Politecnico di Torino

Master's degree programme in

Territorial, Urban, Environmental and Landscape Planning

Curriculum: Urban and Regional Planning

Master Thesis

Coastal Nature-based Solution: a proposal for the Italian context starting from the Danish case study.

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Academic Year 2023/2024

Project title:

Coastal Nature-based Solution: a proposal for the Italian context starting from the Danish case study

Keywords:

Coastal Nature-based Solution, Climate Change, Adaptation, Mitigation, Up-Scaling, Territorial Resilience

Curriculum:

Urban and Regional Planning

Study program:

Territorial, Urban, Environmental and Landscape Planning

Planning for the Global Urban agenda,

Politecnico di Torino

Project and project duration:

Master Thesis (MSc), July 2023 – July 2024

Number of pages:

93 pages from the introduction to the conclusions,

122 total pages.

End date:

Uploaded July the 15th, 2024

Thesis development:

This Research Thesis has been developed in the frame of an internship at **UNESCO Chair on Urban Resilience**, at the Civil and Architectural Engineering University of Southern Denmark (SDU), Department of Technology and Innovation. Under the supervision of prof. Nicola Tollin, prof. Alberto Innocenti and prof. Ombretta Caldarice, **Politecnico di Torino**.

''We have to wake up to the fierce urgency of the now.''

Jim Yong Kim

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Acknowledgements

There are several people I would like to thank in connection with my research Thesis.

Firstly, I would like to thank my supervisor Ombretta Caldarice for always being so professional, for always positively supporting my ideas and for believing in me throughout the whole writing process.

I would like to thank my co-supervisors Nicola Tollin and Alberto Innocenti for their constructive criticism and for always being available to discuss my ideas and progress. Nature-based Solution surely are a great and compelling topic.

I would also like to thank the UNESCO Chair on Urban Resilience research group of the University of Southern Denmark (SDU) for the internship experience and for my personal and professional growth. I am grateful to have had the chance to meet you.

A special thanks goes to my friends that have been there, and always backed me up when I was in need thank you Francesco, Riccardo, Alessandro,
Paola, Tommaso, Letizia, Maria Chiara, Daniele, Nico e Michi.

Finally, and not for importance, I would like to express my profound gratitude to my family for an unconditional support and love along this journey, for your patience and your understanding.

Thank you all for your support and for being part of this important chapter in my life.

Abstract

In Europe, **coastal areas** are among the most affected and exposed places to **climate change**. Coastal areas stretch over the first 50 km of the coast (from the sea towards the inland), they cover about 13% of Europe's land surface and are home to approximately 41% of the entire European Union population (Eurostat 2011). Besides being densely populated, these areas do also accommodate numerous economic activities (e.g., touristic, agricultural, industrial, or commercial activities) and are *''dynamic environmental and socioeconomic systems that provide services including wildlife habitat, erosion and flooding protection, and economic and recreational activities''* (Pantusa et., al., 2022). However, starting from the 1900s onwards, **climate change and growing anthropic pressures have significantly altered the natural balance in coastal areas, whose vulnerability and exposure to climate threats have increased since then.**

Coastal Nature-based Solutions (Coastal NbS) are design elements of paramount importance, needed to tackle the negative side-effects of climate change on coastal areas. In fact, these solutions are able to **enhance territorial resilience, they support processes of climate mitigation and of climate adaptation, they provide different types of socio-economic and environmental benefits, they preserve cultural and aesthetic values in coastal areas, having at the same time a holistic and sustainable approach.** However, despite being great alternatives to traditional Grey coastal protection Solutions (based on hard engineering approaches that are often inadequate to counter the unpredictable and dynamic consequences of climate change), research on- and large-scale implementation of Coastal NbS is still limited.

To support and encourage a broader implementation of Coastal NbS along vulnerable coastal environments, this thesis studies how these solutions are adopted and implemented in successful climate adaptation and climate mitigation projects. Denmark is an excellent starting point for this study, on the one hand because the country is a European front-runner in this field, on the other hand because its geo-morphological configuration (flat and with soft coasts) increases its overall exposure to storm surges, sea level rise, coastal erosion, and flooding. Finally, based on the insights gained from studying the Danish case, **the thesis attempts to transfer successful elements and solutions from the Danish case to the Italian coastal context**, similarly exposed to climate change.

Keywords

Coastal Nature-based Solution, Climate Change, Adaptation, Mitigation, Up-Scaling, Territorial Resilience.

Abstract (Italiano)

In Europa, tra le aree più affette ed esposte al **cambiamento climatico** troviamo le **zone costiere**. Le zone costiere si estendono per i primi 50km di costa (tra mare ed entroterra), occupando circa il 13% delle superfici emerse Europee ed ospitando approssimativamente il 41% della sua intera popolazione (Eurostat 2011). Oltre ad essere densamente popolate, queste zone accolgono innumerevoli attività economiche (es. turistiche, agricole, industriali, commerciali) e sono *''sistemi ambientali e socio-economici dinamici, che offrono servizi indispensabili quali habitat selvatici, protezione dall'erosione e dagli allagamenti, e servizi di carattere economico e/o ricreativo''* (Pantusa et., al., 2022). Tuttavia, degli inizi del 1900 **il cambiamento climatico e le crescenti pressioni antropiche hanno fortemente alterato gli equilibri naturali delle zone costiere, ora sempre più vulnerabili ed esposte agli effetti del cambiamento climatico.**

Coastal Nature-based Solutions (Soluzioni per la Costa basate sulla Natura) sono elementi di design fondamentali per contrastare gli effetti negativi che il cambiamento climatico esercita sulle Zone Costiere. Queste Soluzioni **migliorano la resilienza territoriale, supportano processi di adattamento e mitigazione al cambiamento climatico, apportano benefici di tipo socio-economico ed ambientale, proteggono assetti culturali ed estetici avendo al contempo un approccio sostenibile e olistico in materia.** Tuttavia, pur qualificandosi come eccellenti alternative alle tradizionali Soluzioni di protezione costiera Grigie (basate su un approccio ingegneristico duro, difficilmente in grado di contrastare le conseguenze imprevedibili e dinamiche del cambiamento climatico), la ricerca e l'implementazione su ampia scala di Coastal NbS risulta limitata.

Al fine di facilitare ed incentivare una maggiore implementazione di Coastal NbS in contesi costieri vulnerabili, la tesi ricerca come queste vengono implementate in progetti di grande successo di Adattamento e Mitigazione al cambiamento climatico. Come punto di partenza abbiamo optato per la Danimarca, leader Europeo del settore e particolarmente esposta alle conseguenze del cambiamento climatico per la sua conformazione geo-morfologica (pianeggiante e con coste morbide) che ne aumenta l'esposizione a mareggiate, all'innalzamento del mare, a fenomeni di erosione costiera e alle inondazioni. Infine, sulla base delle nozioni acquisite dallo studio del caso danese, la tesi tenta di **trasferire elementi e soluzioni di successo dal caso danese al caso costiero italiano**, similmente esposto al cambiamento climatico.

List of figures and tables

List of abbreviations

CBD	Convention on Biological Diversity
CC	Climate Change
CCA	Climate Change Adaptation
COP	Conference of the parties
DCA	Danish Coastal Authority
DRR	Disaster Risk Reduction
EBA	Ecosystem-based Approach
EC	European Commission
EEA	European Environment Agency
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
IUNC	International Union for Conservation of Nature
NBS	Nature-based Solution
PNACC	Piano Nazionale di Adattamento ai Cambiamenti Climatici
SLR	Sea Level Rise
SNACC	Strategia Nazionale di Adattamento ai Cambiamenti Climatici
UN	United Nations
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Programme

UNGC	United Nation Global Compact
WB	World Bank

1. Introduction

To better understand what ***Coastal Nature-based Solutions*** (Coastal NbS) are, and to acknowledge why their implementation at national level becomes so ***relevant to tackle the shift of climate***, it is first important to understand why climate change itself represents a big threat for the current and the future generations. Once this is clear, the Thesis will deepen the concepts of ***territorial resilience***, ***climate adaptation*** and ***climate mitigation*** as key approaches adopted by Coastal NbS to reduce or avoid the negative effects of climate change on both the natural and on the socio-economic sphere.

1.1. Climate change, a global threat

The phenomenon of ***climate change*** is referred to as a ***long-term shift in temperature patterns and weather patterns*** across the globe. These shifts are generally set in motion by natural events (e.g. sun's activity, large volcano eruptions) and therefore are defined as ***natural shifts*** of climate. However, from the 1800s onwards, the natural shift of climate has been altered and accelerated by side effects of human activities (e.g. fossil fuel combustion) which gave birth to a new model of climate shift referred to as ***anthropogenic shift*** of climate.

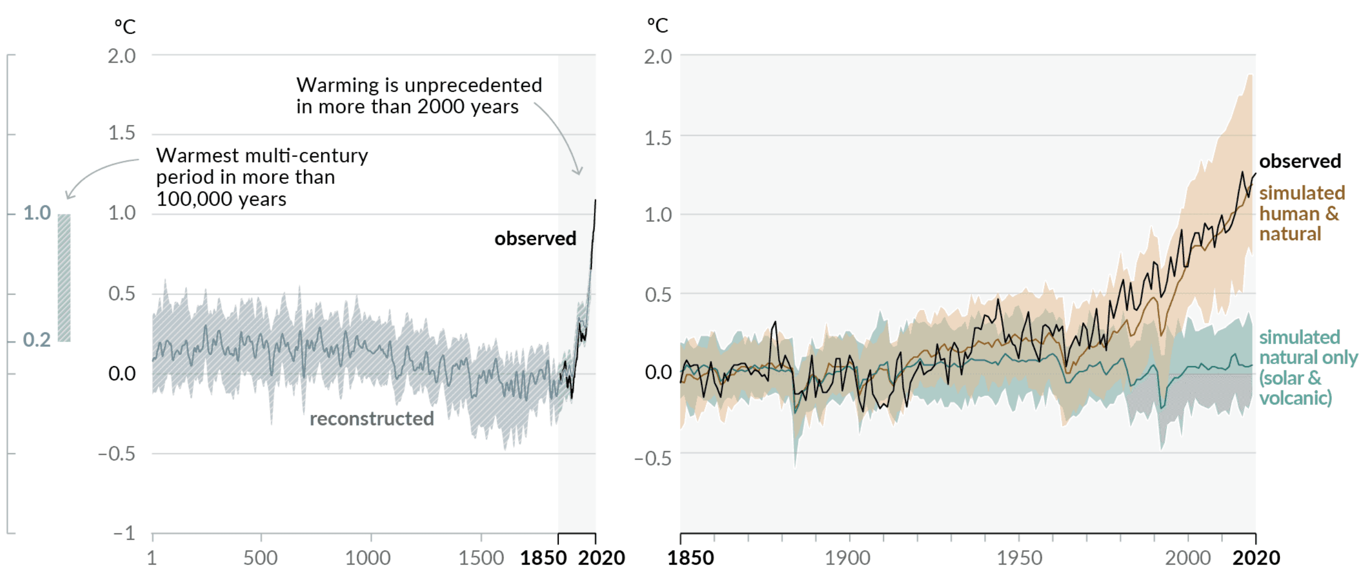

Fig. 1. History of global temperature change and causes of recent warming. Credit: Summary for Policymakers.1 in IPCC 2021, pg.6

As highlighted in the Intergovernmental Panel on Climate Change, *'human activities, principally through **emissions of greenhouse gases*** (e.g. carbon dioxide and methane)*, **have unequivocally caused global warming**, with global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020'* (IPCC, 2023).

This trend of increasing global temperatures ***presents drastic, undeniable, and negative effects to both the global environments and on the overall human well-being*** (Preti et., al., 2022). For instance, one negative side effect of climate change is the increasing frequency of extreme weather events occurred over the last two centuries, reaching from heat waves to heavy precipitation, river floods, windstorms, droughts, forest fires, storm surges, or slow onset events (e.g. coastal erosion) and more (EEA Report, 2021).

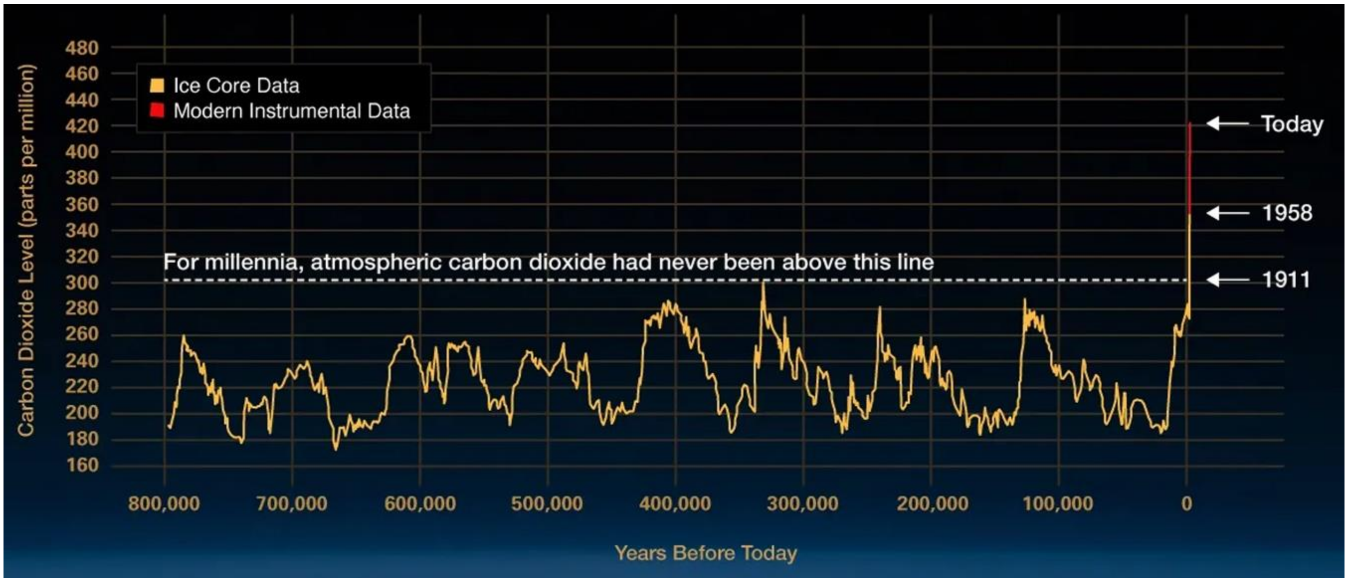

Fig. 2. History of atmospheric carbon dioxide levels. Credit: Luthi D., et al., 2008; Etheridge, D.M., et al. 2010; Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO2 record. Data from: climate.nasa.gov/evidence/

It is however crucial to underline that, ***beside the urgent need to cut further greenhouse gas*** (GHG) ***emissions*** to avoid worst negative climate impacts in the future, the amounts of already emitted GHG will take time to be reabsorbed by the planet, and therefore ***other measures are required and must be adopted to ensure the safety of the current and the future generations***. Worldwide scientists have gathered to find new solutions, and ***Nature-based Solutions turned out to be of outstanding efficiency in the fight against climate change*** (see chapter 2).

