment to the dunes. The dune landscape was constructed to reinforce the coastal defense system in an area where the existing system that did no longer meet the Dutch national safety standards.

The project was initiated by Hoogheemraadschap Noorderkwartier, the regional water board responsible for determining an appropriate protection strategy. Given the regional water board's long-time presence in the area, they were already in contact with key stakeholders, such as the province and the municipality. To ensure inclusivity, they also spent some time searching for additional stakeholders (i.e., any new organizations), but no new relevant ones were identified.

Aim and included co-benefits

In addition to strengthening coastal protection, the demonstrator was designed to enhance **recreation** and **biodiversity** co-benefits. For the province, a key objective was to attract more tourists to reduce pressure on other destinations, such as Texel. The beach nourishment created a wider beach, providing more space for recreation, and the lagoon – although originally not intended for recreation – became a popular spot for swimming and sailing. To protect biodiversity, parts of the dunes are restricted, with public access allowed only in designated areas at the northern and southern edges. There are a few observation points where visitors can view the dunes, including one spot specifically for birdwatching. The interviewees highlighted the importance of maintaining conditions that allowed local and migratory bird populations to continue to thrive within the area, for example by maintaining the bird breeding area De Putten on the opposite side of the dike.

There was also another unexpected co-benefit for recreation and education, as it became popular to go and watch the construction work of the Hondsbossche dunes during the years when it was developed.

Barriers and enablers in the planning and implementation of the demonstrator

The discussion regarding the type of coastal protection measure to be implemented in the area lasted for 10 years. During this time, a major barrier to building a dune landscape instead of reinforcing the dike was **public opinion**. The existing dike had been in place for approximately 100 years, and parts of the public wanted to keep the straight element, as this represented a familiar form of protection measure. People found it difficult to imagine what a sandy landscape in front of the dike would mean for the area. One interviewee noted that residents of the villages near the dike, many of whom are fishermen, also showed limited interest in beach recreation. Furthermore, the regional water board was initially

reluctant to **finance** a soft engineering solution as it was estimated to cost nearly twice as much as reinforcing the existing dike.

During the ten years of discussion, both public sentiment and the regional water authority's position shifted. There were multiple reasons for this change. New calculations demonstrated that the dike would need to be higher than initially planned, which raised concerns for the regional water board. Local inhabitants were informed that reinforcing the existing dikes would mean that several houses would need to be removed. At a later stage, an excursion to the neighboring town of Noordwijk was organized for interested residents to learn about an existing nature-based coastal protection system. Collectively, these developments contributed to a shift in both the public opinion, and in the position of the regional water board, towards the construction of a dune landscape.

When the dune landscape was implemented, there was some initial **tension between biodiversity and recreational values**. The implementers thought that biodiversity protection should be implemented everywhere but then realized that this was not necessary as the people didn't disperse far away from their recreation localities.

The interviewees emphasized the importance of holding a **variety of stakeholder meetings** to ensure broad participation and inclusion. The project team organized both large public meetings, which were widely advertised, and smaller co-creating sessions for targeted stakeholder groups.

The interviewees also mentioned that there is **tension between the many levels of stakeholders** involved in large coastal protection projects like Hondsbossche dunes. There has always been tension between the water board, the municipality, and the province as they are all dealing with the same area. Besides the national stakeholders, big international companies are usually contracted to carry out nourishments and maintenance. One interviewee suggested that contracting these companies for the Hondsbossche project was a mistake, as they have the money and power to control national authorities. Furthermore, a new challenge that stakeholders faced during the Hondsbossche project was the spread of **misinformation on social media**. For example, as part of the project, two sand deposits were constructed to prepare for the formation of a new dune. Because of this, some social-media actors spread information that authorities were making breaches in the coastal defense, which would cause flooding. These actors also asked their followers to go after the contractors and threaten them. The interviewees noted that this is a worrying new development for the future.

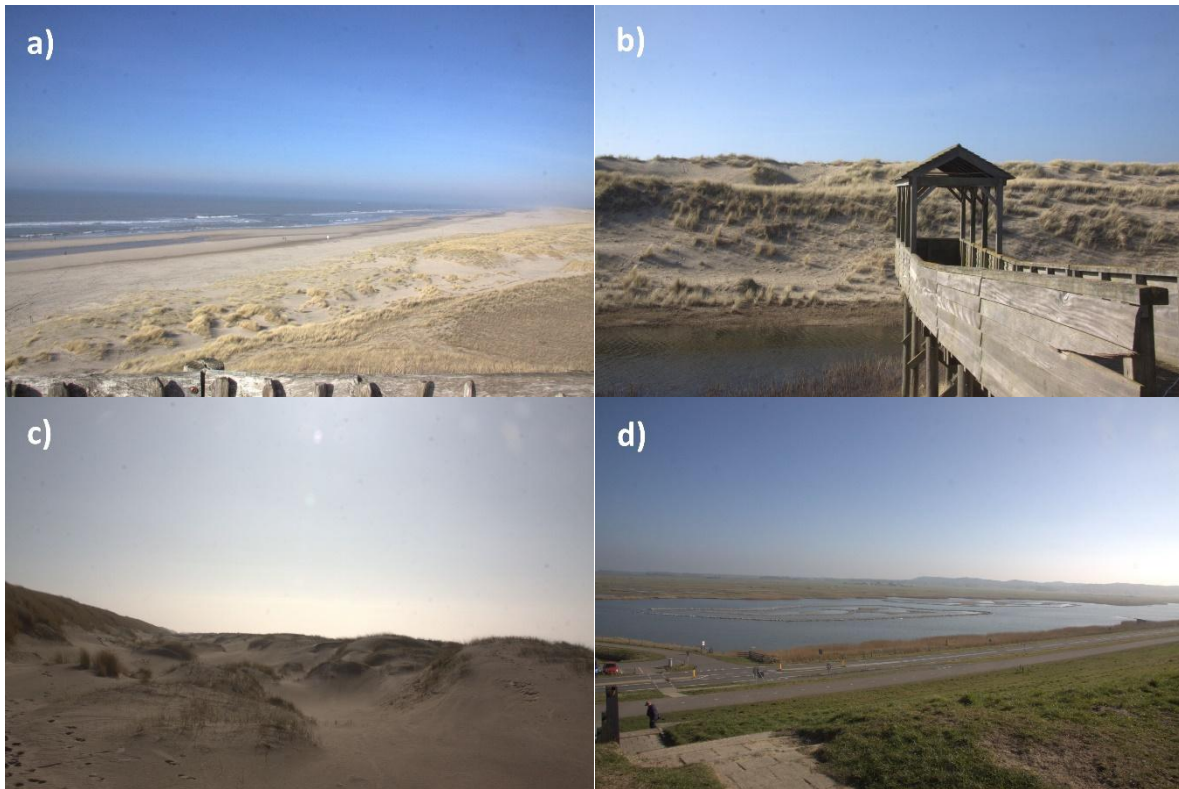


Figure 5 Hondsbosche (NL) demonstrator – a) view from a viewing point over the beach and dune landscape; b) birdwatching hut overlooking the lagoon; c) close-up of the dune landscape; d) De Putten bird sanctuary on the opposite side of the dike.

3.3.3 Katwijk

Geographical and organizational conditions

The demonstrator, which is located in Katwijk, in the mid-western Netherlands, consists of a dike-in-dune solution, with a parking garage situated beneath the dike. The solution has an adaptable design, which allows for future extensions both upwards and seawards. The solution was implemented because the coastline around Katwijk was considered a weak link in the Dutch coastal defense system.

The project was initiated by the regional water authority Hoogheemraadschap van Rijnland in collaboration with the municipality of Katwijk. Initially, the national government attempted to halt the project, as Katwijk was not considered the most urgent 'weak link.' However, since the project had already started, they were able to proceed. During the planning phase, 75 stakeholders participated in a game workshop, working in groups to generate ideas for the design of the solution. In the construction phase, residents were invited to create artwork on the dike before the construction of the dune landscape.

Aim and included co-benefits

In addition to coastal protection, the project also addressed values of **recreation, economic activity, communication, and nature**. A key priority was maintaining the connection between the city and the sea, particularly preserving the sea view from the city boulevard. This consideration guided the decision to construct a dike-in-dune rather than relying solely on sand nourishment, as a dune without a hard core would need to be higher and would therefore obstruct the ocean view.

Social costs and benefits analyses were integrated from the beginning of the project. In the designing of the dune, particular attention was given to creating a space that supports social interaction. The parking garage beneath the dike enhances accessibility between the city and the beach, making it a natural gathering place for both locals and visitors. One of the garage entrances connects directly to a shopping area, linking the beach to the municipality's economic activity.

During the construction of the dike-in-dune solution, the project team focused on communication with the public. There was a visitors' information center, a dedicated website, newsletters, and a webcam at a viewing point that allowed people from around the world to follow the construction process. These combined communication efforts generated significant public interest, which has had a positive impact on the municipality.

Although not a primary objective in the project's planning, the dune landscape also created additional space for nature. Katwijk lies between two Natura 2000 areas, and the solution creates a connection between them, which benefits species migration.

Barriers and enablers in the planning and implementation of the demonstrator

According to the interviewees, the greatest challenge of the planning and construction of the demonstrator was to develop a solution across **multiple governance levels**. It was especially difficult to divide the budget. The national, regional, and municipal government prioritized different aspects: the municipality emphasized quality, the national government prioritized cost, and the province focused on time. The respondents interviewed also highlighted the importance of **political will** at both municipal and provincial levels, as well as the personal connections between individual politicians. To facilitate the collaboration, all parties signed a declaration of intent at the outset of the project, which helped to facilitate budget division.

The inclusion of a **wide range of stakeholders** in the early stages of the project served as both an enabling factor and a challenge. The pre-design phase differed from previous coastal protection projects in the Netherlands, beginning with an open-market tender to encourage creative input. The selected bidder proposed a three-dimensional game for stakeholders to explore new coastal protection solutions. In the game, participants were divided into groups and given different budgets. According to the respondent, many locals felt that they were able to influence the process and developed a sense of ownership over it. This phase of the project was productive, generating new ideas that the project team had not previously considered.

One of the challenges of involving the public in the planning stage was that people could get expectations that would be difficult to meet. To address this, the responsible authorities worked on **expectation management** and created 'rules of the game' to ensure that creative ideas remained within realistic boundaries. Public involvement also extended the project's timeline compared to other coastal protection projects in the Netherlands. However, the interviewees argued that the collaborative approach ultimately led to fewer complaints in the end.

Although the feedback on the solution was mainly positive, some concerns were raised – particularly regarding the increased **distance to the sea**. Some locals complained that they could no longer hear the waves and that the increased distance meant losing a bit of the town's identity. To address this, project partners sought to reduce the perceived distance to the beach by creating squares designed to invite people to stop and rest on their way to the sea.