1.2. The vulnerability of coastal areas

Climate change is a global phenomenon, but among the many vulnerable areas across the globe to directly suffer under its consequences, ***coastal areas*** (and especially coastal areas in Europe) are particularly affected. In Europe, coastal areas are overall densely populated, highly developed and rich in natural habitats which makes them extremely exposed to the ***rising sea levels***, to the increasing frequency and intensity of ***extreme weather events*** (e.g. storms or storm surges) and to the consequent ***coastal erosion*** and ***coastal floodings dynamics*** (EEA Report, 2021) considering the significant economic damages which they can experience**.**

Besides being the ***largest maritime region in the world*** with its approximately 68.000 km of coastline (EEA Report, 2021), the EU's coastal areas are also densely populated, host important economic activities and are characterized by unique natural environments. According to EUROSTAT data, in 2011 about ***41% of the entire European Union's population lived*** concentrated in urban settlements located ***less than 50 km away from the sea*** (Eurostat, 2011), counting a ***coastal infrastructure value worth between 500 and 1000 billion Euros alone,*** and ***generating about 30% of the entire European Union's GDP*** (Boteler et., al., 2014). Currently, up to ***10.000 people are annually flooded in the EU, causing an average damage of 1.9 billion Euros***, and scientific evidence suggest that up to other ***425.000 additional people might be affected by coastal floodings by 2080***, with an expected ***annual damage as high as 25.4 billion Euros*** (McKenna et., al., 2016). The protection of coastal areas becomes therefore important to safeguard both the vulnerable population, but also to protect the whole economic asset built upon these territories. Finally, another key element which makes the defense of coastal areas of high importance, is ***biodiversity***. According to Copernicus, Europe's coastal areas host tens of thousands of different plant and animal species which rely on ***unique coastal ecosystems*** (e.g. inland or salt marshes and intertidal flats), ***vital to the health of global oceans*** but at risk of getting lost under the effects of climate change.

Historically, vulnerable coastal areas in Europe have been artificially protected following what in this Thesis is referred to as ***hard engineering strategies*** (Edexcel, 2024). Hard engineered coastal defense systems are physical elements (e.g. seawalls, dikes, groynes, breakwaters or levees) implemented to protect the coastline from erosion or floodings and seek to offer an immediate counteraction to a given predicted scenario (expected to have impacts within historical range). Solutions of this kind rely on hard structural elements often made of non-renewable materials which on the long run can create environmental degradation and disrupt natural habitats, and typically involve high construction and high maintenance costs. However, as climate change leads to more frequent and intense weather events with outcomes far beyond the historical registered ranges, hard engineered solutions often become obsolete and unable to cope with evolving climate challenges calling for constant repairments or reinforcements which further weight on the maintenance costs of these protections.

A different approach which has developed and has gained global attention over the last few decades is the ***Nature-based approach,*** further developed in the next chapter (chapter 2). Coastal Nature-based Solutions specifically focus on addressing climate challenges related to coastal areas (e.g. erosion, flooding, and habitat loss) by using natural processes and elements to enhance the resilience of coastal ecosystems and coastal communities, via climate mitigation and climate adaptation processes. Coastal Nature-based Solutions can either wholly rely on natural features (and are referred to as ***soft NbS*** in this Thesis) or rely on a mix of hard engineered and natural features (referred to as ***hybrid NbS*** in this Thesis) and, differently than hard solutions, these can offer multiple co-benefits both to the socio-economic sphere and the natural sphere.

While hard engineered solutions remain necessary in certain contexts, Coastal NbS offer a holistic strategy that integrates environmental, economic, and social benefits, making them an attractive alternative for enhancing coastal resilience against the impacts of climate change.

1.3. The problem of the Italian coastline

Inside the European Union, Italy is among the countries with more kilometers of coastline, and counts approxximately 7.500km of shoreline. These are classified according to their geologic and morphologic characters into: (i) ***high coasts***, elevated rocky coasts with articulated and jagged shapes and (ii) ***low coasts***, often wide and low-lying sandy or rocky coasts (ISPRA, 2011). Coastal areas are dynamic environments naturally shaped by the interaction between wind, sea and coast, and together influence the natural flow of sediments through coastal erosion and coastal accretion processes. Historically speaking, these two processes have always been in balance in Italy, but starting from the 1960s onwards, a significant increase of erosion dynamics over accretion dynamics has been registred, affecting espetially sandy low-beaches (Regina, 2024) which represent more than 50% of Italy's national beaches (aproxximately 4.700km) (ISPRA, 2011).

The causes to this immediate and ongoing change are many, and combine natural and anthropic interrelated factors. On the one hand, from the 1960s onwards human activities (including urbanization, industrial development, and tourism) experienced a massively expansion along the Italian coastal areas, significantly compromising natural coastal defense systems like wetlands and dunes (originally functioning as buffer areas against erosion). On the other hand, climate change influences sea level rise and increases the frequency and intensity of extreme weather event (e.g. storm surges, heavy rainfalls and coastal floodings), which also result in an overall higher vulnerability of the sandy shorelines to coastal erosion dynamics.

Besides the significant environmental threats set by climate change, Italy's coastal regions are also densely clustered with human settlements, agricultural and touristic activities and extensive infrastructures

(Legambiente, 2023). Nevertheless, the political framework governing coastal management in Italy is characterized by fragmentation and overlapping jurisdictions among national, regional, and local authorities which do not approach climate threats in a holistic way, and this complexity hinders the implementation of cohesive and effective national climate adaptation strategies. The Italian government's efforts, including the National Adaptation Plan for Climate Change (PNACC) adopted on the 21st of December 2023, aim to address these vulnerabilities through integrated coastal zone management and green solutions, but a traditional reliance on hard engineering solutions is often prefered over innovative solutions (in depth analyzed in chapter 4).

Coastal Nature-based Solutions do represent great alternative to traditional coastal protection measures but are not yet properly explored and developed in Italy (with the exclusion of a few case studies). Therefore, this Thesis wants go give a better insight on the topic, grounded on an analysis of Danish Coastal NbS since Denmark is one of the European frontrunners in the coastal protection field. The final goal is to be able to encentivize an up-scale or transfer of effective case studies to the Italian context, and support the development of a national territorial resilence to Climate Change threats.

1.4. Denmark as starting point

Denmark is a great starting point for the Thesis since the country is a ***European front-runner in the coastal protection field*** due to its national low-lying morphology, which for centuries has been threatened by the sea. According to the Danish Ministry of the Environment, the construction of the first coastal defenses can be traced down to around 1000 A.D., as farmers begun to protect their agricultural land from coastal floods with large soil banks (Miljøministeriet, 2024). Today, approximately 1800km of the entire Danish shoreline (about 8700km long) is protected, and host major hard engineered infrastructures as defense systems (Danish Ministry of the Environment, 2005).

However, the overall ***progressive sea level rise*** which could increase to up-to 1m in height compared to the current scenario (Fig. 3), combined with ***chronic coastal erosion*** dynamics in the northern Jutland as well as in the central west coasts (Pranzini et., al., 2013) and the continuous threat of ***more frequent and intense extreme weather events led Denmark to experiment*** with new coastal protection systems, more likely to cope and withstand current and future coastal threats: ***Coastal Nature-based Solutions***.

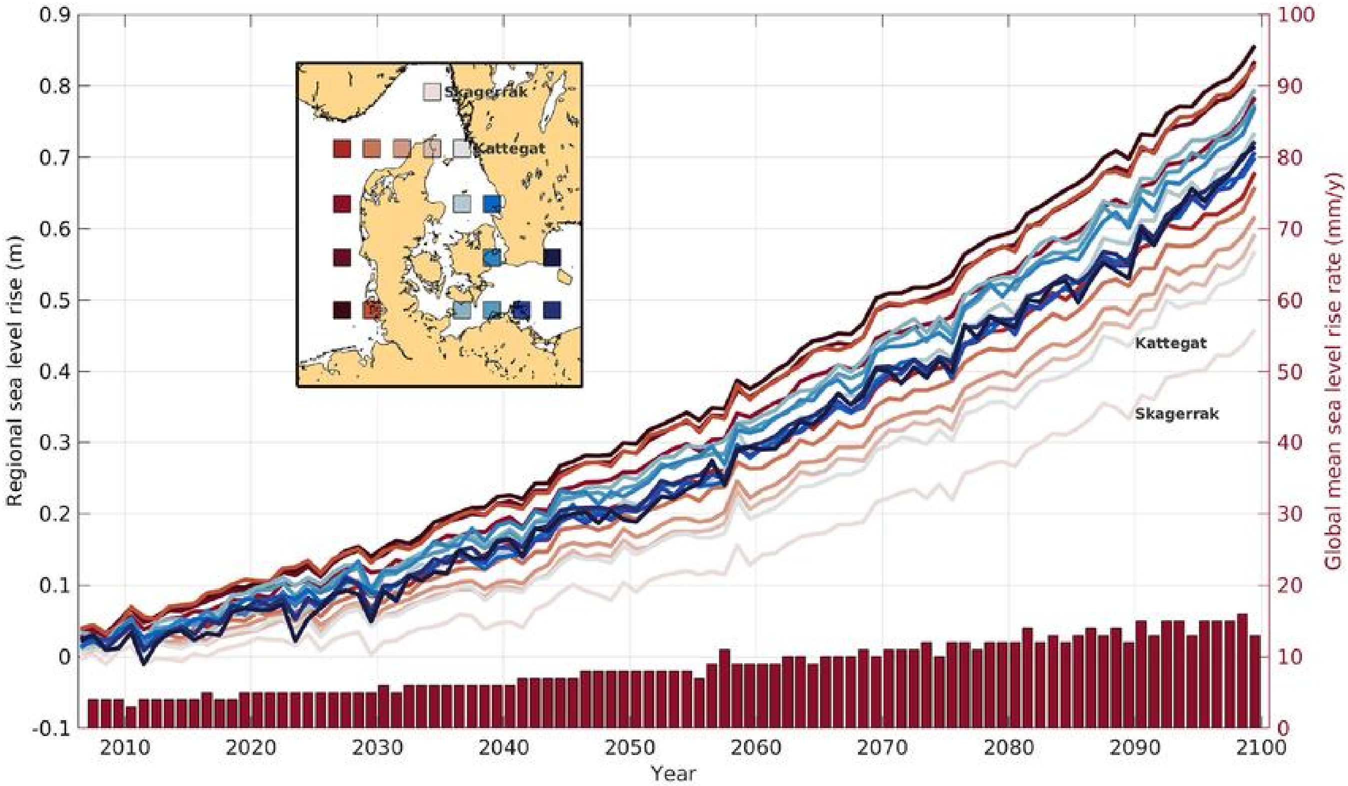

Fig. 3. Sea Level Projections in Denmark. Credit: IPCC, SR on the Ocean and Cryosphere Call for a New Climate Adaptation Strategy in the Skagerrak-Kattegat Seas. Data from: SROCC-Ch4ArticleSM

Denmark has pioneered several successful Coastal NbS projects over the past decades, and Køge Bugt Strandparken, Seden Strand, Gyldensteen Strand, and Amager Strand are all great case studies where significant benefits of coastal protection, biodiversity conservation, and community engagement have been archived (in depth analyzed and explained in Chapter 3). These projects have set benchmarks in ***integrating adaptive management***, ***multi-functional designs***, and ***strong stakeholder participation*** but need to be better framed and analyzed to enable their possible up-scaling to other similar contexts across the globe. Effective and successful coastal protection projects which implements NbS, focus on the *restoration of natural habitats* (stretching from salt marshes to meadows, wetlands and lagoon systems), *the stabilization of disappearing coastal dune systems and beach nourishments*.

Furthermore, ***Denmark*** becomes also a significant case study given its advanced level of implementation of NbS in its coastal management policy-framework which ***supports the planning, the implementation and the maintenance of NbS at national scale***. On April 2024, the Danish parliament made an agreement known as ***Green Fund*** (Grøn Fond) ***to channel*** new ***670Million Euros into advancing green initiatives and projects*** (as NbS) to bolster biodiversity, protect water environments and prepare climate adaptation plans by 2030. These funds, supported by national and EU directives, laws and strategies (in depth analyzed and explained in Chapter 3) seek ***to sustainably manage coastal areas, promoting ecological resilience, conservation of biodiversity and climate adaptation processes*** to tackle and respond to climate change threats (State of Green, 2024). Furthermore, besides the political and governmental backbone, ***Denmark is investing a lot into research and innovation*** for the study, the development and the implementation of new coastal protection solutions, ***supporting the collaboration between researchers, universities and governmental agencies***.

1.5. Research question

Grounded on the problems emerged from the Introduction, this thesis aims to explore the potential to transfer effective Coastal NbS from Denmark to Italy, focusing on the similarities and differences in their coastal management approaches. By examining the theoretical underpinnings, practical implementations, and measurable outcomes of NbS in Denmark, this study seeks to provide actionable recommendations and to develop a prototype project for a case study in the Italian context.

Therefore, the research begins with a theoretical chapter (Chapter 2). Here we lay-out the methodology which has been followed along the Thesis development, and define what has been said so far about NbS, how NbS have been integrated into the EU policy-framework, and what exactly *Coastal* Nature-based Solutions are inside the contemporary scientific debate. Following up, the body of the Thesis (Chapter 3) orbits around the study of Denmark as a best practice. In this chapter we deepen the Danish approach to coastal governance and coastal protection (at national, sub-national and international level), we understand how these integrate Coastal NbS at different levels, and conclude with an in-depth analysis and comparison of significant national Coastal NbS case studies through a comparison matrix. From these outcomes, we move onto the last chapter of the Thesis which focuses on the Italian case study (Chapter 4). This final chapter compares the Italian case study and the Danish case study, and highlights their differences in the coastal governance and coastal protection approach. The goal is to understand hot to develop an effective NbS for a vulnerable Italian coastal area (Marina Romea), grounded on the lesson learned from the Danish experience.

Summing up, the leading research question which has been followed and has structured this Thesis is:

'Can effective Coastal Nature-based Solutions be transferred to the Italian case study, learning from Denmark as European front-runner in the coastal protection field?'

1.6. Rational and justification of the problem

As highlighted above, Coastal NbS represent a cardinal design element in the current coastal protection discourse threatened by climate change, and their implementation is urgently required at a global level. However, besides being supported and recommended by different Global and European policies (as explained in depth in chapter 2), NbS are not adopted or developed at the expected speed and at the expected scale. In the following segment of the Thesis, the main causes to this problem are briefly going to be listed and analyzed.

Among the factors which hinder a wider implementation of NbS, the most relevant one's concern: (a) the ***difficulty to measure and predict*** the exact '***cost-effectiveness***' of NbS, compared to traditional hard engineered alternatives (Vogelsang et., al., 2023). NbS are complex solutions with many co-benefits (e.g. adding social, recreational or touristic values) which are challenging to estimate in empirical numbers compared to the hard engineered and grey alternatives.
(b) the ***poor financial models and flawed approaches to economic appraisal*** which leads to an underinvestment on the matter. Appraisals in general do not use an appropriate framework and underestimate the economic benefits of working with nature on the long run (Seddon et., al., 2019).
(c) the ***inflexible*** or ***highly sectorized forms of governance*** which hinder an easy uptake of NbS, especially when they are subject to cross-border or intermunicipal/regional involvement (Vogelsang et., al., 2023).

To help to accomplish the ambitious goals of the European Green Deal; to facilitate an inter-governmental information exchange on the outcomes of the already implemented case-studies; to overcome some of the before listed limitations and therefore to facilitate policymakers to up-scale NbS, the Thesis has a particular focus on a data-collection section where the main outcomes of implemented Danish Coastal NbS are collected, summed-up and put into a system to allow an easy acknowledgement and up-scale on the matter (see Comparison Matrix in chapter 3).

1.7. Objectives

The problem which is going to be addressed in this Thesis is the lack of implemented or up-scaled Coastal NbS in the European context throughout the definition of proper guidelines. For this reason, the research part will move along three paths: define the general framework of NbS, understand in dept one frame of the wide gamma of NbS (the Coastal NbS in Denmark) supported by an in-depth analysis of four different local case studies, needed to develop new guidelines for future Coastal NbS up-scaling, to finish-off with some recommendations for the future implementations. A Systematic Literature review (through a Basic search and a Full search) has been carried out to better frame the research on NbS and on Coastal NbS. Then, four best practices were studied and incorporated in a matrix in which the main key findings of the research were collected. Finally, some recommendations are going to be suggested to help activate intergovernmental information exchange for a better co-design and up-scale on the Coastal NbS matter.

1.8. Limitation of the study

The final study of this Thesis is limited to four Danish case studies, and therefore might not fully represent the full gamma of Coastal Nature-based Solutions developed along various coastlines. In terms of data availability, many interesting case studies have been discarded due to the lack of accessible or available data, required to carry out a comprehensive analysis and to compare the selected case studies in a comparison-matrix. Among these, the most common data gaps encompass data on specific socio-economic benefits (often difficult to measure), and data with term environmental impact assessments (since most Coastal NbS have been developed and implemented in recent years). From a geographical point of view, the Thesis is locked onto the examination of Coastal NbS in Danmark and, while this study provides great insight and new prospectives for the Italian case study, extending the study to wider geographical contexts could provide even more valuable and accurate results. Finally, language can also be considered a limitation, since not all the Coastal Nature-based Solution implemented and studied in Denmark were documented or descripted in English making their analysis not a-hundred percent accurate.

1.9. Potential follow-up

Future research should include a broader range of case studies from different regions and countries in order to gain a more comprehensive understanding of the effectiveness and adaptability of different Coastal NbS types, and across diverse coastal environments.

Conducting long-term studies to monitor and evaluate the performance and impacts of Coastal NbS over time would most likely provide more valuable data on their sustainability and resilience to climate change.

Improving data collection and data sharing methods (e.g. specific international websites and data servers) would enhance the robustness of future analyses both at national and international level facilitating the learning process for these new and high potential solutions. Further research should also focus on analyzing policy frameworks and governance structures that facilitate or hinder the adoption of NbS, as in our case the comparative study of the Danish and the Italian case study lead to future (more consistent) policy recommendations.

By addressing the above listed limitations, and by exploring the suggested potential follow-up research directions, future studies can contribute to a deeper and more comprehensive understanding of Coastal Nature-Based Solutions in the field of sustainable coastal management and defense against climate change threats.

Theoretical Framework

A taxonomy for Coastal Nature-based Solutions

2. A taxonomy for Coastal Nature-based Solutions

In the following segment, the Thesis shifts its focus on the definition of NbS as a concept, and on how this concept has been implemented inside the European Union policy-framework to promote and support climate mitigation and climate adaptation processes. Particular attention is paid to *European standards*, *European indicators* and on *questions* which have been selected by the European Commission (EC), which must be answered properly to classify climate mitigation and climate adaptation processes as NbS. Finally, this chapter introduces and frames Coastal NbS as specific intervention of the gamma of NbS, as key instruments inside this Thesis.

2.1. Research Methodology

The methodology section of this thesis aims to detail the research design, the processes and the methods used to explore the evolving concept of Nature-based Solutions (NbS) at international scale, as well as to explore the integration of NbS into the European Union (EU) policy framework. Moreover, on the one hand this study seeks to analyze how NbS projects are framed as such (according to European standards, European indicators and Questions), and on the other hands to position Coastal NbS within the broader paradigm of NbS. Therefore, the following explanation is provided to facilitate the replicability of the presented project and to ensure the reliability and validity of the research findings.

Note: From a more comprehensive point of view, the research aims to provide a solid lineout to the complex and changing topic of NbS, and thus facilitate and incentivize their implementation at scale along climate change adaptation and climate change mitigation projects.

2.1.1. Literature Search Strategy

The initial idea is to start the research from a basic knowledge level on the matter and then develop a holistic acknowledgement on the topic by digging into a scientific database made of peer articles on the issue. Therefore, to define a taxonomy for Coastal NbS, a comprehensive literature search has been conducted using a two-tiered approach: an initial ***basic search*** (to gain a general understanding on the topic), followed-up by a ***full search*** (to comprehensively cover all relevant literature on the topic). This strategy ensured both breadth and depth in understanding the existing international body of knowledge on Nature-based Solutions (NbS) and their integration into European policies.

2.1.2. Limits of the research

Despite efforts to conduct both a basic and full search, also supported by grey literature, some pertinent studies or reports may be missed due to the vast and expanding body of literature on NbS and on Coastal NbS. Furthermore, adding grey literature elements to the study introduces the risk of utilizing sources that may lack the rigorous peer-review process typical of academic research. Moreover, NbS are still a quite new topic inside the scientific discourse and since our analysis is based on the most current data available today, new developments could emerge that may alter the relevance or applicability of our findings.

2.2. Systematic literature review

Given the complex nature of NbS, a systematic literature review has been performed to critically analyze relevant key publications on the research matter (NbS in the contemporary scientific paradigm), and to map the existing literature, identify key concepts, theories, and gaps. Thus, we are able to provide a solid backbone to supports our study, including the current state of art in the NbS field, and developing an in-depth understanding on existing researches. The rigor of this type of literature review is given by the application of systematic and explicit methods, used to precisely identify relevant searches, articles and publications. Finally, the analysis part of how NbS have been introduced into the EU policy framework is based on available documents up to December 2023 (as we finished the theoretical framework). Any new policies or amendments introduced after this period will not be reflected in the study, potentially affecting its relevance and accuracy.

2.2.1 Methodology

To collect an exhaustive number of articles able to provide a comprehensive view on the NbS issue, the here followed methodology has been structured on nine fundamental steps along a basic search first, and a full search afterwards. The nine-steps followed in the systematic literature review are:

1. **Keyword search**: This step is fundamental for the whole research since it involves the definition of relevant terms and concepts (***keywords***) which are going to be looked-up among other searches, articles and publications. In our Thesis, the following key-concepts have been chosen as research indicators: *Nature-based Solutions, Coastal, Planning and Adaptation*.

2. **Selection criteria:** Once the fundamental keywords for the search were defined and set, we further narrowed the research through the use of specific ***advanced settings***. Differently from keywords, these can be modified, refined, or confirmed later on, and can be of different types.
For our Thesis, the search was locked onto the following criteria: (a) language, (b) keywords, (c) document type (article, review, or conference paper), (d) publication year and (e) subject area.

3. **Keyword combination (Boolean tools):** With help of ***Boolean tools*** (or the Boolean system), it is possible to specify if the search must include or exclude specific keywords, thus further narrowing the quarry into a specific direction. Tools which are used the most are ''AND'', ''OR'' and ''AND NOT''. ''AND'' is used to include at least two terms in the result; ''OR'' is used to include at least one term in the result; while ''AND NOT'' is used when a specific term must be excluded from the results.

4. **Data storing and software:** Once the quarry has been processed, all the relevant results are temporarily stored online. However, it is possible and recommended to download the outcomes of the quarry onto an Excel file in which the article's title, author/authors, source, theme, current number of citations, publication year and the type of document are listed.

N°	Title	Author	Source	Theme	Citations	Year	Type of document	Notes
1								
2								

5. **Pre-reading of articles and methodology review:** Sometimes, after reading the abstract of the first articles provided by the document search, the main topics discussed by the papers can have a different focus than the one relevant for the Thesis. In these cases, it is important to go one step back and review the initial search criteria, change or adjust some, and then re-do the search to collect new and more coherent documents (this step can be carried out multiple times).

6. **Combination of articles:** Once the most research-related articles have been selected, the next step is to explore their references in order to find other similar or related documents which could support and enrich the initial research.

7. **Selection of final articles:** This step regards the final selection and the final collection of all the relevant articles and references which have been read, and which are going to be used to develop the theoretical background of the Thesis.

8. **Data analysis:** Once the final articles and references have been selected, the research shifts its focus towards their accurate analysis. First, the most important information and citation have been noted and isolated into a new paper sheet, supported with notes and comments. With these main topics in mind, we structured a table of content (prototype) which has been followed to organize the main parts discussed and analyzed in the theoretical background of the Thesis. In our case, the data analysis was used to frame NbS as climate adaptation and climate mitigation processes, to understand how the concept of NbS has changed globally over the past few decades, and to frame an internationally agreed upon definition of NbS, adopted also by the European Union inside its policy-framework. Finally, from the study of different papers we have also been able to frame Coastal NbS as one specific category among the different types of NbS.

9. **Writing the literature review:** Outcomes and results of the literature review which has been carried out are collected and put together at the end of Chapter 2.

2.2.2. Basic search

The initial phase involved a basic search to familiarize with the topic and identify key themes, major studies, and influential works. Scopus has been chosen as source database, and the Boolean tools (or Boolean system) have been used for keyword combination (''AND'' was used to include at least two terms in the result; ''OR'' was used to include at least one term in the result; while ''AND NOT'' was used when a specific term had to be excluded from the search).
The keyword search was first carried out in the Scopus database, through the English key-words ''*Nature-based Solutions*'' and *''Coastal''*, excluding at the same time the ''*urban*'' keyword, as widespread in the results and not relevant to the dissertation.

Phase 1. Basic search	
Database	Scopus
Keywords in Title, Abstract and Key words	nature based solution AND coastal
Boundaries	AND NOT urban
Date range	published from 1989 to 2023
Document type	Article, review, book chapter and book
Access	All
Language	English
Quick read	Title and abstract

Fig. 4. Systematic literature review: Selection criteria for the basic search on Scopus database. Data from: Personal elaboration

From the first quarry carried out with the above listed criteria, the Scopus database showed a total of **176 documents,** filtered for relevance, for amount of citations and for publication date. Out of these articles, the first 50 have been read (title and abstract) to understand how to further organize and narrow the research since many topics were repeated, or out of the research field.

2.2.3. Full search

Once the basic search was completed, it was clear that many articles were discussing similar or overlapping topics, or concerning topics completely out of our research frame. By implementing additional keywords, setting up new boundaries and by changing the use of the Boolean tools, we succeeded in narrowing the research and found an appropriate searching framework for our Thesis.
After different adjustments and tries, the full research of the literature review was carried out as follows:

Phase 2. Full search	
Database	Scopus
Keywords in Title, Abstract and Key words	nature based solution AND coastal AND planning AND adaptation
Boundaries	AND NOT urban; AND NOT marine
Date range	published from 2016 to 2023
Document type	Article, review and book chapter
Access	All
Language	English
Quick read	Title and abstract

Fig. 5. Systematic literature review: Selection criteria for the full search on Scopus database. Data from: Personal elaboration

The final search with the above listed criteria provided **26 final documents** (listed at pg. xxii, 'full search document list'), sorted for relevance, for amount of citations and for publication date. These have all been read entirely if title, abstract and conclusions were relevant to our theoretical framework, we checked their most relevant references and this way we developed our final state of art on NbS.

2.2.4. Gaps of the literature review

Since NbS are a complex topic (as will be described below in this chapter), and because the Systematic Literature review is a straight methodology, some aspects have not been considered in our quarry to not overextend the boundaries of the research. For instance, the concept of 'Nature-based Solutions' is implemented with different names across the globe, and in time frames; it could be possible to explore other similar approaches by adjusting keywords and the Boolean tools.

2.2.5. Grey literature

In order to provide a comprehensive and holistic analysis within this thesis, grey literature has also been adopted into the research methodology. Grey literature, which includes sources such as government reports, policy documents, conference proceedings, and other non-peer-reviewed materials, are essential for capturing a broader spectrum of information that may not be available in traditional academic publications, or on the selected database on which the search has been carried out (Scopus). Furthermore, by integrating grey literature we have been able to access valuable data, and perspectives of policymakers, and other stakeholders (directly involved in the field of NbS and Coastal NbS), which had not yet been extensively covered in publications, thereby enriching the theoretical and practical framework of the overall research.

2.3. NbS as climate adaptation and mitigation processes

Negative consequences of temperature and weather shifts are registered all over the world, resulting in a significant rise of extreme and calamitous events as floods, droughts, heatwaves and others (IPCC, 2021). Ways to adapt the present paradigm to climate change are studied at global scale since these disastrous phenomena do not only disrupt the environmental sphere (natural habitats, biodiversity…) but also the human well-being (society and economy) overall (Świerkosz et., al., 2022). Worldwide, **Nature-based Solutions** are seen as a new potential cardinal key-planning element to **archive Spatial Resilience** (Box.1) **via climate Adaptation** (Box.2) **and climate Mitigation processes** (Box.3) (Tyllianakis et., al., 2022). Their proper implementation can ensure high benefits to nature, society and economy, and at the same time counteract climate change threats by absorbing emitted GHG gases. The importance of Nature-based Solutions, is highlighted by the United Nations Environment Assembly (UNEA) of the United Nations Environment Programme (UNEP) who see NbS as '**supporting the implementation of the 2030 Agenda for Sustainable Development and Sustainable Development Goals**' (UNEP/EA.5/Res.5) **and** are considered '**an essential component of the overall global effort to achieve the goals of the Paris Agreement on Climate Change**' by the United Nation Global Compact (UN Global Compact, 2019) (UN Global Compact, 2023). In fact, according to UNGC '**NbS can provide over one-third of cost-effective climate mitigation needed between now and 2030 to stabilize warming below 2°C**' (UN Global Compact, 2023).

The purpose of this Thesis is therefore to offer an analysis and an overview on different existing coastal protection case studies which follow a Nature-based Solution approach in order to study and evaluate their outcomes. The research is carried out in one of the most important and frontrunning countries in the sector which is Denmark. The final goal of the study is to gain better understanding and an in-depth insight on the topic, through the development of a matrix which can support and facilitate the comparison between different case studies and can function as support for their future up-scaling to other similar contexts across the globe.

Box 1: **Spatial Resilience**

There are different definitions of Resilience, the one adopted in this Thesis is provided by the Sustainable Cities and Communities. Spatial Resilience is defined as '*the ability of a territorial system to bounce back to desired functions after unexpected shocks and disturbances in order to improve its adaptive capacity intending to evolve all its material and immaterial components toward a new territorial system's organization'* (Brunetta and Caldarice, 2020).

Box 2: **Climate Mitigation**

There are different definitions of Climate Mitigation, the one adopted in this Thesis is the one provided by the IPCC report. Climate Mitigation is considered *'a human intervention to reduce emissions or enhance the sinks of greenhouse gases'* (IPCC, 2021).

Box 3: **Climate Adaptation**

There are different definitions of Climate Adaptation, the one adopted in this Thesis is the one provided by the IPCC report. In human systems, Climate Adaptation is referred to as *'the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects'* (IPCC, 2021).

2.4. The conceptual metamorphosis of Nature-based Solution

Before exploring how NbS are defined in the current state of scientific and political debate, the Thesis is going to introduce how the concept 'Nature-based Solution' has changed over the past few decades.

The first prototype-concept of NbS can be traced down to the idea of **Ecosystem Approaches** (EA) introduced at the COP5 during the Convention on Biological Diversity (CBD) in 2000 (EA are referred to as Ecosystem-based Approaches (EbA) from the CBD in 2004 onwards). Both EA and EbA shift the attention of international governments on **the need of public participation to guarantee ecological conservation and fulfill different socio-economic needs of society**. While both NBS and EA/EbA adopt natural processes and ecosystem services to address challenges, they differ in terms of primary objectives, scope and application methods. NBS are designed to provide direct societal benefits and are often implemented through specific projects addressing urban and rural challenges, EA/EbA on the other hand focus more on maintaining ecosystem healthy and resilient, setting societal benefits as secondary outcomes.