Figure 6 Katwijk (NL) demonstrator – a) entrance to the underground parking garage integrated into the dune landscape; b) path including seating area situated within the dune landscape; c) Beach hut next to a path leading down to the beach; d) overview of the multifunctional coastal protection solution with multiple access points

3.3.4 The Sand Motor

Geographical and organizational conditions

The demonstrator, called the Sand Motor, is located on the Delfland coast, close to The Hague in the Netherlands. It is an experimental 'mega-nourishment' that was implemented to research coastal dynamics, and to explore whether this type of measure could be useful for the future. The project site was considered as one of the 'weak links' in the Dutch coastal defense system. The Sand Motor was designed like a hook, with a lagoon that changes shape depending on the tide. The design also incorporates an inland dune lake. Both the lagoon and the dune lake were designed to disappear and to self-nourish the dunes.

The project was initiated by the Ministry of Public Works, through its executive body Rijkswaterstaat, together with the province of South Holland that conceptualized the idea of the specific shape of the Sand Motor. Academic experts were also involved before and after the Sand Motor was constructed, for example in coastal morphology modelling. Monitoring and evaluation of the project, which is still ongoing, is carried out by Deltares – an independent research institute.

Aim and included co-benefits

The Sand Motor was designed with three primary objectives: (1) to construct innovative long-term coastal protection for the area, (2) to minimize disturbance to marine ecosystems, and (3) to create more **recreational space** for the public. Although one of the goals is coastal protection, the Sand Motor was not necessary as a safety measure when it was constructed. Instead, the project was established as a test bed to gain knowledge about how a mega nourishment like the Sand Motor develops over time – insights intended to inform future coastal management policy. Recreational co-benefits were a key consideration as there was limited space for recreation in the area prior to the Sand Motor. The lagoon was designed to enhance aesthetic co-benefits while also providing a **new ecotope**. According to one interviewee, the province also considered the Sand Motor valuable for **international business**, as it would represent a good image for the city of The Hague.

The Sand Motor has also generated several unanticipated co-benefits. Although quite a rare phenomenon along the Dutch coast, embryonic dune fields began forming on the nourished beach. The area, and the lagoon in particular, has also become a prime location for kitesurfing, leading to the establishment of several kitesurfing schools. Additionally, bones from pre-historic animals were discovered in the area, making it a significant site for paleontologic research.

Barriers and enablers in the planning and implementation of the demonstrator

A key challenge for the decision to create the Sand Motor was the **funding structure** of the coastal protection system in the Netherlands. The national government, through the regional water authorities, only pays for the safety aspects of a solution – they do not pay for other

functions or quality. One of the interviewees from the province mentioned that it was difficult to understand this, as he argued that the different values belong together. Furthermore, during the planning and implementation of the Sand Motor, there was **resistance** from the local government and from nature protection organizations. Oppositions primarily focused on the **costs, the ecological effects, and the access to the sea**. According to one of the interviewees, the realization of the project was dependent on finding momentum around a common objective across different governance levels.

In the first few years following the implementation, **safety concerns** arose due to unstable dunes, strong currents, and localized quicksand around the lagoon. Normally, the municipality is responsible for the beach, but because of these issues, the province coordinated the safety measures during this period. Interventions included increased safety levels and accident preventions, and deployment of safety guards to oversee the water areas. The national government, together with the rescue brigade, also developed an app to monitor water safety. To further mitigate safety concerns, signs were put up throughout the area, and information was published on the website for the Sand Motor. In relation to communication in general, one interviewee mentioned that it was important to convey the reasons behind the Sand Motor being constructed.

There has been some **tension between coastal protection, nature and recreational co-benefits**. Because recreation was one of the three main goals, it was decided to keep the area largely unfenced, which opened for recreational activities, such as off-road driving—that posed risks to dune stability. To mitigate these impacts, management plans were implemented restricting vehicles to designated tracks. Furthermore, although a growing kitesurfing community represents a positive co-benefit, it also faces challenges due to the dynamic and changing nature of the Sand Motor. The channel and the lagoon are shrinking, limiting recreational activities in the sheltered waters. The province has advocated for dredging them open again, but as the Sand Motor is still an experiment, it is not something that Rijkswaterstaat has agreed on. The main purpose is still to see how the area develops over time without any further human intervention.

According to one of the interviewees, the **global economy** was an important enabler to implement the project. During the financial crisis of 2009, the cost per cubic meter of sand was very low. This made it relatively cheap to purchase the amount of sand that was needed to construct the Sand Motor. Another economic enabler was that Rijkswaterstaat could use fundings that was reserved for the next 20 years of coastal protection of the area, creating a larger budget than normal.

Another topic that was discussed in the interviews was **access to sand**. The interviewees stated that access to sand was not a barrier for implementing the Sand Motor but could potentially be an issue for similar projects in the future. The sand is extracted from sand pits that are designated for beach nourishments in the North Sea. However, sea-level rise may

increase the demand for nourishment material, potentially requiring extraction of sand from new locations, which could create ecological and safety concerns.

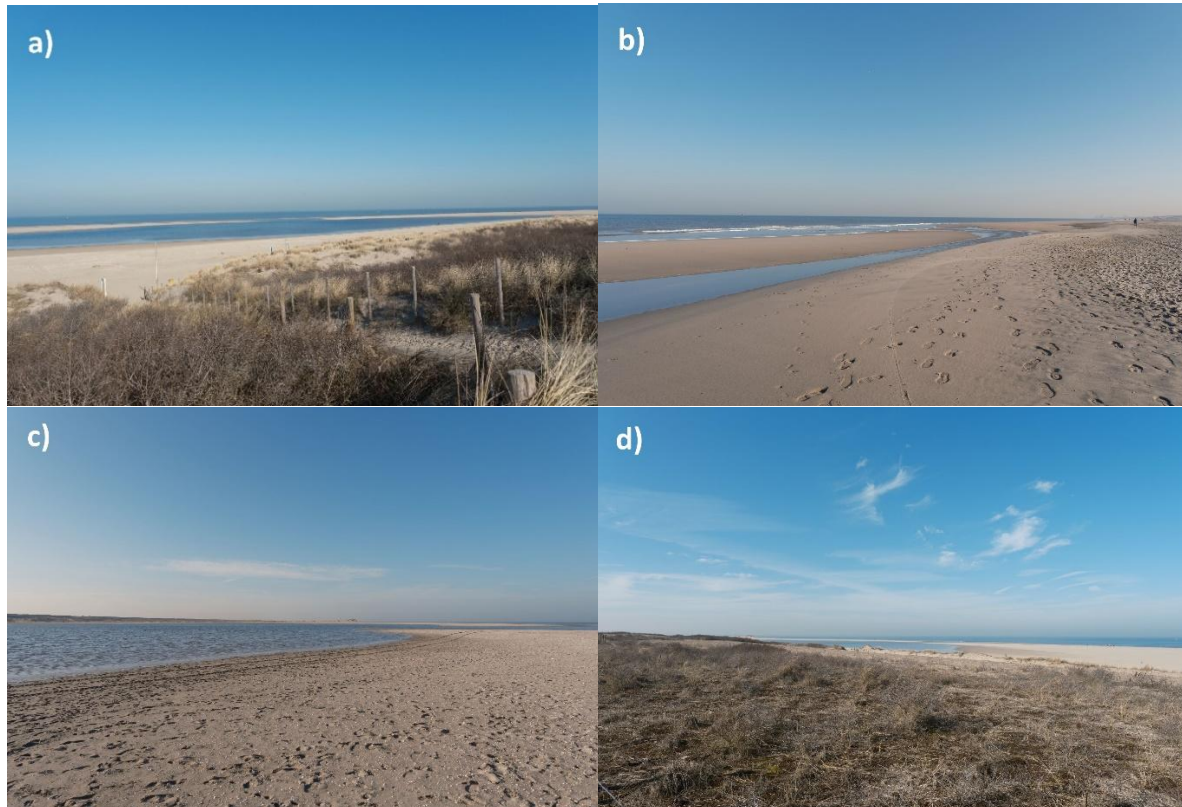


Figure 7 Sand motor (NL) demonstrator – a)–c) overview of the ‘mega-nourishment’ from multiple perspectives, showing faintly the hook and lagoon features; d) engineered channel visible within the design.

3.4 Belgium

Coastal protection in Belgium is primarily managed at the regional level by the Flemish government. The Coastal Division of the Flemish government Agency for Maritime and Coastal Services (MDK) is the responsible authority for investment and construction of coastal protection solutions, while local governments are responsible for maintenance. The federal government has a broader focus on environmental policy and international responsibilities. In 2011, the Masterplan for Coastal Safety was approved, in which it was stated that ‘hard’ measures (e.g. dikes) would, where possible, be complemented with ‘soft’ measures (e.g. dunes). The Flemish region, according to its most recent strategic plan, *Coastal Vision*, plans for coastal protection to withstand sea-level rise of up to 3 m (D16.2).

3.4.1 Living Lab Raversijde

Geographical and organizational conditions

The Raversijde demonstrator, located on the outskirts of Ostend along the Belgian North Sea coast is a test bed for research aiming to study dune development in front of a dike. The test bed consists of 10×10-meter blocks planted with marram grass in varying patterns and densities, protected by fences made of willow branches. It was constructed by the municipality as they had problems with sand drift from the beach onto the tramway, which runs along the coastline. While not required for flood protection, the test bed evaluates whether marram grass could stabilize the sand and its future potential for flood protection. The results of the project demonstrate that sand drift has been significantly reduced.

The Raversijde demonstrator was initiated by the Flemish governmental agency for Maritime and Coastal Services (MDK) in collaboration with the city of Ostend, with financial support from the European project SARCC (Sustainable and Resilient Coastal Cities, 2019–2022). As part of the living labs, Flanders Hydraulics, in partnership with universities in Leuven and Ghent, among others, coordinates the overall monitoring.

Aim and included co-benefits

In addition to studying dune succession, the demonstrator’s main co-benefit is reducing landward sand drift onto the tramway. The respondents also raised potential co-benefits if the project were upscaled. In areas with higher residential density, one respondent argued that recreation could become an important co-benefit. One idea mentioned was the construction of a second promenade in the dunes. Moreover, because the test bed has been successful, it may facilitate stakeholder communication in future projects, where different perspectives may lead to conflicts. The test bed has also yielded unexpected co-benefits. Following the establishment of marram grass, additional plant species colonized the area, enhancing the local biodiversity.

Barriers and enablers in the planning and implementation of the demonstrator

Currently, no conflicts of interest exist at the test bed, but one respondent assumes that there may be challenges in the future if it is upscaled. A potential risk is a conflict between biodiversity and recreational co-benefits. For instance, environmental laws may restrict alterations of the dune landscape once protected plants have established themselves, limiting plans to construct a second promenade on the dunes.

According to one respondent, the construction of the test bed was generally well received, as most **people were interested** in its potential to reduce sand drift onto the tramway and road. The respondent reasoned that the limited negative feedback is likely due to its location, with no residential housing directly behind the beach and few pedestrians on the promenade. The respondent expects that future expansions of marram grass plantation to more populated areas, especially places where people own beach huts (see demonstrator Middelkerke) may cause discussions.

The respondent expressed that it is easier to convey the need to construct sand dunes when addressing immediate issues, such as sand blowing onto roads and gardens as compared to long-term coastal protection due to climate change and sea level rise. For future coastal protection that does not address any immediate visible issues, there may be discussions about why it is needed. At the same time, it is possible that those discussions could be avoided as dunes grow slowly, allowing people to have time to gradually adapt to a new coastal protection system.

The interviewee noted that the willow branches introduced to capture sand also created a physical barrier that prevented trampling, allowing the dunes to develop undisturbed. However, they also seem to have had a negative impact on the growth of marram grass as too much sand was accumulated at the demonstrator.

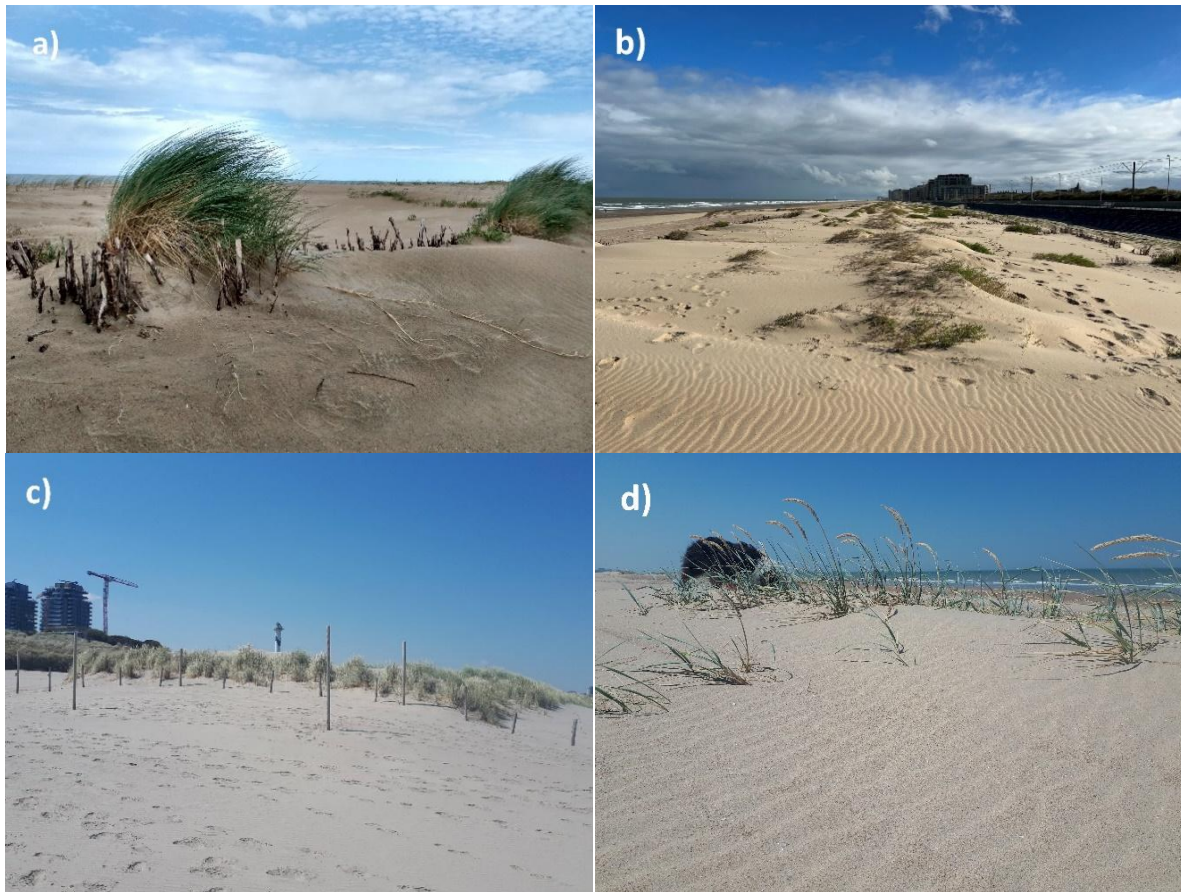


Figure 8 Living Lab Raversijde (BE) demonstrator: a) marram grass growing within willow-branch fences; b) dune formation with tramline visible in the background; c) beach and marram grass; d) marram grass establishing on newly formed dunes

3.4.2 Middelkerke Grasdijk

Geographical and organizational conditions

The demonstrator, which is a dune in front of a dike, is located in Middelkerke on the Belgian North Sea coast. It is a constructed dune landscape, planted with marram grass, situated in front of an existing seawall. The old seawall, which was built at the end of the 19th century, had failed the safety assessments as it did not bring enough flood protection.

The Belgian governmental agency for Maritime and coastal Services (MDK) performed the safety assessments of the existing seawall. Together with the city of Middelkerke, they planned the dune landscape. The new development was also funded by the EU project SAARC.

Aim and included co-benefits

Besides coastal protection, the project also focused on adding **recreational co-benefits**. The promenade had previously been shadowed, because of the tall apartment complex on the seawall. The new dune landscape was designed with walking paths, where the sun could reach. The paths are fenced off to prevent people from walking on the dunes, as this could cause erosion. The idea of walking paths was presented by the coastal community of Middelkerke, who wanted a greener solution. According to the stakeholder interviewed, the visitors to the area are pleased with the solution, and the houses in the area have doubled in price.

Barriers and enablers in the planning and implementation of the demonstrator

One of the most important enabling factors for the planning and implementation of the grass dike was **community participation**. The Flemish government reached out to the coastal community, who agreed on the idea of constructing a new seawall. However, locals in Middelkerke also wanted to gain other values, such as a sunnier promenade. According to the interviewee, there has been a change in the mindset of the coastal community from the view that green solutions are, e.g., costly in terms of maintenance, to appreciate the natural environments more. This has enabled the implementation of NbS.

Another enabling factor has been the **strong collaboration** between different governance levels. The government and the municipality have different responsibilities withing coastal protection projects; the MDK has knowledge about construction and safety, and the municipality knows what their community needs. According to the respondent, the collaboration works well. They have an agreement that is renewed every ten years, which gives stability to the collaboration. There is also usually one project leader from the Flemish government and one from the municipality.

Although the new promenade has become popular, there has been some **discussion about the sea view**, which highlights a potential future conflict between growing dunes and recreational co-benefits. It was a demand by the city council that the dunes should not be too high and block the ocean view from the lower floors of the buildings and the

promenade. According to current discussions, if the dunes grow too high, the plan is to lower them. The respondent argues, however, that this may not be possible, as Marram grass is a protected species, meaning that it is not allowed to be removed once it has established itself in the area.

Another challenge was **communication** regarding continued beach nourishment. The development of the dune landscape reduced the size of the beach, and as the budget is limited, the governmental agency for Maritime and coastal Services could not both construct the dune landscape and continue to nourish the beach to keep it in the same size. According to the interviewee, this was a challenging conversation to have with the coastal community, who were used to regular nourishments.



Figure 9 Middelkerke (BE) demonstrator – a) walking path in the sun through marram grass vegetation; b) shadowed promenade; c) close-up of dunes; d) beach and dunes with the ‘Atlantic Wall’ visible in the background.

3.5 France

In France, coastal protection is primarily managed at the national and local levels. The national government sets policy, often through the Ministry of Ecology, Sustainable development and Land settlement, while local entities (like municipalities and inter-municipal bodies) implement these policies, such as constructing dikes and other flood protection solutions. National authorities also supply technical guidance and financial support, often complemented by EU funding. The general goal of the French government is to retreat from the coastal areas where there is ongoing coastal erosion. This involves limiting new constructions in low-lying coastal areas as well as relocating vulnerable populations. When land is under state jurisdiction, authorities may intervene to remove or demolish buildings. However, there seems to be a disconnect between national policy aims and local implementation on the ground, which continues to experiment with coastal protection measures (Koedooder et al., 2024). France incorporates sea-level rise into coastal protection, but it does not set a single fixed national value that all projects must apply. (D7.1).

3.5.1 Dunkerque

Geographical and organizational conditions

The demonstrator is a dune-in-front-of-dike solution, situated in the sea front center of Dunkerque, a city on the North Sea coast of northern France. The dike runs along a canal that serves as the final outlet for water drainage from the area south of Dunkerque, which is low-lying polder land. At the end of the dike, there is a long jetty serving as protection for the canal. The jetty in combination with winter storms causes strong currents, leading to severe coastal erosion. In the 1950s, the dike breached twice, causing significant flooding in the low-lying areas. To ensure dike stability, beach nourishments are now carried out annually at the jetty-beach interface using sand from Belgium as well as from the adjacent harbor. Dunes are created with the help of active sand management through beach nourishment, Marram grass plantation, and aeolian processes acting during low tide when the sand is exposed.

The main partners of the project are the communauté urbaine – an organization comprising the municipalities of the area – and the port of Dunkerque, where the port is the main provider of sand and the communauté urbaine is responsible for the work. The Pôle Métropolitain de la Côte d'Opale (PMCO), an inter-municipal cooperation structure, is also involved in the project, mainly by providing scientific and legal support to local stakeholders in relation to technical aspects of coastal erosion.

Aim and included co-benefits

Besides enhancing coastal protection for the low-lying areas of Dunkerque, the dunes have been designed for **recreational purposes**. Dunkerque and its surrounding polder land are a populated area, and during the summer, it also attracts a significant number of tourists. The

dunes have been constructed in front of a beach-front hotel, and according to the interviewees, the hotel owner has been supportive of the dunes as they provide a nice atmosphere outside the hotel. Furthermore, the plantation of marram grass on the dunes inspired other coastal cities along the coast, including Middelkerke and Ostende, to carry out similar measures. The marram grass has also led to slightly less sand on the beach promenade that stretches along the coast, which reduces the need for sweeping.

Although biodiversity enhancement was not a primary objective, the project delivers notable **ecological co-benefits**. The area supports protected fauna, including native and migratory bird species inhabiting the dunes, along with various protected plant species. Restrictions to walk in the Marram grass to reduce the risk of dune erosion also protect avian breeding habitats.