Nature-based Solution (NbS) as concept has **appeared** for the first time **in the late 2000s, mentioned by the World Bank** (WB) (MacKinnon et., al., 2008) and since then it has grown in popularity across different stakeholders in the policy market, in the research field, in the civil society and in the private sector (de Los Casares et., al., 2023)**.** The goal of the WB was to coin a new terminology **to describe 'innovative solutions which manage natural systems in such a way that they provide benefits both for nature and society'**. A new idea was rising in which humans could move towards a resilient, resource-effective, and green economy by working with nature, instead of working against nature (Sowińska-Świerkosz et., al., 2022).

Subsequently, the International Union for Conservation of Nature (IUCN) partially redeveloped the purport of NbS given by the World Bank, highlighting the importance of nature in general, but biodiversity in particular to support climate change adaptation and mitigation (Nehren et., al., 2023). This set the roots for a bigger change of the concept, as in 2016 NbS were defined as "*actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*" (IUCN, 2016) in occasion of the 2016 World Conservation Congress and General Ambassy.

Finally, further political attention was brought to the NbS topic in 2019, as first the UN Climate Action Summit launched the manifesto *Nature-based Solutions for Climate* (Science for Environment Policy, 2021), and second as the European Commission (EC) submitted the *Green Deal* in which NbS were referred to as the ''lasting climate change adaptation and mitigation measures involving both terrestrial and marine ecosystems'' (E.C., 2020).

At the current stage of debate, NbS are considered an umbrella term referred to in two ways:
The first definition is provided by IUNC, where **NbS** are seen as actions which **'address societal challenges through the protection, sustainable management, and restoration of both natural and modified ecosystems, benefiting both biodiversity and human well-being. Nature-based Solutions are underpinned by benefits that flow from healthy ecosystems. They target major challenges like climate change, disaster risk reduction, food and water security, biodiversity loss and human health, and are critical to sustainable economic development'** (IUCN, 2023)**.**

The second definition is provided by the EC and refers to **NbS** as **'solutions (...) inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes, and seascapes, through locally adapted, resource-efficient, and systemic interventions'** (EC, 2023).

Both definitions orbit around the pillars of climate adaptation, climate mitigation and social well-being, however, the definition provided by the EC sets a higher focus on the ''cost-effectiveness'' of the interventions and on their positive outcomes on the economic and financial perspective (as co-benefits). In this Thesis we refer to NbS adopting the second definition, provided by the European Commission.

2.5. NbS in the EU policy-framework

Given the fact that all Coastal Nature-based Solution case studies analyzed in this Thesis are to be found in the European Union borders, and the fact that the proposed Thesis projects are also performed in Europe, the Thesis is going to analyze in depth what NbS are, especially in the European Union policy framework.

From 2019 onwards, the ***European Green Deal*** (EGD) became EU's main plan to make the continent climate-neutral by 2050. The concept of Climate Neutrality implies that all the emissions of GHGs released into the atmosphere at the end of the given timespan, are going to be counterbalanced by an equal amount GHGs removed (or offset) from the atmosphere. To support this ambitious objective, first GHG emissions must be reduced significantly across various sectors such as energy, industry, transport, agriculture, and buildings; then, to further support this transition and limit the current climate and environmental challenges, NbS should be implemented and adopted at scale, as crucial sustainable, biodiversity supportive and climate friendly actions.

On this purpose, the ***European Union*** has issued policies in ***five different policy-areas*** over time and most NbS-relevant have been includes in the climate change adaptation and mitigation processes of the EGD vision (de Los Casares et., al., 2023; EEA Report, 2021):

1) Cross-cutting: European Green Deal (2019) and Bioeconomy Strategy (2012/2018).

2) Biodiversity: Biodiversity Strategy for 2030 (2020), Green Infrastructure Strategy (2013), Habitats Directive (1992), Birds Directive (1979/2009), Natura 2000 (1992), EU Forest Strategy (2013), LULUCF Regulation (2018) and the Nature Restoration Law (2023).

3) Climate: Action Plan on the Sendai Framework for Disaster Risk Reduction 2015-2030 (2016) and Strategy on Adaptation to Climate Change (2013, 2021).

4) Water and Agriculture: Farm to Fork Strategy (2020), Foods Directive (2007), Water Framework Directive (2000), Common Agriculture Policy (2013) and Nitrates Directive (1991).

5) Urban: Urban Agenda for the EU (i.e. Pact of Amsterdam, 2016)

2.6. Framing NbS (European standards, indicators and questions)

However***, until 2020 the definitions of Nature-based Solutions did not provide a proper and clear framework to differentiate 'regular' green and/or blue action from 'real' Nature-based Solutions***. The lack of a precise framework turned out into a series of problems, especially when NbS were adopted in the field of policymaking. Interventions which nowadays would be referred-to as ''supporting'' or ''related'' to NbS, were welcomed and approved as NbS.

To overcome the rise of misunderstandings, IUCN introduced a set of ***8 Criterions*** (Standards), further supported by an additional ***28 Indicators***, which must be adopted in the process of verification, design and scaling-up of Nature-based Solutions. All these rules are in line with the concept's principles of Nature-based Solutions, re-modelled in a dynamic way with the feedback of different stakeholders and actual/potential NbS users so that all national governments, city and local governments, planners, businesses, donors, financial institutions (including non-profit organizations) and other can act and intervene in a holistic way on the matter (IUNC, 2020).

NbS, to be referred to as such, must comply with the listed criteria and indicators from the IUNC:

1. Nature-based Solution must address societal challenges.

1.1 The most pressing societal challenge(s) for rights-holders and beneficiaries are prioritized.

1.2 The societal challenge(s) addressed are clearly understood and documented.

1.3 Human well-being outcomes arising from the NbS are identified, benchmarked and periodically assessed.

2. Nature-based Solution must have scale dependent designs.

2.1 The design of the NbS recognizes and responds to interactions of the economy, society and ecosystems.

2.2 The design of the NbS is integrated with other complementary interventions to synergies across sectors.

2.3 The design of the NbS incorporates risk identification and risk management beyond the intervention site.

3. Nature-based Solution must ensure biodiversity and ecosystem integrity gains.

3.1 The NbS actions directly respond to evidence-based assessment of the current state of the ecosystem and prevailing drivers of degradation and loss.

3.2 Clear and measurable biodiversity conservation outcomes are identified, benchmarked and periodically.

3.3 Monitoring includes periodic assessments of unintended adverse consequences on nature arising from the NbS.

3.4 Opportunities to enhance ecosystem integrity and connectivity are identified and incorporated into the NbS.

4. Nature-based Solution must be economically viable.

4.1 The direct and indirect benefits and costs associated with the NbS, who pays and who benefits, are identified and documented.

4.2 A cost-effectiveness study is provided to support the choice of NbS including the likely impact of any relevant regulations and subsidies.

4.3 The effectiveness of the NbS design is justified against available alternative solutions, taking into account any associated.

4.4 NbS design considers a portfolio of resourcing options such as market-based, public sector, voluntary commitments and actions to support regulatory compliance.

5. Nature-based Solution must guarantee governance capability

5.1 A defined and fully agreed upon feedback and grievance resolution mechanism is available to all stakeholders before an NbS intervention is available to all stakeholders before an NbS intervention is initiated.

5.2 Participation is based on mutual respect and equality, regardless of gender, age or social status, and upholds the right of Indigenous Peoples to Free, Prior and Informed Consent (FPIC).

5.3 Stakeholders who are directly and indirectly affected by the NbS have been identified and involved in all processes of the NbS intervention.

5.4 Decision-making processes document and respond to the rights and interests of participating and stakeholders.

5.5 Where the scale of the NbS extends beyond jurisdictional boundaries, mechanisms are established to enable joint decision-making of the stakeholders in the affected jurisdictions.

6. Nature-based Solution must guarantee governance capability.

6.1 The potential costs and benefits of associated trade-offs of the NbS intervention are explicitly acknowledged and inform safeguards and any appropriate corrective actions.

6.2 The rights, usage of and access to land and resources, along with the responsibilities of different stakeholders, are acknowledged and respected.

6.3 The established safeguards are periodically reviewed to ensure that mutually-agreed trade-off limits are respected and do not destabilize the entire NbS.

7. Nature-based Solution must enhance adaptive management.

7.1 A NbS strategy is established and used as a basis for regular monitoring and evaluation of the intervention.

7.2 A monitoring and evaluation plan is developed and implemented throughout the intervention lifecycle.

7.3 A framework for iterative learning that enables adaptive management is applied throughout the intervention lifecycle.

8. Nature-based Solution must be mainstreamed within an appropriate jurisdictional context.

8.1 The NbS design, implementation and lessons learnt are shared to trigger transformative change

8.2 The NbS informs/enhances facilitating policy/regulation frameworks to support its uptake and mainstreaming

8.3 Where relevant, the NbS contributes to national and global targets for human well-being, CC, biodiversity and human rights, including the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP)

Finally, to support the above listed criteria and indicators and, to guarantee a *measured* and *multi-benefit analysis* of all case studies, the EC's Directorate-General Environment provides **5** further **questions** which need to be answered in order to define whether or not a given project can be framed as NbS (Science for Environment Policy, 2021 pg.10). The following questions have partially inspired some of the Criteria adopted in Chapter 3, used to analyze and compare selected Danish case studies (Chapter 3).

A *measured* and *multi-benefit analysis* for Nature-based Solution: Questions

1. Does the selected project use nature/natural processes?
2. Does the selected project provide/improve social benefits?
3. Does the selected project provide/improve economic benefits?
4. Does the selected project provide/improve environmental benefits?
5. Does the selected project have a net benefit for biodiversity?

2.7. Coastal Nature-based Solutions

This paragraph explores the concept, significance and implementation of Coastal Nature-based Solution as one specific typology of Nature-based Solution, able to address climate change challenges specifically in Coastal Areas. It will highlight their benefits, their current challenges and highlight some existing examples to underline their crucial role in enhancing coastal resilience against climate change. As has been already introduced before in this chapter, Nature-based Solutions encompass a wide range of strategies that through natural processes try to address various environmental, social and economic challenges. According to the type of intervention, the environment in which they are implemented-at, and the climate challenge they try to tackle, NbS can be classified into five macro categories (EEA Report, 2021):

- **NbS for water management,** mainly implemented to *tackle water scarcity* and *water quality deterioration* due to ***droughts*** OR to *tackle floods and landslides* due to ***heavy precipitation*** (e.g. river restoration, rainwater harvesting).
- **NbS for forests and forestry,** mainly implemented to *tackle increasing tree mortality and pest outbreaks* due to ***droughts*** and ***forest fires*** OR to *tackle landslides and soil losses* due to ***extreme rainfall events*** (e.g. restoration of degraded forests, sustainable forest management).
- **NbS for agriculture,** mainly implemented to tackle *crop and livestock loss* due to ***heat stress, pest and disease outbreaks*** and ***water scarcity*** OR to *tackle damage to yield, transportation and asset loss* due to ***flooding*** (e.g. soil/water management, agroforestry or crop rotation/diversification)
- **NbS for urban areas**, mainly implemented to *tackle heat stress* due to ***heatwaves*** OR to *tackle urban flooding* due to ***heavy precipitation*** (e.g. park implementation, urban forests, street trees, green building or detention ponds and bioswales).
- **NbS for coastal areas,** mainly implemented to *tackle loss of land* due to ***sea level rise*** and ***coastal erosion*** OR to *tackle loss of life* due to ***storm surges and inundation*** (e.g. rehabilitation and restoration of coastal habitats, near-shore enhancement of coastal morphology or hybrid solutions).

Coastal NbS are main focus of this Thesis, given the high exposure and vulnerability of coastal areas analyzed in the Introduction. In line with the sustainable development goals of the 2030 Agenda, these solutions provide different ecological benefits (by enhancing biodiversity, by restoring natural habitats, and by improving ecosystem services), socio-economic benefits (by providing recreational spaces, by improving water quality and by being cost-efficient in the long run) and climate resilience benefits (increasing the environmental adaptability to CC threats and reducing its vulnerability to natural disasters).

Most common examples of Coastal NbS include ecosystem-based approaches which seek to resolve the degradation and vulnerability of coastal environments (especially to SLR, coastal erosion and floodings) by restoring ecosystem functions of coastal systems such as dunes, wetlands and mangroves (Dack, 2023). Upscaling these solutions to other contexts across the world becomes a challenging task, especially when differences in socio-economic and environment patterns are not taken into consideration. ***Coastal NbS are highly dependent on local environmental conditions*** such as climate, hydrology, soil type, and existing ecosystems; 'what works in one region may not be suitable in another' (Temmerman et., al., 2013). Same can be said for socio-economic conditions, since implementing and maintaining NbS can require significant upfront investment and might not be feasible for regions with limited financial resources (Pretty et., al., 2006). Therefore, as the knowledge and experience with NbS increases, it becomes more important to draw lessons learned and insights for replicating and scaling up NbS, especially in coastal areas where their implementation is still limited compared to other environments. (Morales et., al., 2022).

Best practice

Coastal planning in Denmark

3. Coastal planning in Denmark

The previous chapters explored the concepts of NbS and of Coastal NbS, providing a better and in depth understanding on the matter starting from a state of art review. Coastal NbS have emerged as sustainable solutions, addressing multifaceted challenges posed by climate change (e.g. coastal erosion, sea-level rise, more frequent and intense extreme weather events) and, by harnessing natural processes, these solutions are proven to enhance also spatial resilience, support biodiversity, and provide valuable ecosystem services to coastal environments. Furthermore, we discussed how the EU has integrated NbS into its policy framework, promoting their implementation through various directives and programs.

In the following chapter, we will delve into the Danish case study (European frontrunner in the field of coastal protection) and analyze, study and compare effective best practices. This is going to provide valuable lessons and could help to upscale and/or transfer successful Coastal NbS to other similar vulnerable coastal regions, like Italy in our case. The final goal of the Thesis is to bridge the gaps between theoretical concepts and practical applications, demonstrating the effectiveness of Coastal NBS in real-world scenarios and drawing lessen-learned.

3.1. Framing the Danish coastal planning system

The country of Denmark consists of a main peninsula (Jutland peninsula) and an archipelago of 400 plus islands. Together, the country has a coastline which spans over 8,700 km in width (Statistics Denmark, 2019) and includes diverse coastal environments, from sandy beaches to rocky cliffs, to sand dunes and wetlands (World Bank Group, 2018). However, due to its low-lying nature the country has many vulnerable coastal areas at risk of erosion, flooding and/or storm surges which have been sources of massive damage and loss over time. These phenomena have even exacerbated in intensity over the past few decades due to Global Warming and Climate Change, and therefore have forced Denmark to act quickly on its coastal defense systems.

To safeguard the most relevant Danish coastal areas, in 1874 the Danish Parliament enacted the ***Dike Act*** (Dige Loven) which introduced for the first time a legal framework and regulatory mechanisms to manage dikes as critical infrastructures for coastal defense and flood risk reduction. The act governed the construction, the maintenance and the management of dikes at national scale and delineated, at the same time, the responsibilities of the different Authorities and Stakeholders involved in the planning, construction and maintenance process.

Nowadays, coastal planning in Denmark involves a more holistic approach then in the past and is governed by a solid national legislation further supported by a set of regulations and guidelines which define the general legal framework. The most relevant laws in the national coastal protection field are the ***Coastal Protection Act***, the ***Environment Protection Act***, the ***Planning Act*** and the ***Nature Conservation Act***.