Barriers and enablers in the planning and implementation of the demonstrator

A key barrier for the implementation of these soft solutions has been the different views of their utility as well as their costs across different governance levels in France. The national adaptation strategy focuses on managed retreat, but according to the interviewee, this is impossible for polder areas such as the surroundings of Dunkerque (population >400,000). The respondent argued that there is a **lack of willingness** to protect the coast on state level, hindering the implementation of coastal protection measures. Also adding that the national decision to focus on managed retreat may work for many areas of France, but not polder areas where large amount of people may live behind the coastal front. The interviewee also noted that the state has contradictory objectives, as there are also national plans to develop the harbor.

Another barrier is the **limited public awareness** of coastal flood risks. According to the interviewee, it seems that residents in Dunkerque are more concerned about inland flooding than coastal floodings. He argues that, despite the city's coastal location, the population's relation to the sea is not the same as in the Netherlands. To improve public awareness, the urban community is working together with other organizations on sensitization of these issues. Hybrid solutions of **combining dunes and dikes** are not so common in France, and the interviewee describes that there is a general view that "hard solutions should be totally separated from soft and nature-based solutions".

At the demonstrator site, there is also a **conflict of interest** between recreational activities and nature conservation. People walking in the dunes, even though it is not allowed, destroy eggs of breeding birds. There are no fences or signs to prevent people from walking in the dunes, as this according to the interviewee, is not expected to help, as such measures are generally not respected in France.

In Dunkerque, **sand is easily accessible** from the adjacent harbor which needs dredging at regular intervals to maintain its required depth. There is an issue with sand drifting from the beach to the seafront promenade. To prevent further sand drift, the municipality wants to extend the plantation of marram grass further along the beach promenade.

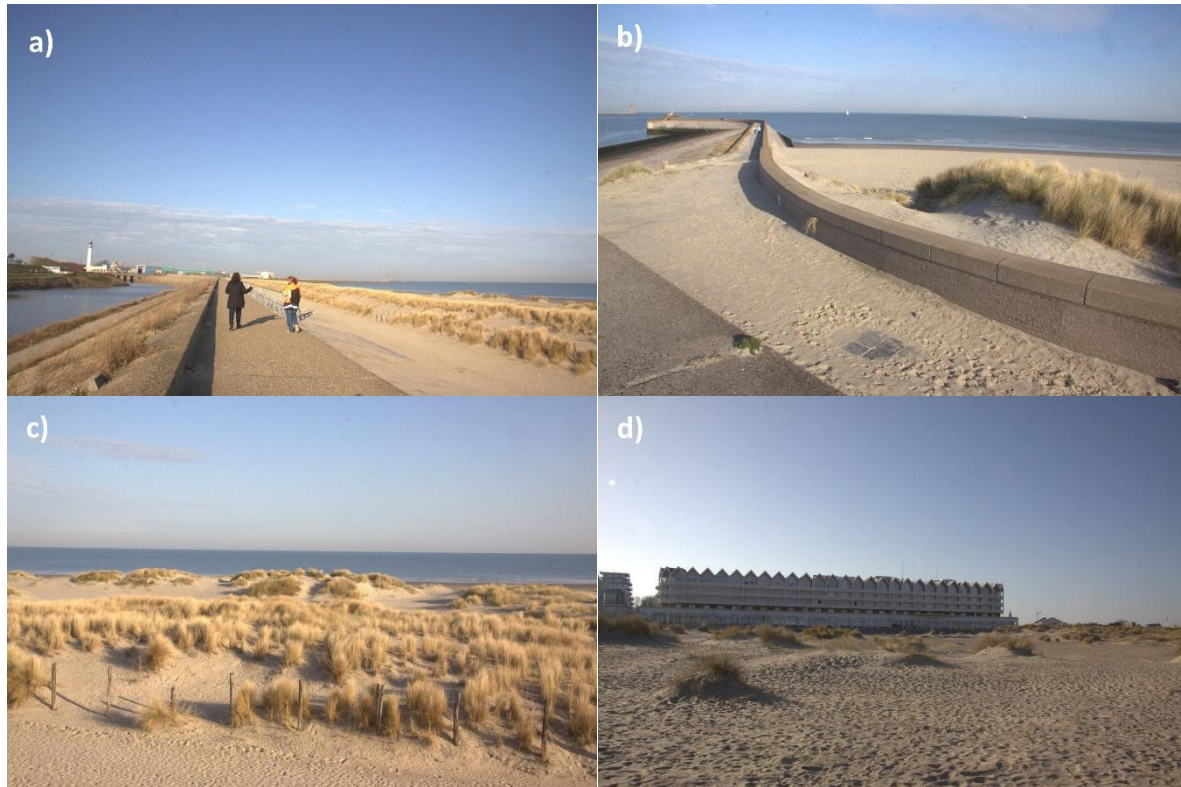


Figure 10 Dunkerque (FR) demonstrator – a) dike protecting the canal on the left with walking path on top; b) beach–jetty interface where sand has been added, but severe erosion continues; c) close-up of the dune landscape; d) hotel near the beach with growing dunes in front.

3.5.2 Soulac

Geographical and organizational conditions

The demonstrator is categorized as a dune-in-front-of-a-dike, and is situated in Soulac, southwestern France, on the Atlantic coast. For many decades, the area has been affected by severe erosion. Throughout the 20th century, dikes were constructed by the city to protect the area behind the beach, comprising both marshes and agricultural land and an overtime increasing amount of mainly summer houses. In 2024, marram grass was planted in two areas to support dune restoration and to reduce aeolian sand transport into the coastal resort. A groin is also located updrift of the marram grass plantations, where sand accumulates.

The Soulac Demonstrator is overseen by the Communauté de Communes Médoc Atlantic (a regional association of municipalities) and managed by the Soulac city council and the Office National des Forêts (the French National Forestry Office). The French National Forestry Office works in close collaboration with the local community.

Aim and included co-benefits

The main aim of the demonstrator is to reduce windblown sand into the town of Soulac, which is a popular tourist resort but also to increase the accumulation of sand to protect the beach. The project team works along the whole sediment cell with other solutions, including beach nourishment, especially on areas adjacent to the south side of the break water closest to the testbed but also along the coastline south of Soulac, which is heavily eroded. The main aim of this work is to protect the beaches as well as to **support tourism** and maintain a nice coastal stretch for the coastal community.

Barriers and enablers in the planning and implementation of the demonstrator

No major barriers and enablers were mentioned in relation to the marram grass plantations. However, the respondent noted that the grass grows better in one of the two areas, most likely due to greater sand drift from the beach, which is necessary for the grass to thrive. Why one area is more fed by sand is probably related to the breakwater that collects sand at one end of the beach.

The demonstrator is only a small part of the package of solutions that is used to protect the beach and control the sand along the Soulac coastline. A key barrier to counteracting sand erosion along the coast has been the **lack of knowledge (or lack of inclusion of knowledge)** about the dynamics of the whole sediment cell, as well as knowledge about which methods are most effective for erosion control. The sediment cell included the deposition of sediment from the river Gironde, which earlier was transported back to the coastal stretch from Soulac and southward by the south to north currents along the coast. However, the construction of several hydropower dams upstream, as well as the removal of sand from the estuary (dumping it in the deep sea), has changed the dynamics of the sand transport in the cell. However, in spring 2025, a decision was made to take the sand from

the deep sea and put it back in the cell – with the aim to hopefully nourish the coastline with sand. In relation to coastal protection methods, several hard solutions have been implemented over the years, but they have been unsuccessful. For example, a dike built of blocks in front of a group of houses, which is now being undermined by the sea.

One enabler for raising awareness about coastal floodings was the **winter storm in 2014** in Soulac where the sea over a night crept up to within 20 meters of a large apartment hotel (Le Signal), which led to an immediate evacuation (alerte de péril). The house was later demolished in 2023. This house is now referred to as the ‘starting point’ of a new era in France coastal protection policy – planned retreat, as it was the first building that had to be demolished due to coastal erosion as the authorities may intervene to remove or demolish buildings that are in danger from the sea. The demolition of Le Signal is also an example of the **tension between the value** of tourism for the town of Soulac (as well as other coastal communities especially along the Atlantic coast) and the French government’s strategy. There are also **conflicting laws** that exacerbate this tension. For example, there is still no possibility of banning new building permits in areas planned for retreat if they are within already defined areas for housing.

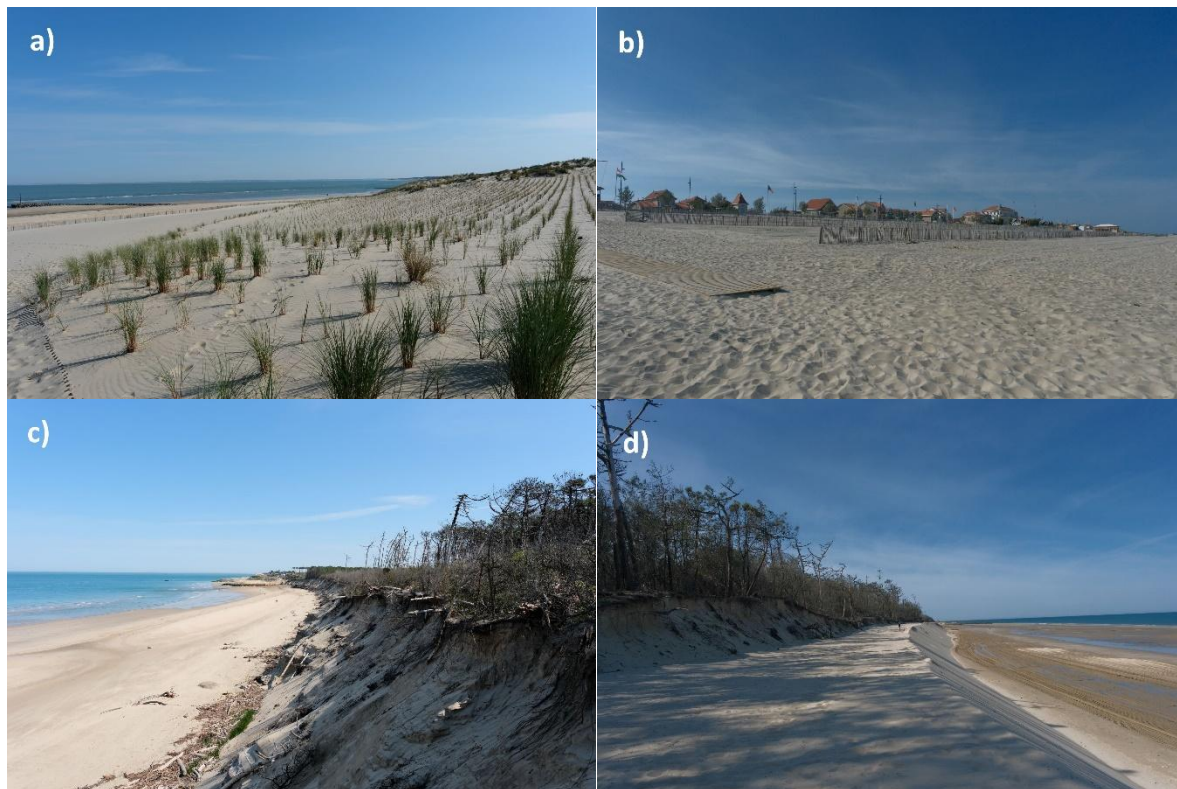


Figure 11 Soulac (FR) demonstrator – a) marram grass plantation; b) sand fences with the town of Soulac visible in the background; c) areas of severe erosion; d) beach nourishments to mitigate erosion.

3.5.3 Sainte-Marie-la-Mer

Geographical and organizational conditions

The demonstrator, consisting of sand fences on the east side (facing the sea) of a constructed sea wall, is located in Sainte-Marie-la-Mer on the east coast of France, by the Mediterranean Sea. There is vegetation on the sand dunes, including marram grass, which has been naturally established, i.e., not planted. The purpose of the fences has been to support dune development with the aim of limiting erosion, which is a challenge in the area. Following a flood in the 1940s that moved a nearby river delta southward, sediment transport has changed radically. The sediment from the river therefore no longer reaches the beaches north of the harbor, causing them to erode. The strongest erosion is just north of the north harbor pier.

The project was initiated by the inter-municipal organization Perpignan Méditerranée Métropole (PMM). PMM classifies geographical areas according to their vulnerability to climate risks and collects tax from inhabitants based on this classification. This tax is used for the funding of coastal protection measures in the area. Examples of other organizations that have been involved are Université de Perpignan and Obs Cat, which is a participatory lab focusing on developing possible solutions for a retreat plan.

Aim and included co-benefits

During the planning and implementation of the demonstrator, **recreational** co-benefits were considered. The preservation of the beach is considered important as it is a popular spot for recreation for local inhabitants, mainly secondary housing. According to the interviewees, the beach is especially important for those who do not own a garden in the Perpignan region, something that became clear during Covid-19. Additionally, beach bars and restaurants are vital for the **local economy**.

Barriers and enablers in the planning and implementation of the demonstrator

There is **tension between** the economic necessity of beach bars and restaurants and the negative impact of their activities on the beach. To run their business on the beach, bars and restaurants must get a special permit, which is valid for 10 years. Similarly to Soulac, it is still allowed to build new houses on empty lots, even though France has decided to use retreat as a climate adaptation strategy on eroding coastlines.

One of the biggest challenges for the demonstrator is the **uncertainty** related to whether dunes can develop naturally in relation to existent boundary conditions, such as wave action and wind patterns. Because there are mostly mild winds in the area, dunes are not growing quickly enough as dunes are mainly rebuilt during a few, but strong winter storms from the southeast. Erosion has already caused one third of the fences to fall into the water.

Further, **access to sand** is limited. Although the harbor is a source for sand nourishment, as it needs dredging, the amount of sand is not enough. As part of a plan to extend the harbor, a sand bypass system is being considered, which would increase access to more sand.

However, there isn't enough **funding** for this. There is also no other place nearby where sand can be extracted. According to the interviewees, transporting sand from somewhere further away is both an ethical as well as an economic issue.

Even if local inhabitants were not involved in designing the seawall and despite complaints in the beginning, the wall has become partly covered in sand and vegetation over time and is now an appreciated promenade.

Another barrier discussed was the difficulty of **communicating with politicians**, particularly the contradiction created by installing fences, which may lead local politicians to believe that protecting the coast is economically feasible—despite national policies that promote planned retreat. The interviewees argued that it's not easy for politicians to understand that it can't continue like this. First, the coastal community developed from the 1950s till the 2000s, then coastal erosion was realized leading to the implementation of hard protection measures, and now, the state has decided that this is not the way forward. Explaining this in parallel with the fact that the beach is the financial income for the municipality is a difficult pedagogical task.



Figure 12 Sainte-Marie-La-Mer (FR) demonstrator – a) sand fences with naturally established vegetation; b) sand fences from another angle; c) groin extending into the sea near the demonstrator; d) severe erosion with fences having fallen into the sea.

3.6 Portugal

Coastal protection in Portugal is a national responsibility, overseen by the Ministry for the Environment, with implementation carried out by the Portuguese Environmental Agency (APA). The port administrations and the Ministry of Defence are also responsible authorities. Portugal does not have legislation specifically for coastal management – instead it is addressed through spatial planning laws (Coastal & Marine Union (EUCC), 2017). Consequently, governance of Portugal's coastal areas is fragmented, with many institutions involved, often holding conflicting priorities, which complicates effective implementation of coastal protection solutions (Koedooder et al., 2024). Portugal considers projected future sea-level rise in coastal planning but does not define a single fixed national value that all projects must apply (Soares, 2024).

3.6.1 Porto

Geographical and organizational conditions

The demonstrator is located at the Douro River estuary in Porto, Portugal, at the Atlantic coast. It consists of a naturally formed sandspit and two constructed breakwater structures, one of which is detached from the sandspit. The main role of the sandspit at the Douro River estuary is to act as a natural barrier that protects the inland areas and the harbor from storm events. Historically, the area has been severely affected by major floods, with waves reaching up to 10 meters. The Douro River, starting in Spain, is a very strong river and used to transport large amounts of sediment to the estuary. Over the past centuries, several dams have been constructed, which has significantly reduced the transport of sediment toward the estuary. This changed the characteristics of the sandspit, which started retreating. Its dynamic shape has made navigation difficult and even dangerous, which led to the construction of the breakwaters to stabilize the sandspit, improve navigability, and reduce storm wave impacts.

Behind the sandspit, a marshland area has formed, which has been turned into a nature reserve. Because of the demonstrator, sand nourishments to surrounding areas have only been needed twice in the last ten years. In addition, it is also not needed to dredge the harbor anymore.

The project was initiated by the port authority, which issued two tenders involving multiple contractors and other stakeholders. The faculty of engineering at the University of Porto was a key partner involved in this process. Other stakeholders include the municipality of Porto and the Institute for Nature Conservation and Forests (Instituto da Conservação da Natureza e das Florestas, ICNF). The ICNF is responsible for the nature protection area behind the sandspit.

Aim and included co-benefits

Besides the three main goals of the demonstrator – improving the safety of the navigation channel, protecting the sandspit and strengthening coastal protection – additional co-

benefits of **recreation and nature** were also considered. The sandspit provides recreational areas and is visited by many locals. Recreational co-benefits were also addressed in the design of the breakwaters. One of the revetments is hollow, enabling visits to the inside of the structure. Right now, however, it is closed due to safety reasons. The nature reserve also includes a bird sanctuary. Access is restricted, but many locals visit the viewpoints.

Although not implemented, additional co-benefits of energy production were also considered in the planning phase of the project. A wave energy converter was planned at the head of one of the breakwaters. However, due to financial reasons, it could not be implemented.

Barriers and enablers in the planning and implementation of the demonstrator

The planning and implementation of the coastal protection solution in Porto was enabled by an **inclusive planning and decision-making** process, involving public participation and close relationships between key stakeholders. In the first tender, the port authority defined the solution, in which they proposed the construction of two revetment breakwaters parallel to each other, which is a common solution for river estuaries. This proposal generated public discussion, especially about the potential impact on the ocean view from the north banks of the river mouth. The discussions resulted in the cancellation of the proposal. A second tender was therefore issued, in which contractors were asked to propose their own solutions. The proposals were evaluated by a committee of different stakeholders, including the University of Porto. The second tender resulted in the solution that was later implemented.

Although the inclusive process was successful, there was a conflict of interest concerning the evaluation process. The proposals were evaluated from both **engineering and architectural perspectives**, with greater emphasis on architectural aspects. According to one of the interviewees, some engineers disagreed with the greater emphasis placed on architectural aspects rather than on technical issues. They argued that mitigating risk should be prioritized over aesthetics.

Furthermore, regarding the maintenance of the sandspit, there is some **tension between risk management and biodiversity values**, as the sandspit has grown more than expected. As the sandspit is becoming increasingly stabilized, there is a risk that it will not break in future storms events when the river is flooded, creating increased risks of flooding in Porto. A channel in the sandspit may be needed so the water from the river can exit the area. According to one of the interviewees, it might meet some resistance from stakeholders working in the nature reserve, as such measures may affect ecosystems in the nature reserve negatively. It will be important to be careful when improving coastal protection, to have the least possible effect on the nature reserve.

The possible future need to open a channel in the sandspit is also linked to **public risk awareness** and communication, which one of the interviewees described as challenging. It

is difficult to communicate the risk of floods to the public, especially to generations that have not experienced it. The measures needed for coastal protection are often complex and difficult to explain and may include restrictions for building permissions or the need for infrastructural investments that may show up on the tax bill. As a result, there is a possibility that future interventions can be difficult to implement.



Figure 13 Porto (PT) demonstrator – a–c) Different angles of the sandspit d) View into the nature reserve from a birdwatching hut – public access restricted.

3.7 Summary of results from demonstrators

In this section, the findings of the different demonstrators are compiled and compared, providing an overview of the results. The section is divided into three subsections, following the order of the research questions, starting with the geographical and organizational contexts of the demonstrators. Thereafter, co-benefits delivered by the demonstrators are presented, and lastly, barriers and enablers are summarized.

3.7.1 Demonstrator context

The twelve demonstrators have different physical conditions based on their locations along the Atlantic, Mediterranean, or Baltic coasts. The tide and waves influence erosion rates, but also the development of dunes. Some demonstrators are situated close to or at a river's mouth, which further affects the coastal dynamics. Other demonstrator sites have been implemented in highly developed areas including housing and infrastructure (trams, roads). The implemented solutions are very different both in terms of size and what they protect, for example, a city, agricultural land, and housing or infrastructure adjacent to the beach. Furthermore, all countries except Sweden have a type of overarching organization at national and regional level with clear responsibility for coastal protection included were fundings should come from. However, the level of funding is different, where the Netherlands stands out with much larger budgets for these types of solutions than the other countries. In Sweden, financing is entirely the responsibility of the municipality. In most countries, responsibility is divided between assessment of coastal protection needs and implementation and management of concrete solutions. The countries have slightly different policies in relation to the coastal protection where France stand out with a national goal of planned retreat.

The solutions have been initiated by a broad range of stakeholders. In Belgium, Germany, and the Netherlands, national and regional water boards are the primary actors driving these efforts. In many cases, the waterboards initiate projects in collaboration with the local municipality or province. In France, intermunicipal authorities, such as the Communauté urbaine, have been key stakeholders in initiating the projects. For the demonstrator in Porto, the port authority, with support from the University of Porto, initiated the process of constructing a new solution. Similarly, in Ystad, Sweden, Lund university was a key actor, supporting the municipality that initiated the project. Other stakeholders that have been involved in the planning and implementation of the demonstrators include other state agencies, such as national forest authorities in the Netherlands, France and Portugal, environmental non-governmental organizations, research institutes, construction companies and residents.