- The Coastal Protection Act (Kystbeskyttelsesloven) has been adopted in 1958 and since then has undergone revisions and amendments to tackle new and evolving coastal challenges (as for today, related to climate change). Main objective of this act is to set the legal framework for implementing coastal protection measures, mitigate erosion, reduce flood risk and safeguard coastal communities, infrastructures, and natural habitats through sustainable planning. It is also important to highlight that since 2007, this piece of legislation has incorporated the *Flood Directives* of the European Union (Directive 2007/60/EC) which require member states to assess flood risks, develop flood risk management plans, and take measures to prevent, prepare and respond to floods.

- With a broader focus, the Environmental Protection Act (Miljøbeskyttelsesloven) was firstly adopted in 1974 and represents a milestone in Denmark's environmental legislation. The act seeks to address various aspects of environmental protection and environmental management inside the national borders, including coastal areas. Main target is the regulation of all the activities that may have environmental impacts (such as land uses, construction, industry or wastewater management) to guarantee a sustainable coastal development, pollution control and a stronger habitat control.

- As the Environmental Protection Act, also the Planning Act (Planloven) introduced in 1992 does not focus exclusively on coastal areas but sees coastal planning as part of the framework. The act governs spatial planning and land-use regulation in Denmark, becoming the legal basis for municipal and regional planning, and promotes sustainable development principles to safeguard natural resources, cultural heritage as well as public welfare. Today, municipalities must develop Local Coastal Zone Plans (Kystnaerhedszoner) to manage land uses and development activities, considering all the different environmental, social and economic factors in the planning process.

- Finally, the Nature Conservation Act (Naturbeskyttelsesloven) of 1969, has its focus on the protection and conservation of natural habitats, species, and landscapes inside the national borders. For instance, protected areas as Nature Reserves, Wildlife Sanctuaries, and Natura2000 sites are designated by this Act which seek to safeguard biodiversity, natural habitats of special significance, and ecological processes in the inland and along the coasts. To achieve these goals, the law regulates activities that may impact protected areas (construction, infrastructure development, tourism and recreational activities) and coordinates them with nature conservation objectives.

From a political perspective, in Denmark, the protection and the management of coastal areas is carried out through a combination of National, Regional and Local Government structures, policies and initiatives. These, together with public participation and international cooperation, define the sustainable and resilient management plan of the Danish coasts.

General and large-scale coastal protection planning at national level is archived through ***National Coordination***. Here, the Danish Government and, more precisely the Ministry of Climate, Energy & Utilities and, the Ministry of Environment & Food (all experts on Climate Change, environmental conservation, and sustainable development), develop national policies, regulations and strategies to address coastal erosion, sea level rise, storm surges and other coastal issues.

Besides National Coordination, since the country shares many coastal problems with other bordering nations, the Danish Government does also participate in ***International Cooperation*** which is then integrated in the national planning process. For instance, Denmark collaborates with the European Union in projects like the EU's LIFE Programme (EU), Baltic Sea Region Programme (EU), North Sea Region Programme (EU) and other projects to address issues related to coastal management, marine conservation, and sustainable development in the Baltic Sea and/or the North Sea regions. Denmark also collaborates with the United Nations in projects such as the UNESCO Man and Biosphere Programme (UN), to promote sustainable development and conservation in designated biosphere reserves and coastal areas. By sharing resources, best practices and knowledge, Denmark strongly contributes to the development of effective coastal protection and management strategies of national and international importance.

Once the national and international coastal protection mechanisms, policies and regulations are set, their management and other related activities are carried out and supervised by the governmental agency ''Danish Coastal Authority'' (Kystdirektoratet) or DCA. This agency mediates with the regional authorities, the Municipal authorities, the Public, and different other stakeholders to ensure the resilient and sustainable development of Denmark's coastline.

Below the national coordination level there is the ***Regional Coordination*** level. In the country there are five regions (Capital Region of Denmark, Central Denmark Region, North Denmark Region, Region Zealand and Region of Southern Denmark), each of which has its own Regional Authority responsible for spatial planning, environmental protection and coastal management within their jurisdiction. The Regional Authority main purpose is to collaborate with municipalities, private landowners, and other stakeholders to enable and facilitate the implementation of broader national directives (including infrastructure project, NbS or land-use planning) and adapt them to the different local conditions. However, since coastal protection measures often span across multiple municipalities, regional coordination helps to ensure consistency and compatibility in planning, design, and implementation of inter-municipal or inter-regional coastal protection projects.

Municipalities, on the other hand, work on the ***Local Coordination*** level. In fact, local authorities have responsibilities in land-use planning, and in managing local infrastructure systems (including coastal protection structures and flood risk management systems) to guarantee the safety and the well-being of their communities. In this purpose, Regional Authorities and Local Municipalities must work closely together to guarantee national coherence in the planning scheme.

It is however important to highlight that even if most of the fundings and the planning for large scale coastal protection projects are provided by the National Government, the overall principle for coastal protection is that the landowner is responsible for protecting his own property. Therefore, unless the threatened area is under a large-scale national project, protection measures must be initiated, financed, implemented and maintained by the landowners, or arranged for within the municipality. ***Stakeholder engagement and public participation*** are therefore cardinal parts of Denmark's coastal planning procedures, which often sees municipalities, government agencies, NGOs, businesses and local communities collaborate to develop and implement coastal management plans, ensuring that different perspectives and interests are taken into consideration.

3.2. What is Denmark doing in the current coastal protection discourse?

As stated in the paragraphs above, Denmark has a long history in the coastal protection discourse (especially due to the national low-lying morphology) and is therefore engaged both at national and international level in its research and improvement. If in the past, coastal protection was archived through hard/engineered and often small-scale infrastructural solutions (as groins, revetments, seawalls and dikes) (Kok et., al., 2020), increasing storm intensity and sea level rise linked to Climate Change (IPCC 2021) led to their structural inefficiency in current and future scenarios. However, the evolving understandings of coastal dynamics, recognition of the importance of ecosystem services, and the need for more climate-resilient strategies, shift national attentions towards more holistic and cost-effective approaches, where softer and nature-based related solutions gain importance.

This national trend towards a sustainable and resilient coastal system is also a respond to recent international frameworks such as the EU Water Framework Directive (2003) and the Ramsar Conservation of Wetlands, which prioritize nature-based approaches and solutions for water management and wetland conservation to the traditional hard engineered coastal solutions.

The following section is going to list and explain some of the main coastal protection interventions carried out and studied inside Denmark's borders, both at large scale and at small to medium scale.

Large national interventions are not very common along the Danish coastline since on the one hand most of the coastal areas have low levels of habitation and development, and on the other hand erosion and floodings often happen at local scale, affecting mainly single properties (Kok et., al., 2020). In these cases, it is the private or public landowner who, by law, is responsible for the protection, the funding and the maintenance of the protection measures which are put in place.

However, when coastal erosion, flooding or storm surges become (or are expected to become) threatening to wider coastal areas, they are labeled as of 'national importance' by the Danish Government. In this case, the Danish Coastal Authority participates in a Joint Agreement with local authorities and stakeholders, and co-funds the coastal protection measures (Kok et., al., 2020).

As can be noticed in the figure below (Fig. 6), the DCA is currently involved in different projects along the coastline; in some the DCA is directly responsible, in others the DCA is part of a joint venture with municipalities and local stakeholders, and in others the DCA cooperates with the European Union or other international stakeholders in the coastal protection discourse.

Fig. 6. The tasks of The Danish Coastal Authority. Data from: kyst.dk/english/about-us/the-tasks-of-the-danish-coastal-authority

Large coastal protection projects in Denmark can be found along the Western coastline of the Jutland peninsula (marked by a red line in Fig. 6). This coastal area directly faces the North Sea with its strong currents, waves and intense winds, and is characterized by large sandy beaches and width sand dunes which function as natural protection system for the urban settlements and holiday homes located in the hinterland (Miljøministeriet, 2024). Together, the sum of these geographic, morphologic, and geologic factors makes Jutland's Westcoast particularly subject to coastal erosion, reflected in a constant coastal retreat which varies between 1m/year and 8m/year in the most vulnerable areas (World Bank Group, 2018). To aggravate the overall coastal exposure to the sea, recent and more frequent high water levels during storm surges, the progressive disappearance of natural dune belts and the low-lying hinterland increase the risk of flooding, not only threatening coastal properties in a significant way, but also coastal infrastructures and natural environments.

Many projects and initiatives are therefore in development, the most relevant of which are Building with Nature Interreg projects (BwN) and Coast to Coat Climate Challenge projects (C2C CC).

- Building with Nature Interreg Project is an EU co-funded project in which the Danish Coastal Authority (together with partners from the Netherlands, Germany, Scotland, Sweden, Norway and Belgium) takes part of. Its main objective is to make coasts and catchments in the Baltic Sea more adaptable and resilient to the effects of climate change, protecting the hinterland from erosion and flooding through cost-efficient and natural-based protection schemes such as coastal-dune replenishments and sand nourishments. The BwN project started in 1982 with a joint agreement between the Danish Government and local municipalities, and currently protects 110 km of Denmark's west coast between Lodbjerg and Nymindegab (Thomsen et., al., 2018).

- Coast to Coat Climate Challenge project seeks to provide local authorities in Denmark with tools to implement Climate Change Adaptation (CCA) plans at the municipal level and therefore make coastal regions (as in this case, Jutland's Westcoast region) more resilient and adapted to Climate Change. In fact, since 2013 the Danish government made it mandatory for municipalities to develop their own CCA plans, but their effective implementation is still limited or missing in most cities in the country. Currently the project involves 21 municipalities in the Central Denmark Region and tries to link and connect them to tackle common threat in a cross-boundary and inter-municipal approach (EU LIFE IP C2C CC, 2015).

Following the European Union's Floods Directive (2007/60/ EC), Denmark has assessed a total of 10 areas which are likely to experience significant floods from the sea, floods from streams and rivers or from a combination of both during extreme weather events (marked by orange lines in Fig. 6).
Since flood events would have strong negative outcomes on human lives, the environment, and the economy, the management and protection of those segments of coastline became national priority. To define the ***10 risk areas***, the DCA analyzed national flood-prone areas which experienced extreme weather events over the past two centuries, like those inundated during the Baltic Sea surge in 1872 or during other similar flood events (Sørensen et., al., 2017). Extreme weather events are most likely to

become more frequent over the next few decades due to Climate Change (IPCC 2021) and, according to experts of the Technical University of Denmark DTU, this represents a massive problem for the existing hard flood protection measures which are put in place in Denmark (dikes, dunes, seawalls etc.) which are functional until extreme water levels exceed their expected height (Sørensen et., al., 2017). To adapt the 10 risk areas to future threats, Denmark is engaged in a variety of protection measures of which the next paragraph is going to analyze and explain some.

Finally, besides large national interventions, most of the coastal defense measures (along approximately 6000km of the Danish coastline) are arranged and funded by local private or local public landowners (Kok et., al., 2020). The fragmentation in the Danish coastal defense discourse, often leads local landowners to opt for traditional hard-engineered solutions which are less expensive in the short term, but aggravate erosion in the bordering coastal areas, reduce landscape quality and habitats, and often are more expensive on the long run (Kok et., al., 2020). The following chapter (Chapter 3) is going to analyze Danish case studies put in place at local level, which adopt nature-based coastal defense systems to highlight their effectiveness and their cost-effectiveness on the long run.

3.3. Methodology for the case study selection

The following segment of chapter 4 highlights the methodology which has been followed to identify and select the case studies on which the research of this Thesis is built on.

A) Context:

The objective of this Thesis is to prove the effectiveness of NbS in the coastal defense discourse, and underline their ability to support, strengthen or substitute traditional hard engineered defense systems in the frame of Climate Adaptation and Territorial Resilience.

Focal point of the analysis has been the Danish case study, on the one hand because Denmark became a front-runner in the coastal protection debate and the study of NbS over the last decades due to its national coastal vulnerability, on the other hand because the internship on which the Thesis has been built upon has been carried out in Denmark, facilitating the gathering of local data and information. Proving the effectiveness of NbS is also helpful to define ways through which these best practices can be upscaled and implemented in other similar scenarios across the globe.

B) Purpose of the Case Selection:

The importance of finding proper and coherent case studies for the Thesis comes from the need for a holistic view on the topic. As mentioned in chapter 3, Nature-based-Solutions started to become an alternative to traditional coastal protection measures only in recent years, and information on their potential to produce territorial resilience, on their cost-effectiveness on the long-run, or on their multiple socio-economic and environmental benefits in comparison to the more traditional and hard approaches are limited and often unexplored. To have a solid starting point for the research, a set of 7 criteria has been defined to guide the selection, the analysis and the comparison of different types of NbS case studies in Denmark.

C) Defining the general context and description of the Criteria:

before introducing the criteria (listed and explained in paragraph 3.4.), which have been used to select, understand, and later to compare the different case studies, it is worth mentioning some general aspects which have been taken into consideration ex-ante to guide the selection process. First, all NbS which have been taken into consideration were developed on the Danish coastline. Second, all case studies are located in areas which are at risk of flooding due to sea level rise, coastal erosion and/or storm surges. Third, all selected case studies do directly protect and support coastal settlement, areas where no human activities are under threat are not considered into the analysis.

D) Limitations:

in Denmark, data on Coastal NbS are not collected in a systematic and organized way, making it often difficult to find matching or comparable information for different case studies.
As matter of fact, coastal protection and coastal governance are extremely fragmented procedures which are exercised by multiple agencies, authorities or stakeholders at various levels (from local landowners to regional authorities, to national agencies and so forth). These yes do operate under the supervision of the DCA, but all individually and not systematically together. This matter of facts represents a limitation for the Thesis, since not all criteria can be explored and compared equally throughout the analytical part of the analysis. Another limitation is given by the newness of the approach to Nature-based-Solution as an alternative to traditional hard engineered solutions in the field of coastal protection. In fact, many of the projects which have been developed over the last two to three decades are still in work-in-progress, and final data on their effectiveness are not yet available or are limited in many aspects. The last identified limitation of the research is that each Coastal NbS which has been selected for the Thesis is directly related to the protection and the enhancement of human well-being in vulnerable coastal areas. The selected projects focus on touristic areas, human settlements or on areas which host relevant human activities (agricultural or industrial activities), and not on NbS which exclusively orbit around the protection of Natural areas and resources.

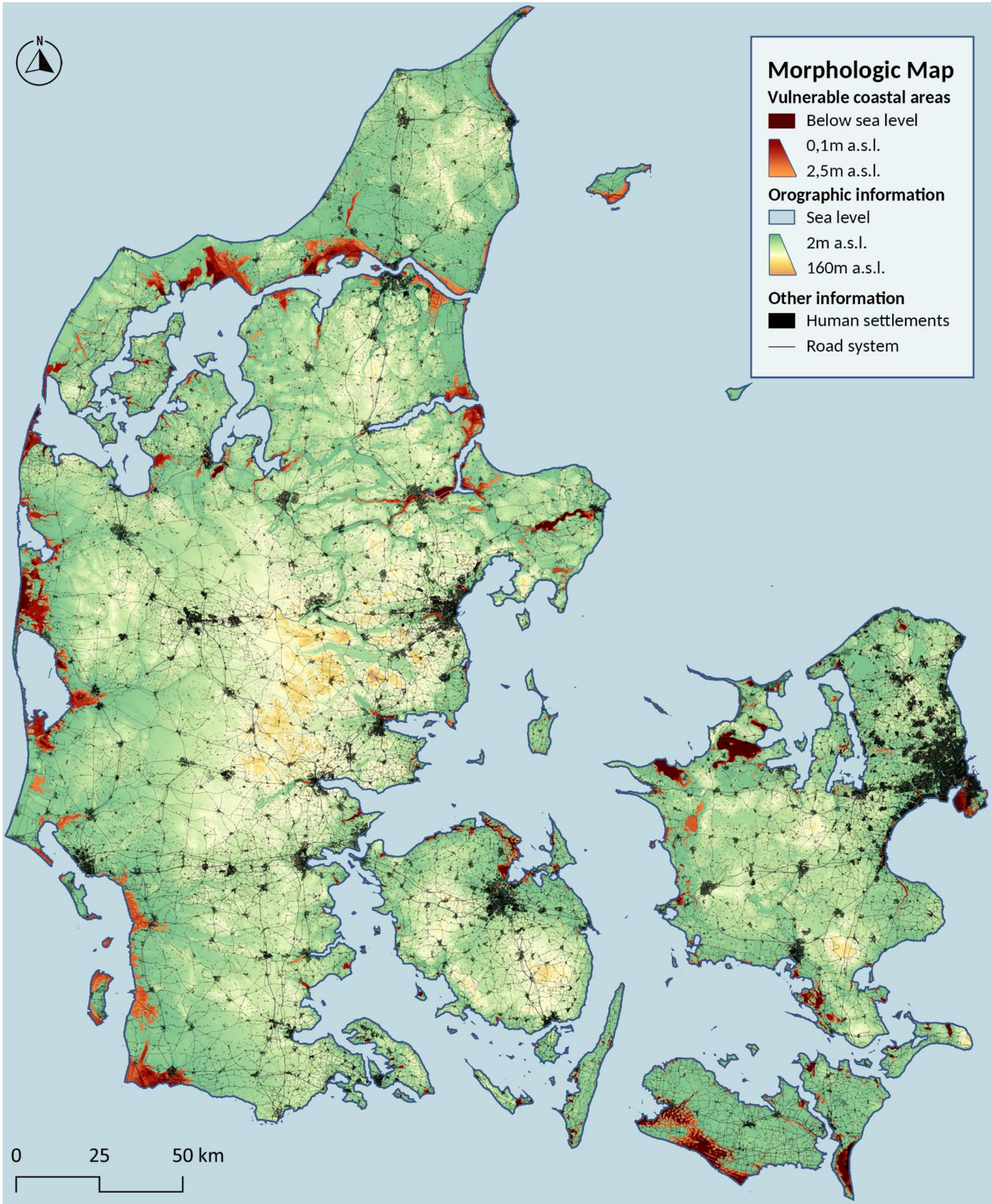

Fig. 7. Danish low-lying areas at risk of extreme weather events and storm surges (2.5m AMSL). Data from: Personal QGIS elaboration, developed with dataforsyningen.dk data

3.4. Comparison Criteria

Criterion 1 - *Have there been any changes in terms of land use over time?*

The first criterion seeks to highlight land-use variations along the vulnerable coastal areas, before and after a NbS has been implemented and developed. Insights on local land management dynamics help to better understand the possible intervention's Trade-offs for both the socio-economic sphere and the environmental sphere and can therefore support the final evaluation.

Criterion 2 - *Did the NbS bring socio-economic benefits to the local sphere?*

Analyzing the socio-economic benefits which NbS can produce is essential to evaluate their overall effectiveness and to communicate these to different stakeholders. This criterion focuses on the ability that NbS have to archive risk mitigation, environmental protection, and improve the social and economic well-being of local societies. On one hand, this process provides a framework for understanding impacts and benefits of NbS, (policymakers, communities, businesses and more), on the other hand, it promotes and incentivizes the adoption of NbS in the conservation, the protection and the sustainable management of existing human and natural resources.

Criterion 3 - *Did the NbS bring benefits to the local ecosystems?*

In line with criterion b, it is important to define all benefits which NbS can provide to local ecosystems, to be able to understand their ecological impacts, assess their effectiveness and sustainability, and communicate these outcomes to different stakeholders. Since NbS mostly rely on natural processes and existing ecosystems, important indicators for the final evaluation are Ecosystem Services, of which the most common ones are the shoreline stabilization, flood regulation, water purification, as well as habitat provision.

Criterion 4 - *Can this NbS be considered a Resilient Solution?*

To understand if a given NbS is resilient, their ability to absorb disturbances, recover from impacts, and adapt to changing condition while maintaining their functionalities and effectiveness in coastal protection must be proven. Indicators to support the study can be the capacity of NbS to withstand storm surge events, resist to coastal erosion phenomena, support the thriving of biodiversity, to be able to adapt to the future sea level rise or to recover from other coastal disturbances.

Criterion 5 - *Who financed the intervention costs of the NbS?*

Acknowledging the funding sources of existing NbS can help developers, planners and stakeholders to find same or similar fundings for future projects, facilitating the up-scaling process for a wider implementation of NbS. On the same purpose, it can be relevant to know Partnerships and Collaborations which have been involved in the project, since collaborating with some could enhance the overall credibility of the project and therefore secure financial backup. Finally, understanding how and why past projects have been accepted can help stakeholders, planners and developers to mature projects which are likely to meet funder expectations, and thus increase the chance of securing financial support.

Criterion 6 - *Has the NbS been a soft solution or a hybrid solution?*

NbS are commonly classified into two sub-categories according to the extent to which their development, maintenance and functioning relies on human intervention. Soft solutions rely predominantly on natural processes and ecosystem conservation, most common examples in Denmark are linked to Salt Marshe restorations, Dune Stabilizations and Beach Nourishments.

Hybrid solutions leverage the benefits of both natural and engineered approaches to achieve sustainable coastal management. In this case, examples which can be found in Denmark are linked to Living Shorelines, Green infrastructures with Grey Engineering or Urban retreats for Nature Restoration. Understanding these differences can help to better frame the case studies and understand which types of coastal NbS are more effective and why they are more effective.

Criterion 7 - *Did the NbS lead to further local/regional/national/international types of protection?*

Knowing whether NbS lead to types of environmental protection is of significant importance for targeting conservation efforts, ensuring compliance with legal frameworks, enhancing collaboration and coordination, promoting long-term sustainability of the case study areas and to contribute to global environmental goals which are rising in recent years in relation to climate change.

3.5. Introduction to the Case Studies

The next segment of chapter 4 is going to introduce and analyze four different case studies which have been selected along the Danish shoreline. Each project is unique in its kind, but all of them rely on a Nature-based Solution approach to archive the protection of vulnerable coastal settlements, infrastructures, activities, or natural environments. To facilitate the selection of best practices, the previously shown coastal vulnerability map has been used.

Fig. 8. Setting the context, geolocation of the four selected case studies across Denmark. Data from: Personal QGIS elaboration, developed with dataforsyningen.dk data.

3.5.1. Køge Bugt Strandparken case study

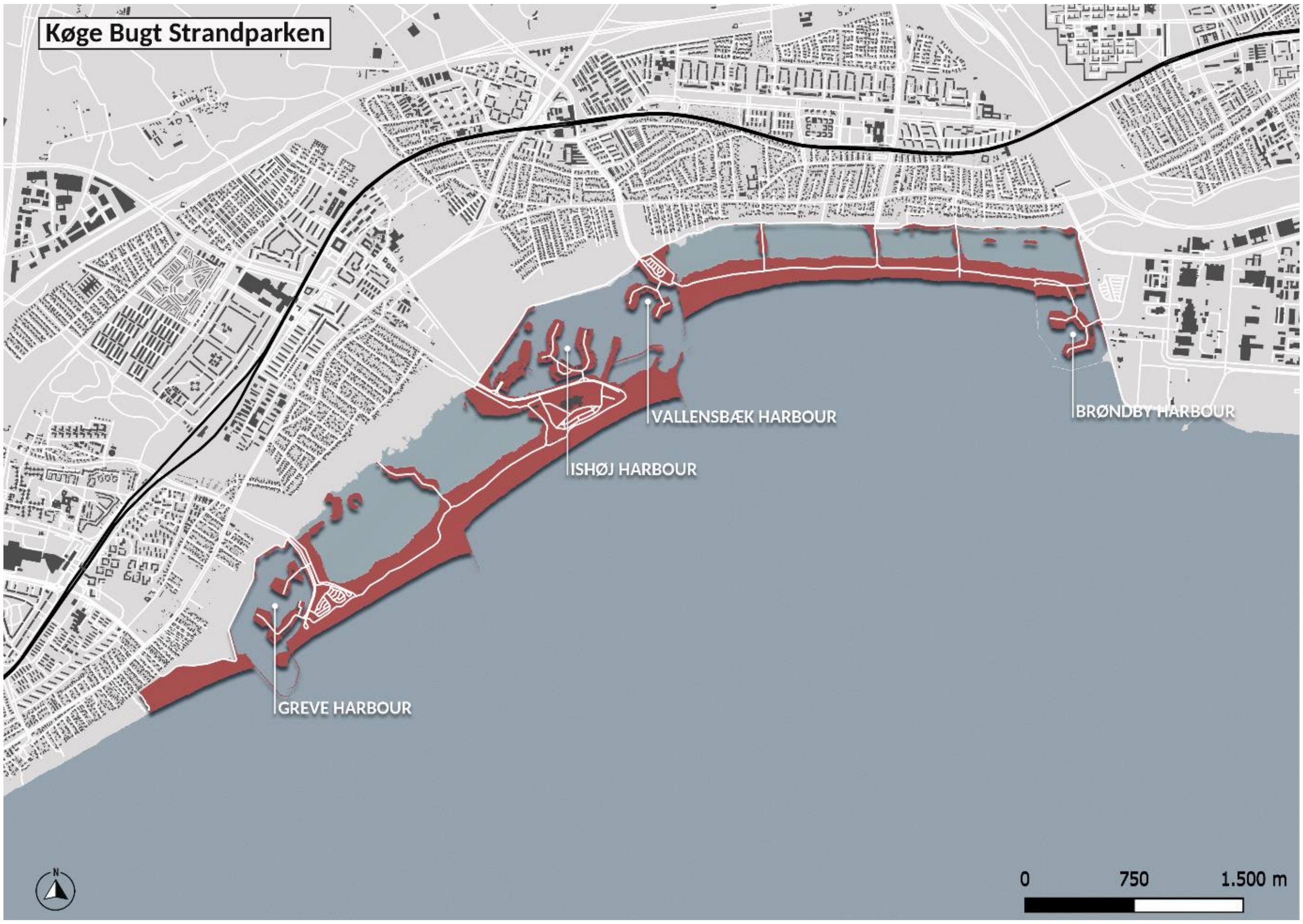

Fig. 9. Setting the context, aerial view on Køge Bugt Strandparken project (2023). Data from: Personal QGIS elaboration, developed with dataforsyningen.dk data

Case study description:

Køge Bay Beach Park (Køge Bugt Strandparken) is a 7km long offshore coastal protection project located in Koge Bay along the municipalities of Greve, Ishøj, Vallensbæk, Brøndby and Hvidovre. This artificial barrier-island was first inaugurated in 1980 (Lorentzen, 2012) and is up to date one of Denmark's largest coastal protection projects to focus on both protecting of the low-lying hinterland from flooding and on enhancing local environmental and ecological values. Historically, the residential areas built along Køge Bay in the 60s and in the 70s were lacking in recreational areas (playgrounds, parks or green spaces), presented poor quality coastal landscapes and suffered from chronic coastal erosion (Jørgensen et., al., 2022). With the goal of creating new recreational landscapes, to slow-down beach erosion and to increase local ecological values, in 1975 a general partnership (Køge Bugt Strandpark I/S) between the affected municipalities and two regional authorities was established to develop Køge Bay Beach Park (Faragò et., al., 2018).

The two main protection islands of Køge Bay Beach Park have been built upon pre-existing natural longshore sand bars (highlighted in Fig. 10, segment A and segment B), and connected to the mainland through a system of piers and pathways. The two islands were further enriched through natural elements over the past 30 years, most important ones are vegetated sand dunes, salty marshes, wide beaches, interconnected lagoon systems and small woodlands to mimic local environments and support the thriving of biodiversity. On the other hand, the presence of different recreational spaces such as parks, playgrounds and sport facilities, or shops and museums support and enhance local socio-economic well-being and the local touristic appeal.

In the following section the analysis criteria are going to be developed for this case study, in order to gain a better understanding of the outcomes of the implemented solution, on the local socio-economic and environmental spheres.

Criteria analysis:

a) Have there been changes in the land-use typologies over time?

Køge Bugt Strandparken is an extraordinary example in which land-uses have been significantly changing over the past 50 years of its lifespan. In fact, before the Strandpark project was finished in 1980, the whole offshore area between the municipality of Greve and the municipality of Brøndby was a complex of naturally formed barrier-islands in constant transformation due to coastal erosion and were not accessible at all to humans. Artificially reinforcing with concrete and clay these natural systems made the area stable and permanent, becoming a playground for human activities and an important natural space for rich and diverse coastal biomes.

Human land uses today: The area that back in the 70s was exclusively natural, today hosts 12 permanently open gastronomic activities (9 caffes and 3 restaurants) and, close to the four harbors, hosts different sport facilities and workshops. To attract residents and tourists, the Strandpark provides also 3 playgrounds for kids, 2 camping areas, a museum (ARKEN, museum of modern arts), a Nature Center (Naturcenter Havhytten), and 12 public sand beaches where swimming and water activities are allowed.
In terms of connectivity, all the listed facilities and attractions are in reach of the 4 train stations (in Greve, Ishøj, Vallensbæk and Brøndby) and connected over the islands through bicycle lines, pedestrian paths or

car roads (also further supported by 8 large parking lots).

Natural land uses today: Even if at the current stage of the project the area is widely accessible to humans, many places are protected and kept natural to enhance biodiversity and safeguard the local coastal identity. To achieve these goals the 6 water bodies, which separate the natural barrier from the coastline, are sites of land reclamation which through a dynamic self-design process became lagoon biomes. Also, directly on the artificial islands, many areas have been kept as in the original scenario: for example, the areas close to the seaside are rich in vegetated sand dunes and wide sandy beaches, while other areas on the island's inland are of public green and host some woods, wetlands and salt meadows.

b) Did the NbS bring socio-economic benefits to the local sphere?

After the establishment of Køge Bugt Strandparken project many aspects have been changed at the local level. The original goal of the project was to make the four municipalities of Greve, Ishøj, Vallensbæk and Brøndby more attractive to new residents and resilient to coastal erosion.

In fact, especially during the 60s and the 70s when the urban areas were expanding, the lack of urban green spaces, spare time and recreational activities in the municipalities were big problems. On the other hand, the natural coastal landscape was poorly maintained and suffering from constant coastal erosion which was reducing the width of local sand beaches and reducing local tourism.

Køge Bugt Strandparken has been a project, able to solve most of the previously listed problems and threats by offering a new system with a vast gamma of different facilities (cafes, restaurants, museums, harbors...) and activities both to local inhabitants and to tourists (tracking, sailing, outdoor playgrounds, beaches...), being in this sense an important socio-economic profit project.

Then, its protective function against sea-level rise and storm surges represents another important socio-economic benefit to the local municipalities, especially given the fact that their historical city-centers are in low-lying areas close to the seaside, and so, at high risk of getting flooded.

c) Did the NbS bring benefits to the local ecosystems?