3.7.2 Co-benefits included in the demonstrators

Co-benefits have been divided into categories of biodiversity, economy (including tourism), and social/cultural (including recreation) co-benefits. Most demonstrators consider more than one of these co-benefits, but only five cover all of them (table 5). However, the degree of integration of specific co-benefits in the planning and implementation process varies, ranging from being highly integrated in the project to only being integrated to a lower degree, sometimes being discovered after the demonstrator was implemented. A highly integrated co-benefit suggests – based on our evaluation – that the value has been deliberately planned for and has been delivered by the implemented demonstrator.

The most frequently mentioned co-benefit across the twelve demonstrators was recreation, which is categorized under the social/cultural category. Generally, recreational co-benefits were also integrated to a higher degree as compared to biodiversity and economic co-benefits. For some of the demonstrators, the purpose has been to preserve the existing beach, as it has been a popular spot for recreation. For example, in Ystad and Sainte-Marie-La-Mer, measures are carried out in response to erosion to ensure that the recreational area can be preserved. For other demonstrators, such as the Sand Motor, Middelkerke, and Porto, the aim has been to create more and improved space for recreation that was not there before.

Furthermore, for many demonstrators, recreation is closely linked with tourism, which was the most frequently highlighted economic co-benefit. In Sankt Peter-Ording, interviewees noted that preserving the dune landscape – rather than constructing another dike – was important for tourism, as the tourists enjoy the natural landscape. In a different way, the Hondsbossche dunes were constructed to relieve the pressure of tourism from other destinations beyond the location of the demonstrator, such as Texel Island and the area south of Hondsbossche.

Biodiversity co-benefits were planned and delivered to the highest degree for the demonstrators in Prins Hendrik Sand dike and Sankt Peter-Ording. In Prins Hendrik, the initial plan was to provide an undisturbed habitat for terns and other types of wildlife and fully restrict public access. Similarly, in Sankt Peter-Ording, enhancing biodiversity is at the core of the project. In comparison, in Dunkerque the added sand and dunes have also provided nesting areas for migratory birds, but this was not the intended aim of the project. For some demonstrators, biodiversity co-benefits have not been delivered by the solution, but the planning included considering the effects on biodiversity and potential mitigating measures, such as considering how to assist species that may experience negative effects.

Most demonstrators have in common that the co-benefits of the demonstrator have evolved over time, which also has changed the need for management. In addition, in several of the test beds, something unexpected has been created that the local community or the ones managing the sites want to preserve. In the Sand motor and Hondsbossche, lagoons

were created as a part of the way the sand nourishment was performed. The idea was that the lagoons should disappear over time. However, because these lagoons are sheltered from the large sea waves and are shallow with warmer water, they have become popular spots for surfing, swimming, and sailing. At Hondsbossche, the lagoon is therefore continuously dredged to maintain it for recreational use.

Table 5 The degree of integration of the three co-benefits categories: biodiversity, economy and social/cultural across the twelve demonstrators. The low–high scale represents our assessment of the extent to which each co-benefit was delivered and integrated at the demonstrator based on the empirical data.

	Biodiversity	Economy	Social/cultural
Ystad	–	Medium	High
Sankt Peter–Ording	High	Medium	High
Prins Hendrik Sand Dike	High	–	Low
Hondsbossche Dunes	Medium	Medium	Medium
Katwijk	Medium	High	High
Sand Motor	Medium	Low	High
Living lab Raversijde	Low	–	–
Middelkerke Grasdijk	–	Low	High
Dunkerque	Low	Medium	Medium
Soulac	–	High	–
Sainte–Marie–la–Mer	–	Medium	Medium
Porto	Medium	–	Medium

3.7.3 Barriers and enablers

Barriers and enablers have been divided into five overarching categories: space and land use; policy and legal structures; communication and knowledge; monetary and natural resources; and uncertainty and risk (see table 6). The most common themes are ‘space and land use’ and ‘communication and knowledge’. In general, across the twelve demonstrators, barriers were mentioned and elaborated on to a higher degree than enabling factors.

For most of the demonstrators, there are or have been conflicts regarding **space and land use** between coastal protection and different co-benefits. How these tensions take shape varies considerably between the different demonstrators and across co-benefits. A common conflict involves the compromise of social and cultural co-benefits when coastal protection and biodiversity are prioritized. Strengthening coastal protection and supporting biodiversity can require restricting public access, which often affects traditional land use and recreation in the area, such as in Prins Hendrik and Sankt Peter–Ording.

However, results from several of the demonstrators indicate that there are possibilities for co-benefits to co-exist with minimized conflict. The demonstrators showcase different solutions to minimize conflict, such as organizing educational activities to increase public

understanding (Sankt Peter–Ording) and opening public access to designated areas (Prins Hendrik) and focusing on biodiversity in areas away from visitor entry points (Hondsbossche). Designating areas for separate co-benefits is easier for the larger demonstrators, but also some of the smaller demonstrators manage this task, such as in Dunkerque, where fences are used to separate areas according to different uses.

Furthermore, there are also **legal structures** that influence the implementation of the demonstrators. Sweden stands out as an outsider with no or weak coordination of coastal climate adaptation as well as complex legal processes around the extraction of sand. These structures have created significant barriers for implementing sand nourishments in Ystad. Although no other country demonstrates such a high level of barrier in this category, there are some similar challenges with lack of authority also in Germany. One of the interviewees from Sankt Peter–Ording highlighted that NbS in Schleswig–Holstein do not have a clearly designated responsible authority, which stands in contrast to dikes, for which authority is clearly defined. For other demonstrators, especially in the Netherlands, it was noted that there is a challenge that many different levels of governance are involved in the same projects. The problem being that different levels of governance do often have different priorities, where some focus on dike protection and others on access to recreation and tourism goals. This will influence the prioritization of management needs.

As to the enabler of successful implementation and management of hybrid and soft coastal protection solutions, **broad stakeholder involvement** and an inclusive approach are overall seen as important factors facilitating the implementation. Although there are challenges with many different stakeholders, such as having to spend more time in the planning phase (Katwijk and Hondsbossche), it enables the development of solutions adapted to the specific characteristics of the site, both social and physical.

The results also showed that the level of **communication and knowledge** was influencing most demonstrators, both as barriers and enablers. In Dunkerque and Porto, limited public awareness of risk and coastal flooding was described as a barrier to implementing and maintaining the demonstrators. Similarly, in Ystad, a lack of knowledge of soft and hybrid solutions, especially in state agencies, was also a challenge. As previously proven solutions were prioritized, state agencies were reluctant to support sand nourishments. Another challenge for several demonstrators has been communicating different kinds of restrictions on the solutions. In Prins Hendrik, interviewees highlighted difficulties communicating with the public about restrictions on access. In Middelkerke, due to financial constraints, the implementation of the demonstrator – a grass covered dune in front of the dike (sea promenade) – prevented further regular beach nourishments, which was something the public was used to for retaining the width of the beach. Communicating the cancellation of these nourishments was difficult.

Most of the respondents argued that good communication and inclusion of all stakeholders, including those with negative opinions, are crucial for the acceptance and successful

implementation of the demonstrators. In Katwijk and Hondsbossche dunes, communication with a wide variety of stakeholders, including the public, was a key component. This meant that more time was spent in the planning phase in comparison to other demonstrators. Local inhabitants were part of the planning and had a better understanding of why this project had to be done and more incentives to be protective of the demonstrators and their benefits. At Prins Hendrik Sand Dike, the respondents realized, looking back, that communication with the public should have been organized earlier in the process as the public was critical of the decisions that had been made.

For some demonstrators, **monetary and natural resources** were factors that influenced the implementation of the solutions. For the largest demonstrators – Hondsbossche and Sand Motor – there was an initial barrier to pay for the solutions, as they were going to be very costly, and for the Hondsbossche demonstrator, also more expensive than reinforcing the existing dike. Moreover, access to sand was considered a challenge in Belgium and Sainte-Marie-la-Mer, France. In Belgium, although sand is available, interviewees noted that extraction of sand is costly, and it is important to be restrictive as sand is also needed in other sectors, such as construction. Conversely, for most demonstrators, the availability of sand acted as an enabling factor. For most demonstrators in the Netherlands, sand could be extracted close to the location of the demonstrator. Furthermore, there are also Dutch extraction sites designated for coastal protection purposes. Likewise, in Dunkerque, the harbor provides easy access to sand as it needs regular dredging, creating a win-win situation for both the harbor and those carrying out the sand nourishment.

A few demonstrators were influenced by factors categorized **under uncertainty and risks**. In Sweden and France (Dunkerque), uncertainty in relation to the effectiveness for hybrid and soft solutions was considered a barrier to the implementation of the demonstrators. In Sweden, stakeholders initially preferred the use of proven hard solutions such as rock revetments and in Dunkerque, one interviewee noted that hybrid solutions are not common in France. Furthermore, safety concerns were considered at multiple demonstrators most clearly present at the Sandmotor, where the design of the demonstrator led to strong and altered currents. Another example is in Soulac, where the coastal erosion was the most extreme in the sand cell as a total, and the national policies of retreat had not been implemented. In several of the cases there was also uncertainty in relation to how the demonstrator will behave in the future. For example, in Porto, there were concerns that the dunes had stabilized and grown too high, potentially increasing flood risks by obstructing the flow of the Douro River to the sea during heavy rainfall events. An enabling factor in managing uncertainty and risk is the use of test beds, which are important for building a knowledge base and provide opportunities for collaboration and co-learning, particularly with universities.

Table 6. Overview of barriers and enablers across the demonstrators categorized in five themes: 1) Space and Land Use, 2) Policy and Legal, 3) Communication and Knowledge, 4) Monetary and Natural Resources, 5) Uncertainty and Risks. The text in red cells provides examples of barriers, while the text in green cells provides examples of enablers. The main aim of the table is to provide an overview of which barriers and enablers themes that are mentioned, and not to provide summarize all barriers and enablers that exist within each theme. Also note that there enabler given as an example for a demonstrator do not need to be connected to the barrier, i.e, the enabler may not be the ‘solution’ for the barrier.

Demonstrator	Space & Land Use	Policy & Legal	Communication & knowledge	Monetary & Natural Resources	Uncertainty & Risks
Ystad	Recreation/aesthetic values vs. dune growth and biodiversity	Complex legal processes	Lack of knowledge, challenge to communicate legal constraints		Preference for proven solution
			Cost-benefit analyses		Learning by doing
Sankt Peter-Ording	Coastal protection vs. recreation & nature conservation	No clear authority for NbS; German forest law vs. nature values	Communication challenges with the public		
		Collaboration between stakeholders through Sandküste	Regular communication and education activities for the public		
Prins Hendrik	Recreation vs. biodiversity; saltwater seepage; sand drift		Communicate restrictions on public access		
		Community support for soft solution	Trust in governmental institutions		
Hondsbosche	Recreation vs. biodiversity	Tension between stakeholder levels; big international contractors	Initial public opinion; misinformation on social media; threats	Willingness to pay; more expensive than traditional dike	
	Separated recreational and biodiversity areas	Stakeholder meetings with broad inclusion	Risk education		
Katwijk	Increased distance to the sea	Multiple governance levels with different priorities			
	Creation of social spaces	Community participation; wide range of stakeholders; political will			
Sand motor	Coastal protection vs. recreation and nature			Water authorities only pay for safety aspects	Safety concerns
		Access to future funds		The global economy; access to sand	

Demonstrator	Space & Land Use	Policy & Legal	Communication & knowledge	Monetary & Natural Resources	Uncertainty & Risks
Living lab Raversijde			Public interest in solving issue of sand drift		
Middelkerke	Sea view (recreation/aesthetics) vs. coastal protection	Community participation; strong collaboration; clear division of responsibility	Communication with the public about future nourishments	Lack of funds for future nourishments	
Dunkerque	Recreation vs. nature conservation and coastal protection; sand drift	Government's view on coastal protection; strategy of planned retreat	Limited public awareness	Sand accessibility	Hybrid solutions not common
Soulac	Tourism vs. strategy of planned retreat	Conflicting laws	Lack of knowledge of effective coastal protection Increase of awareness due to winter storm		
Sainte-Marie-la-Mer	Recreation & economy vs. coastal & nature protection		Communication with politicians	Limited access to sand; not enough funding	Uncertainty about existing boundary conditions
Porto	Engineering vs. architecture; coastal protection vs. biodiversity	Inclusive planning and decision-making process – public participation	Lack of public risk awareness		Risk concerning how to handle the growing sandspit

4. Discussion

In this final chapter, we reflect on key factors influencing the integration of NbS in coastal flood protection of sandy coastlines in Europe, today and in the future. As the results show, all demonstrators include co-benefits to coastal protection solutions to a varying degree, especially in terms of recreational, touristic and biodiversity values. However, the planning and implementation process is complex and influenced by multiple barriers and enablers, some which are specific to the local setting, and some which are more universal. Moving along with the planning and implementation process, we highlight five key factors that need consideration when integrating NbS into coastal flood protection.

4.1 Understanding the contextual boundaries

The results showed that the demonstrators have different physical boundary conditions and are developed in different socio- and economic contexts. Research has shown that it is crucial to understand and address physical site characteristics to successfully implement NbS to combat coastal protection issues, such as erosion (Tweel et al., 2025; Yasmeen et al., 2024). The results demonstrate that many of the demonstrators have been developed in a context with a good understanding of the physical boundary conditions. In many cases, researchers have been involved; providing models and advice in relation to the design of the demonstrator. In contrast, the socio-economic context is less understood, at least when it comes to incorporating residents' experiences and needs. Although there have been efforts to identify and assess public needs for some of the demonstrators, the results suggest that further development in this area is still required and that these efforts should start as early as possible in the planning phase. This is in line with current research, which shows that the planning and implementation of major construction projects are aware of the benefits of inclusion of local communities, but struggle to apply it in practice (Maddaloni & Sabini, 2022; Støttrup et al., 2017). Developing structures and allocating time to collect stakeholders' needs and interests should therefore be prioritized to ensure the effective implementation of NbS for coastal protection.

The historical experiences and storylines of critical coastal events also influence the development of coastal NbS. Although the geographical distance is short between the demonstrators in Germany, the Netherlands, Belgium and northern France, each country has a distinct relationship with the sea, shaped by its history and culture. Landscapes also carry historical legacies, which can create path dependencies when creating new solutions for coastal protection (Tappeiner et al., 2021). The polder system, especially in the Netherlands, reflects a long-established tradition of engineered coastal protection that continues to influence expectations about robust, structural measures. In Belgium, where there are residences close to the beach, maintaining an unobstructed sea view is seen as essential when planning future coastal protection. Both examples illustrate a path dependency to traditional solutions, creating barriers for the implementation of soft and hybrid solutions.

Furthermore, coastal hazards, such as storm surges, continuously shape and re-shape coastal protection (Jordan et al., 2023). Recent events such as the storm 2014 in France and the demolition of the Signal house in Soulac can be interpreted as the start of a new coastal protection era in France – planned retreat is now the main climate adaptation strategy.

Another boundary condition that needs to be considered and fully understood is the existing organizational structure. The results show that, in many of the DuneFront countries, NbS fall under the responsibility of multiple authorities. Currently, there is lack of organizational structure that fully supports new types of coastal protection measures that incorporate a wider range of values. This stands in contrast to traditional hard coastal protection measures, where in countries such as Germany and the Netherlands, a single authority has historically been responsible. Understanding, and handling these organizational boundary conditions, will be important in plans intending to mainstream NbS in coastal protection (see section 4.5).

These contexts, specific to each country, and sometimes to each site, have shaped the political landscape and affected the political will. Several interviewees highlighted the importance of political will for the initiation of the planning for hybrid solutions. In most countries, due to the relatively complex organizational structure of coastal protection, political will and organizational and policy structures must be aligned across multiple levels of governance. This is in line with previous research that emphasizes the need for strong political support for the implementation of NbS (Duvat et al., 2025). As indicated above, many of the demonstrators could be interpreted as a departure from established path dependencies, which could explain the need for increased political support. However, it can also be argued that the additional co-benefits of NbS, compared to hard infrastructure, could generate interest across a broader range of political sectors. This may lead to stronger incentives to implement them. On the other hand, as additional co-benefits invite more stakeholders to the table, this can contribute to more conflicts.

4.2 Securing capital and access to sand

Many forms of capital are required – and high levels of each – for the implementation of soft and hybrid solutions. Human capital – the competences working with coastal protection – is a central factor for the implementation of NbS and looks very different across the demonstrators. Human capital is important both for the initiation and the maintenance of these solutions. One of the biggest sources of human capital is the waterboards in the Netherlands. The waterboards consist of many professionals that have vast knowledge and expertise in coastal protection, both hard, soft, and hybrid. Additionally, individual champions play an important role in advocating soft and hybrid solutions, both within large organizations such as waterboards, but also within smaller municipalities, such as Ystad. It is also common that universities and research institutes have been involved in projects, particularly engineering departments. In these cases, modelling results have been a key factor to predict the behavior of the demonstrator, as well as risk reduction potential,

which is in line with previous research (Boulenger et al., 2024). Furthermore, close engagement with academia seems to have been crucial for the implementation of some of the solutions as it transfers knowledge from research to society. The close relationship with universities has also facilitated evaluation of the demonstrators, which is important for future upscaling.

In addition to human capital, access to financial capital is critical for the implementation of soft and hybrid solutions. The results indicate that, in several cases, the demonstrators were perceived as more costly to implement and maintain than traditional, hard protection measures. Actual costs also tended to exceed initial estimates, which is not unusual for construction projects, but nevertheless highlights the need to understand the complexity of the cost and values. A key challenge is that the long-term effectiveness of soft and hybrid solutions is more difficult to assess, making cost–benefit analyses more complex compared to conventional engineering structures (Morris et al., 2018). Benefits such as biodiversity enhancement and recreational value are inherently harder to quantify, and Morris et al. (2018) notes that there is a lack of standardized methods for evaluating their performance. Furthermore, both biodiversity and recreational value may extend beyond the local site, for example by enhancing ecological connectivity with existing areas of biodiversity concern, as intended in Katwijk. However, standardization itself is complicated, given the diversity of nature-based approaches. These solutions can require higher investments, but they are also expected to generate more value over time, for example through increased tourism and related local business activities, as well as the softer values that are harder to measure. However, when public funds are involved, the justification of expenditure remains a central concern.

The availability and access to financial capital vary widely across the demonstrators and countries. Most NbS are publicly funded (Moraes et al., 2022), which is also the case for the DuneFront demonstrators. In the Netherlands, the Sand Motor and Hondsbossche have been enabled through capitals provided by the regional water authority tax for water management, whereas in Sweden, the beach nourishment of Ystad has been funded by the municipal tax money. The differences in available funding between these projects are substantial. At the Sand Motor, one challenge was that the state only funds the actual coastal protection, not the additional benefits associated with the project. Moraes et al. (2022) highlight that across Europe, funding for NbS rarely comes from a single source. This makes financing more complex, as resources need to be divided among multiple stakeholders. It tends to separate the protection function from potential co-benefits, which can be interpreted as working in silos, which makes it harder to integrate different values effectively.

Following human and financial capital, a further component is availability and access to sand, which varies widely across the demonstrators and countries: some demonstrators have reliable supplies and fast permission processes, while others struggle with scarcity,

costs, or complicated, lengthy approval procedures. Sand is not only needed for coastal protection, but also for other purposes, such as construction. Although there are measures to minimize the impact on aquatic ecosystems, offshore extraction of sand is still a problematic activity affecting aquatic ecosystems. There are also other impacts, ranging from disrupting natural geological processes to threatening human health, showing that the extraction of sand is a controversial issue (Kim & Yoo, 2020; Rangel-Buitrago et al., 2023). The growing demand for sand for beach nourishments inevitably reinforces these concerns, raising questions about whether more circular or sustainable sediment practices could be developed. While beach nourishment is framed as a NbS, it still relies on resource-intensive extraction, which often contradicts ecological sustainability.

4.3 Managing conflicting needs

A democratic society comes with the recognition that there are different opinions and needs within society, which must be considered and handled. The study demonstrates that this issue has been dealt with differently within the different demonstrators. While most of the respondents mention citizens' voice in relation to either the planning or the phase implementation of the demonstrator, few have had a structured methodology for stakeholder engagement. Two cases that stand out are Katwijk and Hornsbosche, where stakeholder meetings were arranged to either gain stakeholders' perspectives in the planning and design phase, or to raise awareness and knowledge among initially concerned and reluctant stakeholders. For the other demonstrators, citizens were mentioned, either as initiators, as for the sand drift in Middelkerke, or as faultfinders during the implementation phase, as in Prins Hendrik where negative voices were raised in relation to the restricted access to a locally used beach adjacent to the demonstrator.