Until the point when Køge Bugt Strandparken project was completed in 1980, the coastal area of the municipalities of Greve, Ishøj, Vallensbæk and Brøndby was poorly maintained and in bad shape. Coastal erosion was progressively damaging the coastal environment of large sandy beaches and threatening the narrow inland wetlands and meadows. At the current stage, the new land reclamation project brought massive benefits to the local ecosystem: the lagoon system is considered a healthy natural area were eelgrass species are thriving (while they are disappearing in many fjords and coastal areas in Denmark); the dune system on the new shoreline is well maintained and populated by local grass species; the inland woods and meadows are home to a vast variety of autochthone flora and fauna, rare or red listed bird species and, thus, rich in biodiversity and the beaches which originally were disappearing are re-established and well maintained. An important note is also to highlight the fact that, thanks to its location (in shallow waters and relatively protected from strong winds) the project has reached stability and the maintenance costs are limited and reduced by these factors.

d) Can this NbS be considered a Resilient Solution?

Over the past 13 years, the Danish Coastal Authority (DCA) identified 10 areas in Denmark which are particularly at risk of flooding, and Koge Bugt is one of these sports. Especially the municipalities of Tårnby-Dragør, Ishøj, Solrød Strand and Køge are the most vulnerable ones in the Bay and, according to the report ''Cities' challenges with sea level rise and storm surge'' (Byernes udfordringer med havvanstigning og stormflod) published by (COWI, 2017), more than 180.000 residents are currently at flood risk in a 1 in 100 years storm surge event. Low-lying hinterlands, historical city centers close to the seaside combined with local sea level to rise in the area, expected to reach a height of up to 100cm more than the normal case are the main factors which lead to endanger this coastal landscape.

On this regard, Køge Bugt Strandparken project represents an important Climate Adaptation case study. The main objective of the project is to safeguard the residential areas of Greve, Ishøj, Vallensbæk and Brøndby close to the seaside with a semi-natural barrier system. The main protection element which protects the hinterland is the reinforced sand dune area on the Strandpark seaside. This dune system is reinforced from the inside by a hard clay structure which keeps the sand dunes in place and is then covered by a sand layer and local vegetation to resist wind and water erosion. The average height of the dunes is 2,5m and stay out of the 1 in 100 years storm surge event.

Furthermore, the coastal lagoon system which separates the artificial barrier from the inland is regulated by 3 sluice gates which, in the case of high-water levels, mitigate the storm surge and the backwash flooding risks for the residential areas.

Even if Climate Mitigation is not the main target of the project, having multiple vegetated areas with trees, eelgrasses and green spaces contributes to sink carbon emissions at a local level, compared to the original stage of the coastal landscape before 1980.

Therefore, the project can be considered a well-designed hybrid solution with hard and soft elements which archives Climate Resilience and a multi-benefit outcome for the local ecosystem (both human and natural).

e) Who financed the intervention costs of the NbS?

The idea to realize Køge Bugt Strandparken was first taken into consideration in 1936, as the seminal plan for 'Green areas for Copenhagen' was established. However, until 1975 no changes happened at the local level and only after a decentral formal partnership took place (between seven municipalities along the Bay and two regional governments), the project started. The size of the project and the size of the involved partnership stakeholders highlight the scale importance of the project of regional interest. Construction costs were covered by funding from the national level and by the local municipalities, while operation costs were covered by the two regional governments (45%), the cities of Copenhagen and Frederiksberg (32%) and the municipalities of Hvidovre, Brøndby, Vallensbæk, Ishøj and Greve (Faragò et., al., 2018). Up to date, the maintenance costs of the project are covered by the municipalities of Greve, Ishøj, Vallensbæk and Brøndby and are in a range of DKK 10M each year.

f) Is the NbS to be considered a soft solution or hybrid solution?

Køge Bugt Strandparken can be considered a hybrid-type solution since different hard and soft elements are used in the NbS. Hard elements are all the concrete and clay reinforcements which were carried out to stabilize the original natural barriers and they consist of:
- three outgoing peers which reduce the coastal erosion along the new beaches,
- inner clay reinforcements of the sand dune structure to avoid wind blowout spots and water erosion
- sluice gates which regulate the inner water level of the six lagoons.

Along the hard engineered elements, we can also find many soft elements which make this case study a NbS an example of Hybrid solution, these soft elements are:
- autochthon grass species which stabilize the sand dunes from outside
- open green patches which create natural habitats like meadows and marshes
- woods which give space to special environments for a rich biodiversity
- lagoons which replicate the original state of the case study area and protect the local identity and serve as buffer area for the residential areas in the hinterland.

g) Did the NbS lead to further local/regional/national/international types of protection?

No, the project did not lead to any sort of further protection of the case study area.

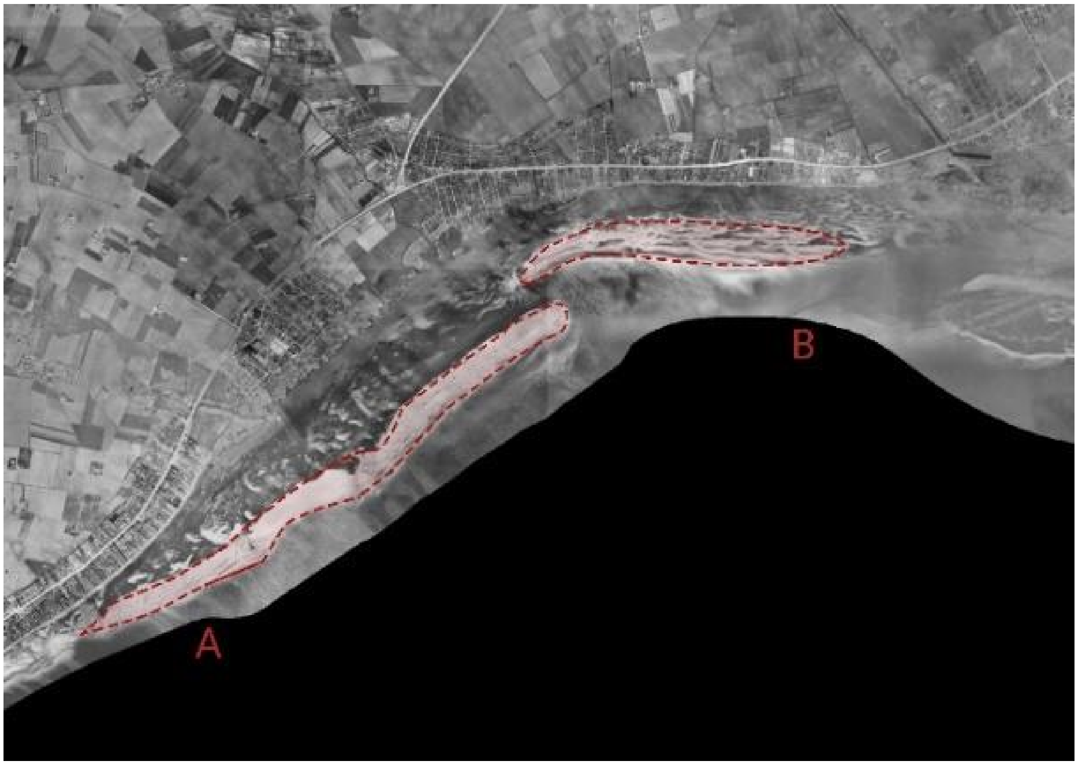

Fig. 10. Orthophoto of Køge Bugt Strandpark (1954), original offshore sand bars highlighted in red. Data from: Personal Photoshop elaboration on kb.dk/danmarksetfraluften data

Fig. 11. Setting the context, current land-use destinations in Køge Bugt Strandparken (2023). Data from: Personal QGIS and Photoshop elaboration on dataforsyningen.dk data

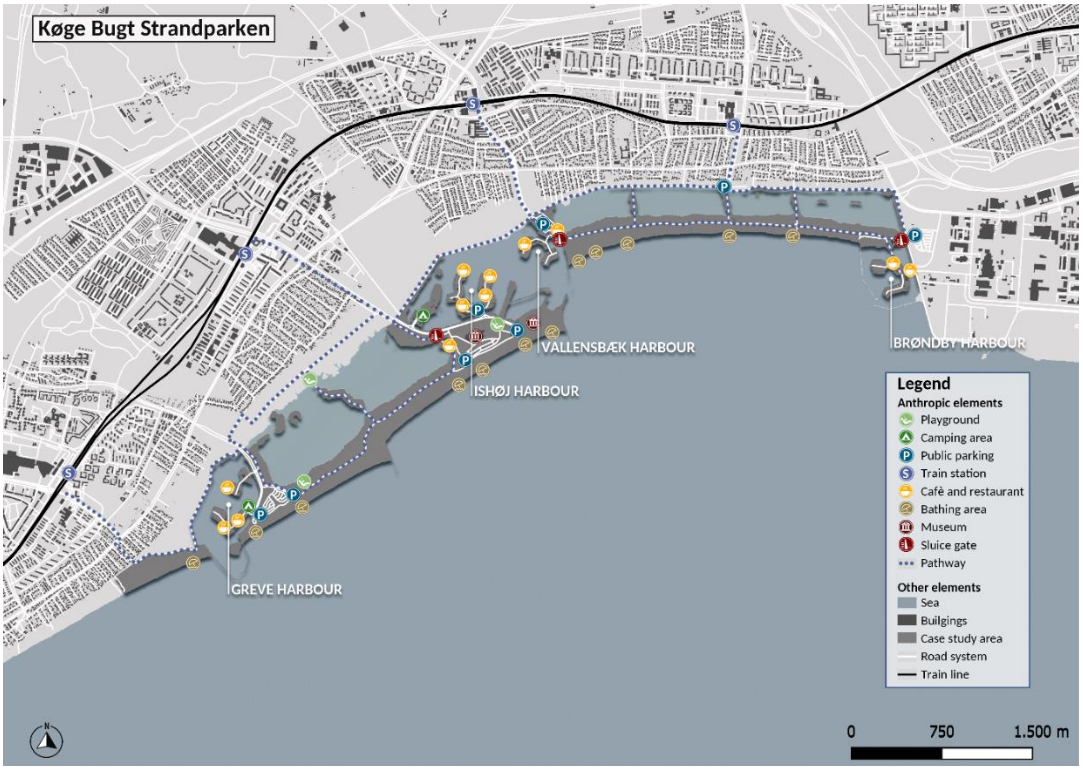

Fig. 12. Setting the context, socio-economic improvements in Køge Bugt Strandparken (2023). Data from: Personal QGIS and Photoshop elaboration on dataforsyningen.dk data

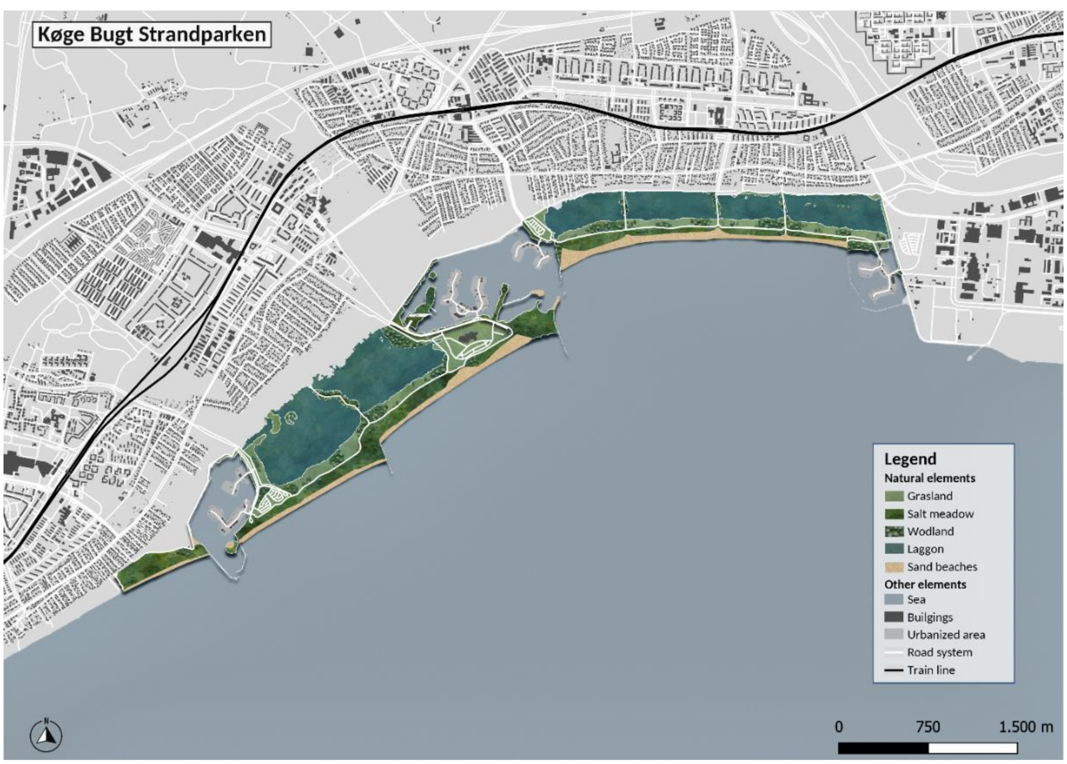

Fig. 13. Setting the context, environmental improvements in Køge Bugt Strandparken (2023). Data from: Personal QGIS and Photoshop elaboration on dataforsyningen.dk data

3.5.2. Seden Strand case study

Fig. 14. Setting the context, aerial view on Seden Strand project (2023). Data from: Personal QGIS elaboration, developed with dataforsyningen.dk data

Case study description:

Seden Strand is a 42ha wide Nature-based Solution implemented along the Odense Fjord in Seden Strandby (Odense) between 2020 and 2023 (L. K. Sønderby, 2023). The primary goal of this project is to protect Seden (counting 142 homes) and its surrounding agricultural lands from coastal flooding; by enhancing local coastal landscapes and improving existing Natura2000 sites (Reconect, 2019). The case study area is included in the Danish high risk coastal areas identified by the EU Flood Directive (2007/60/EC) due to progressive sea level rise, and the increasing storm intensity in low-lying areas. Historically, Seden's low-lying hinterland was secured by a hard engineered dike system but expected higher water levels in future (2.40m above normal sea level) and increased flood frequency over the past decades represented a limitation for the existing defenses (Reconect, 2019). With the support of Odense

Municipality, Amphi Consult, and Rambøll Danmark a new and holistic coastal defense system has been developed and established, rooted upon Nature-based Solutions.

Main interventions in the project have been the re-location of the pre-existing dike systems (from the shoreline, closer towards the settlement) and their structural change to better merge-in with the historic local coastal landscapes. The gained area between the new and the old dikes, which previously was agricultural land, now functions as buffer area to break-down wave intensity during extreme weather events and is left free of use to undergo a natural and 'self-designed' rehabilitation process towards the lost natural habitat of the past. Finally, the agricultural drainage system has been reshaped to follow the original meanders and facilitate the development of salt meadows and tidal creeks.

In the following section the analysis criteria are going to be developed for this case study, in order to gain a better understanding of the outcomes of the implemented solution, on the local socio-economic and environmental spheres.