As the demonstrator has been developed in six different countries – all with different legal regulations, norms and traditions – influencing stakeholder interactions, and as future coastal NbS solutions will be developed within even more countries, a general blueprint about stakeholder interactions is therefore not possible or not even desirable. However, as stakeholder involvement is a central part of the NbS concept (Hanson et al., 2020; IUCN, 2020), it means that stakeholders are supposed to be involved in the development of such solutions. Defining the structure and process for such interactions is therefore essential. If not, there is a risk that stakeholder engagement will be ad hoc, or that cherry picking will exist in relation to who is included and who is not, which in turn may lead to disappointment, conflicts or lack of interest in the solution. A thoughtful and structured stakeholder approach also increases the chances that the implemented solution will be recognized as credible, salient and legitimate (Cash et al., 2003). Such an approach must provide the public with information about the problem, different solutions, and their potential effects, and integrate perceptions and expectations of local communities into the planning process (Lucrezi et al., 2016). In return, local inhabitants could reveal knowledge gaps and misunderstandings, as well as contribute with a unique perspective, which

decision-makers and external stakeholders may not fully understand or grasp (Sauer et al., 2022; Van Well et al., 2023), hence assisting in creating legitimacy for the planning and management (Bar et al., 2016).

Furthermore, a lack of a structured stakeholder approach may also lead to environmental justice issues which in practice mean that some stakeholder interests are favored in relation to other stakeholders' interests (Walker, 2012). By not having a structure of how to identify and include different groups of stakeholders (procedural injustice) there is a risk that some stakeholders' stake and knowledge is not recognized in the planning process (recognitional injustice). This, in combination with inadequate assessments and mapping of both negative and positive environmental issues, such as flood risk and e.g., beach access, may lead to the fact that some parts of society are disproportionally affected by negative consequences (distributional injustice), for example reduced beach access due to the implementation of protected dune vegetation. Environmental justice was not a theme highlighted by the respondents, but it is easy to foresee that it may become an increasing issue in the future, when more areas will be affected by climate change and need for protection (Jevrejeva et al., 2016; Ranasinghe, 2016; Vousdoukas et al., 2018). However, in the longer term, this will most likely not be about access to the coastline, but rather about which stakeholders will be protected by flooding, and who will not.

Another conflict can be discerned between national governance and local needs of coastal protection. In the Netherlands, Belgium and France, there are governance structures managing the relation between national policy goals and local needs. This is lacking in Sweden where the responsibility of coastal protection lies in the hand of the municipality. In practice this means that the national politics not involved in local protection could lead to a situation where municipalities with political will and money could invest in protection measures, whereas poorer municipalities may not have that possibility, which even could be interpreted as an unplanned retreat. In France this conflict plays out in a different way where the national politics of planned retreat is not adapted to the polder areas around Dunkerque. If such politics is implemented it could induce the need for mass relocation of inhabitants.

4.4 Responding to changing systems

Evolution is a central biological concept and conceptualizes to a high degree the destiny of demonstrators. Most of the demonstrators are nourished by sand and without such material, there would be no, or limited possibilities to conserve or develop beaches and dune landscapes. However, the sand is deemed to sooner or later disappear or move to another location due to erosion, and the solution will then evolve into something else, or be repeatedly nourished. Even though beach nourishment is a prerequisite for keeping and developing beaches and dune landscapes it can have negative impacts as it can cause extensive changes to beach sediment structure, and hence habitat suitability (Fegley et al., 2020; Peterson et al., 2014). The response of sand nourishment is species specific, and

studies demonstrate that while some species recover relatively quickly, others did not recover over the monitoring period (Fegley et al., 2020; Leewis et al., 2012). Within the study, few respondents reasoned on the negative impacts of beach nourishment for biodiversity – and if so, it was mainly related to potential negative impacts on the marine ecosystem at the off-sea sand pits.

The evolution of the demonstrators does not only alter the conditions for biodiversity along the coastline but may also influence the value of the coast for people. Initial values may disappear, and others unexpected may develop as there will always exist uncertainties in relation to how people will behave, and how human life will be affected – something that cannot be predicted by models. One illustrating example is the Sand Motor, where the design initially boosted specific activities and businesses (surfing), which, later due to the evolution of the demonstrator, decreased. Improved beaches and dune landscapes may also affect coastal communities in the surroundings of the demonstrator as it could make the area more attractive for visitors and hence increase tourism. This can be seen as a positive development, meaning that the solution provides economic co-benefits, but there is also a downside to it, as it can have negative impacts on some parts of the community. For example, in Middlekerke house prices have doubled after the implementation of the grass dike and new walking paths. Such price increases could lead to gentrification processes, where the original population is replaced by more affluent ones, due to increased housing prices (Lees et al., 2013). Gentrification was not brought up as an issue by the respondents, but it is a well-recognized global phenomenon that higher-spending tourism-led investments dictates the property market for settlements in scenic coastal locations (Di Matteo & Guadagno, 2025; Freeman & Cheyne, 2008).

Managing and communicating the transience nature of the demonstrator, in combination with the risk of extreme events, is a complicated task. Even if there might be models as well as scenarios forecasting future floods, it might be difficult to raise public awareness, as most of the population has not experienced any major flood events in their lifetime. This relates to a lack of collective memory; i.e., memories above the individual level that stores experiences of living pasts and influence behavior of societies and groups living today (Coser, 1992; Edwards & Middleton, 1990; Gongaware, 2003). Communicating these issues to the public, including why they happen, can be challenging for the people responsible, which leads us back to the importance of having a structured stakeholder approach already in the beginning of the project to gain credibility, saliency and legitimacy for the project (Cash et al., 2003).

One way to manage biological systems in the presence of uncertainty, is to apply adaptive management. This approach not only uses management as a tool to change the system but also incorporates learning as a key factor, based on the assumption that improved understanding of the system enables the design of more effective interventions to meet management objectives (Gunderson & Holling, 2002; Walters & Holling, 1990). This stepwise,

structured process of learning and adaptation—often illustrated as a feedback loop—typically includes several stages: goal setting and design, implementation, monitoring, and evaluation (Månsson et al., 2023; Williams & Brown, 2014). However, several challenges can hinder the successful application of adaptive management. These include the costs associated with extensive monitoring and evaluation programs, institutional barriers, and the capacity and conflicting priorities of different stakeholders (McLain & Lee, 1996; Mickwitz & Birnbaum, 2009; Månsson et al., 2023; Walters, 1997).

4.5 Mainstreaming testbeds

Mainstreaming is the last key factor for the uptake of soft and hybrid coastal solutions in coastal flood protection. However, an important question to ask is what should be mainstreamed, and how to do it (Scott et al., 2022). Most of the demonstrators studied can be seen as testbeds, or at least a solution that so far has only been implemented once. Testbeds create opportunities for learning by doing and can be inspiring for others, but it is not a blueprint that can be directly copied to a new location. To be able to mainstream NbS for coastal protection it is important to avoid a flagship label – where only the more successful parts (results) are presented and communicated.

Mainstreaming can be seen from different perspectives. One perspective in relation to coastal NbS is how the demonstrators align to the core ideas of the NbS concept. As there are different definitions of the NbS concept (Cohen-Shacham et al., 2016; European Commission: Directorate-General for & Innovation, 2015; UNEP, 2022), there are also different interpretations, however, using the lens as developed by Hanson et al. (2020), three core ideas need to be present: using nature to solve societal problems, delivering co-benefits and stakeholder involvements. It can always be debated what nature is, and is not, but when aligning with the definition according to the European Commission, all twelve demonstrators can be classified as nature based as they include sand and vegetation. It is also clear that all demonstrators deliver co-benefits, even though the numbers and degrees differ. What needs to be considered is how to balance conflicting needs and trade-offs between different co-benefits – when and how is it possible to combine recreation and biodiversity without having a negative impact on the other? For the last core idea, stakeholder interactions, not all demonstrated have covered this idea, or at least it varies substantially how they have worked with stakeholders. Therefore, it is important to highlight this core idea in new coastal NbS projects, meaning that more efforts must be spent on stakeholder interactions and co-creation processes.

Mainstreaming can also be viewed through the lens of overcoming the implementation barriers identified in the study. Some barriers are site- or country-specific, meaning that solutions may not be transferable to other locations, while others may be more broadly applicable (Hölscher et al., 2023; McPhearson et al., 2025; Wickenberg et al., 2021). This raises the question of how knowledge can be effectively shared across different geographical areas. A key factor is understanding the varying boundary conditions—

physical, geographical, societal, and regulatory—as these will strongly influence the outcomes. When such conditions are similar, replicating a solution in a new context becomes significantly more feasible.

Moreover, results are not always easily transferable between large-scale and small-scale projects, particularly when budgets and resource availability differ. The complexity increases further when multiple co-benefits are involved. Another important and related aspect is the need to break down the learning process into smaller components rather than sharing all information about a project at once. This requires asking: What has been learned, by whom, and why—and who needs this information?

5. Conclusion

The study demonstrates that Dune–Dike hybrid NbS can deliver additional co-benefits beyond their primary function of coastal protection mainly in terms of recreation, tourism and biodiversity co-benefits. At many demonstrators, multiple co-benefits were delivered. The planning and implementation of the 12 demonstrators were influenced by various barriers and enabling factors. Overall, the results show that more barriers than enablers were identified. At nearly all demonstrators, there were tensions between different co-benefits, such as between conserving biodiversity and space for recreation. There were also barriers related to the structure of coastal protection work and the question of authority. While working across multiple governance levels was sometimes considered difficult, the most significant enabling factor was an inclusive and structured planning process with broad stakeholder involvement as this facilitates trust and acceptance. Communication – both across governance levels and with the public – was another key theme, with investment in communication identified as an important enabler. Additional barriers and enablers were noted in relation to financing, natural resources, risk and uncertainty.

To improve the integration of multifunctional Dune–Dike hybrid NbS in planning and implementation process of coastal protection, five key factors should be addressed. (1) improve the understanding of the boundary conditions, (2) secure capital and sand, (3) manage conflicting needs, (4) respond to changing systems and lastly, (5) mainstream testbeds. This will not be an easy task, but it is needed if DD-hybrid NbS should be a significant part of coastal protection of sandy coasts in the future.

6. Annex

Table A.1. The interview guide used for the interviews covering questions in relation to demonstrator design and context, stakeholders, co-benefits, and enablers and barriers

Demonstrator design and context
<i>If necessary: History, how long have you been involved?</i>
1. Can you briefly describe the area? Can you describe what the coastal protection measure looks like? What is included in the coastal protection?
2. What is protected?
3. Why this type of protection?
Stakeholders
4. Can you give examples of who else has been involved in coastal protection work? Who are the stakeholders in the project?
Co-benefits
5. Has the project contributed with any other values than those expected?
6. Have you experienced any tensions between different values?
Enablers/barriers
7. What are the main challenges you have come across in your work with the coastal protection?
8. How have you addressed these challenges?
9. Could you describe the process that led to the implementation of the NbS?
10. How has the public perceived the work on coastal protection?
11. Have you had any strategies for communication with the public? How?
Stakeholders (in dept)
12. During the project, have there been any conflicts of interest between stakeholders?
Conclusion
13. In conclusion, what have been the main drivers for the implementation of coastal protection?
14. Looking forward, how do you think the coastal protection will develop over time?

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