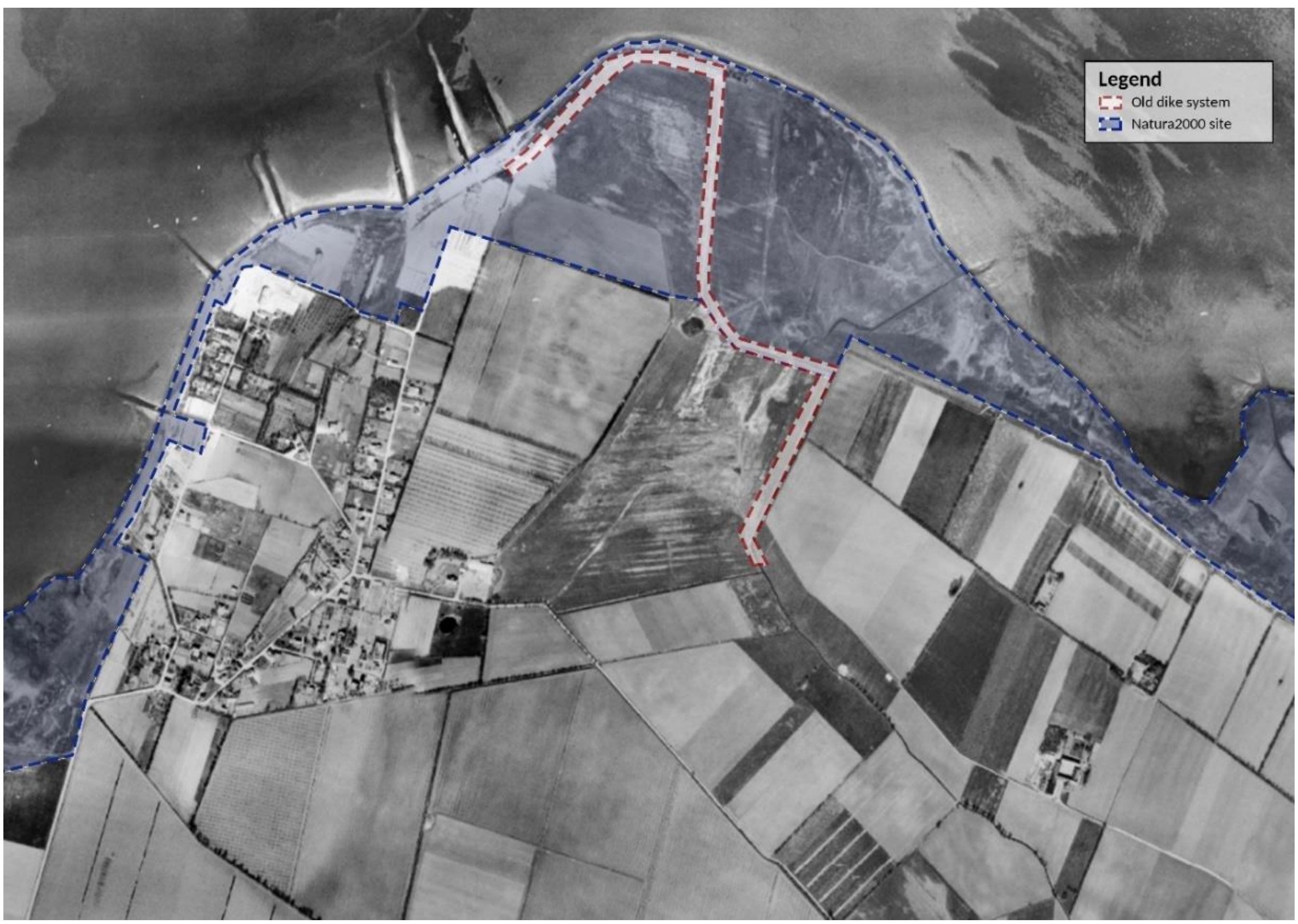

Fig. 15. Seden Strand project area (1954), hard-engineered coastal defense and Natura2000 site. Data from: Personal Photoshop elaboration on kb.dk/danmarksetfraluften data

Criteria analysis:

a) Have there been changes in the land-use typologies over time?

Seden Strand is a case study in which land-use typologies have changed only to a slight extent from the pre-intervention scenario to the post-intervention scenario. The main transition happened on 27ha of agricultural land located between the old dike system (on the coastline) and the new protection elements developed along the residential area. Recently, these the use of these chunks of land has been converted from farmland-use to natural habitat, in order to support the protection and the thriving of autochthonous coastal environments inside the designated Natura2000 area. Along this intervention of farmland re-naturalization, 2ha of woodland have also been removed to facilitate a natural transition of the area towards salt marshes.

Human land uses today: No permanent structures have been developed in the case study area. It is however worth mentioning that a pedestrian pathway has been laid down along the coastline to facilitate a limited access to the case study area, along with two observation towers to practice birdwatching.

Natural land uses today: Even if at the current stage of the project the area is still accessible to humans, most places are protected and kept natural to enhance biodiversity and safeguard the local coastal identity. Most of the case study area (approximately 27ha out of the total 42ha) is of Natural use, and only a limited area is used as agricultural land.

b) Did the NbS bring socio-economic benefits to the local sphere?

Once the Seden Strand project was completed, many aspects changed at the local level from a socio-economic perspective. First, and most relevant benefit archived by the NbS is the total protection of the local residential area. As stated before, the frequency and intensity of extreme weather events increased drastically in Seden Strandby over the last decades representing a consistent challenge to the existing hard engineered dike system (Reconect, 2019). During periods of heavy rainfall, it was already necessary to use water pumps and sandbags to protect the citizens and residential buildings from being flooded, resulting in high economic expenses for the Odense municipality (Odense municipality, 2020). Many future-scenario analysis for the case study are (which consider in the process both the progressive sea level rise and the increasing intensity of winds in the future), foreshadow extreme events of storm-induced coastal floods with water levels up to 2.40m above the average sea level, making the development of a new coastal defense system a mandatory task.

Besides the obvious benefit of coastal defense and damage reduction for the urban settlement, the project also functions as a protection element for the surrounding agricultural lands. Without the new defense system these areas would suffer from soil salinization and saltwater intrusion processes in the existing freshwater bodies, making agricultural cultivation an impossible task. Finally, the development of the Natura2000 site also has the potential to become a future attraction for slow tourism, offering it different spots for birdwatching, and different pedestrian pathways along rare local and natural coastal habitats.

c) Did the NbS bring benefits to the local ecosystems?

As the socio-economic sphere, also the environmental sphere benefitted a lot from the recently implemented Nature-based Solution. In fact, starting from the end of the 19th century (when the construction of the first local dike system took place) the whole open area on the north-eastern side of Seden Strandby was transformed from its original landscape into agricultural land. Prior to the first dike establishment, which enabled the land-reclamation process in favor of farmland, the whole area was characterized by a mix of habitats stretching from salt marshes to meadows, to grasslands, to open wetlands. Currently, about 27ha of the occupied agricultural land are undergoing a self-design process to transit from their current state towards a new and more natural state. The main goal is to support the development of local biodiversity and support the existing Natura200 site and therefore strengthen the local ecosystem.

To further support a smooth transition towards natural landscapes, the project re-established the original river meanders which had been lost during the agricultural use to, on the one hand mimic the original waterflow, and on the other hand to facilitate the interaction between freshwater bodies and the sea. A positive co-benefit of this operation is the reduction of Nitrogen levels in the Odense fjord, by reducing the agricultural discharges in the rivers for an overall better water quality.

d) Can this NbS be considered a Resilient Solution?

Similarly to Køge Bugt Strandparken, the Seden Strand project has also been developed in one of the 10 high risk areas identified by the EU Floods Directive (2007/60/EC) as directly threatened by coastal floodings. To safeguard Seden Strandby's 142 residential buildings, its agricultural lands and the surrounding coastal habitats from extreme weather events, the implementation of a new holistic coastal defense system was developed, funded and implemented between 2020 and 2023.

The newly implemented coastal defense system orbits around both climate adaptation and climate mitigation processes. On this regard, the case study can be defined a climate adaptation system, since its main goal is to reduce the vulnerability of both the local community of the Seden Strandby district, and of its surrounding natural coastal environments. To cope with current and future challenges, the NbS works with open natural areas which reduce the wave intensity during extreme events; and it works on the managements of backwash flooding through the redevelopment of historical natural water bodies and wetlands. At the same time, the Seden Strand project is a valuable example of a climate mitigation project. In fact, the case study converted agricultural land into natural areas to reduce the discharge of fertilizers and Nitrogen into the Odense Fjord, and by developing natural habitats it supports carbon sink mechanisms.

Overall, the project seeks to develop a new coastal system able to adapt to changing challenges and threats, and therefore can be framed as a proper Resilient solution.

e) Who financed the intervention costs of the NbS?

Investment for the Seden Strand project has been collected through a combination of public and private fundings. The main actors involved in the funding of the project were the European Union (through the European Union's Horizon 2020 research and innovation programme) under grant agreement No. 776866, the municipality of Odense and local stakeholders.

f) Is the NbS to be considered a soft solution or hybrid solution?

Differently from its past, the Seden Strandby's new coastal protection project relies more on natural design elements than on hard engineered ones and can be considered a soft solution. In fact, even if the project operates with some harder elements, these are well integrated in the natural environment and can fit into soft-design elements. The new dike system (the only 'hard' element implemented in the case study), is approximately 15m wide and 2,5m heigh; this smooth structure is covered by sand, earth and wooden elements to mimic the natural environment, allowing horses and cows to graze on its surface. Other elements which are part of the project are the old agricultural land which is undergoing a self-design process to become a natural habitat and is characterized by salt marshes, meadows, wetlands and other local environmental components.

g) Did the NbS lead to further local/regional/national/international types of protection?

One goal of the project is to support the already existing Nature2000 site (Odense Fjord, Natura area nr.110), established by the EU Habitats Directives (92/43/EEC) which seeks to protect the most vulnerable and threatened species and habitats at the European level. Therefore, the project is not directly leading to further local or higher levels of coastal protection measures, but it seeks to enhance the already existing protection area and support their positive development adopting coastal adaptation and coastal mitigation measures for an overall stronger environmental resilience.

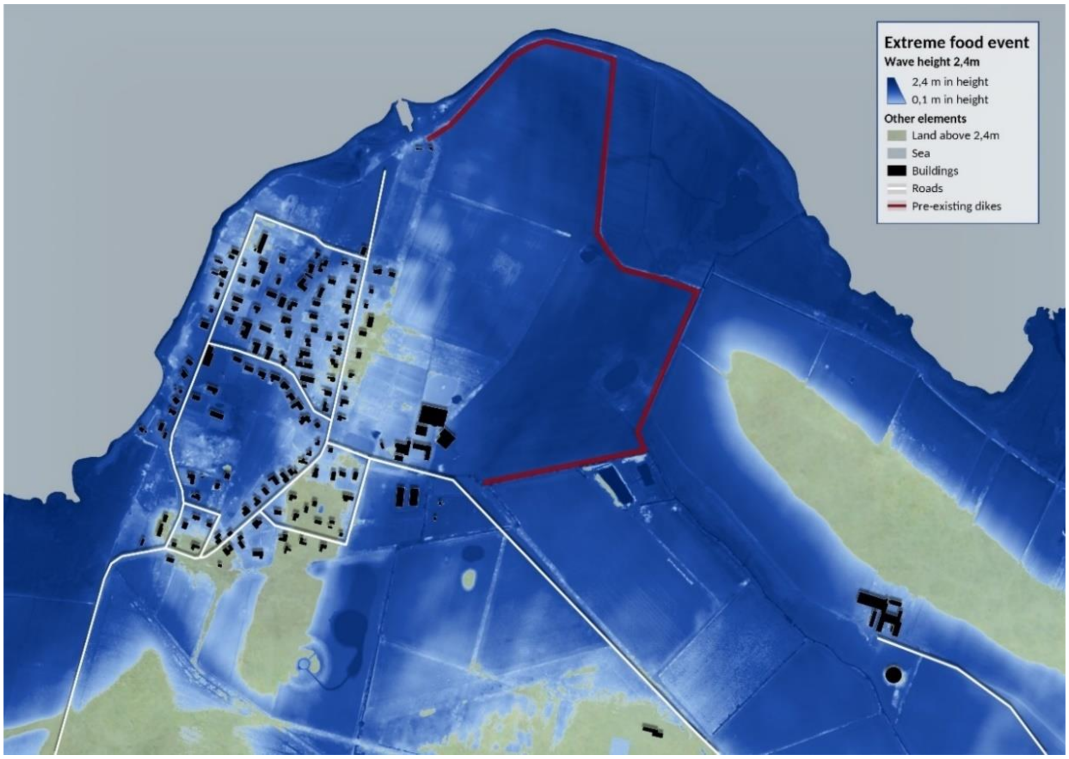

Fig. 16. Seden Strand, simulation 1: extreme events (water +2,40m AMSL) with the old dike system. Data from: Personal Photoshop and QGIS elaboration, on dataforsyningen.dk data

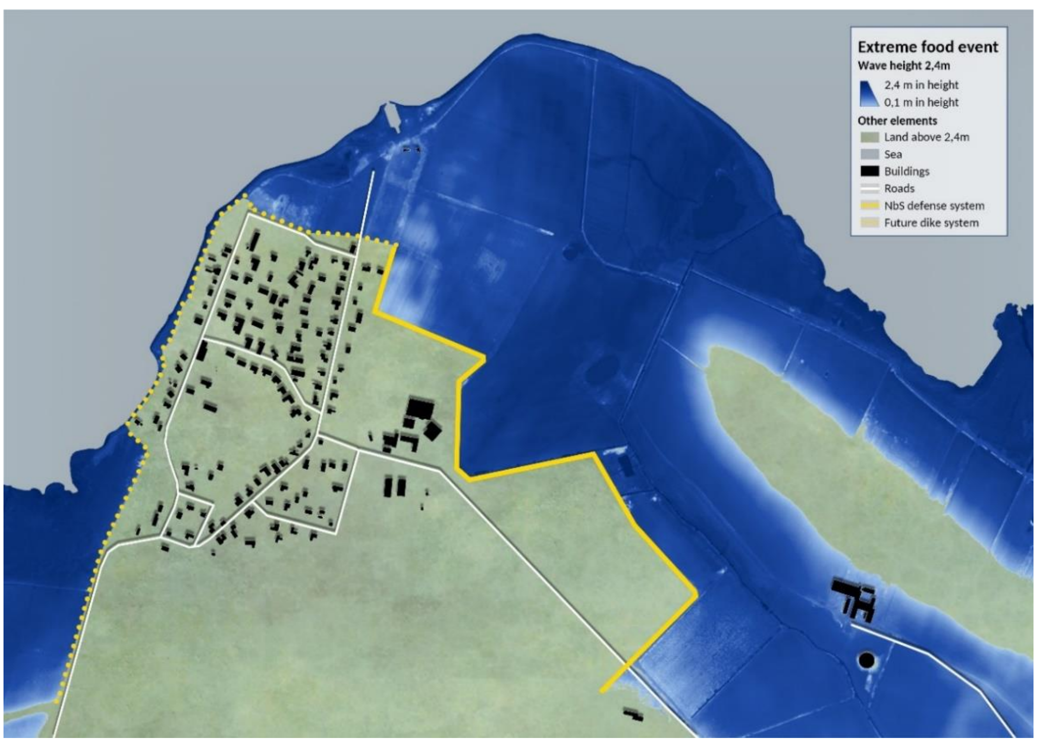

Fig. 17. Seden Strand, simulation 2: extreme events (water +2,40m AMSL) with the new Coastal NbS. Data from: Personal Photoshop and QGIS elaboration, on dataforsyningen.dk data

Fig. 18. Setting the context, the pre-intervention environmental status, Seden Strand (2014). Data from: Personal Photoshop and QGIS elaboration, on dataforsyningen.dk data

Fig. 19. Setting the context, the post-intervention environmental status, Seden Strand (2014). Data from: Personal Photoshop and QGIS elaboration, on dataforsyningen.dk data

3.5.3. Gyldensteen Strand case study

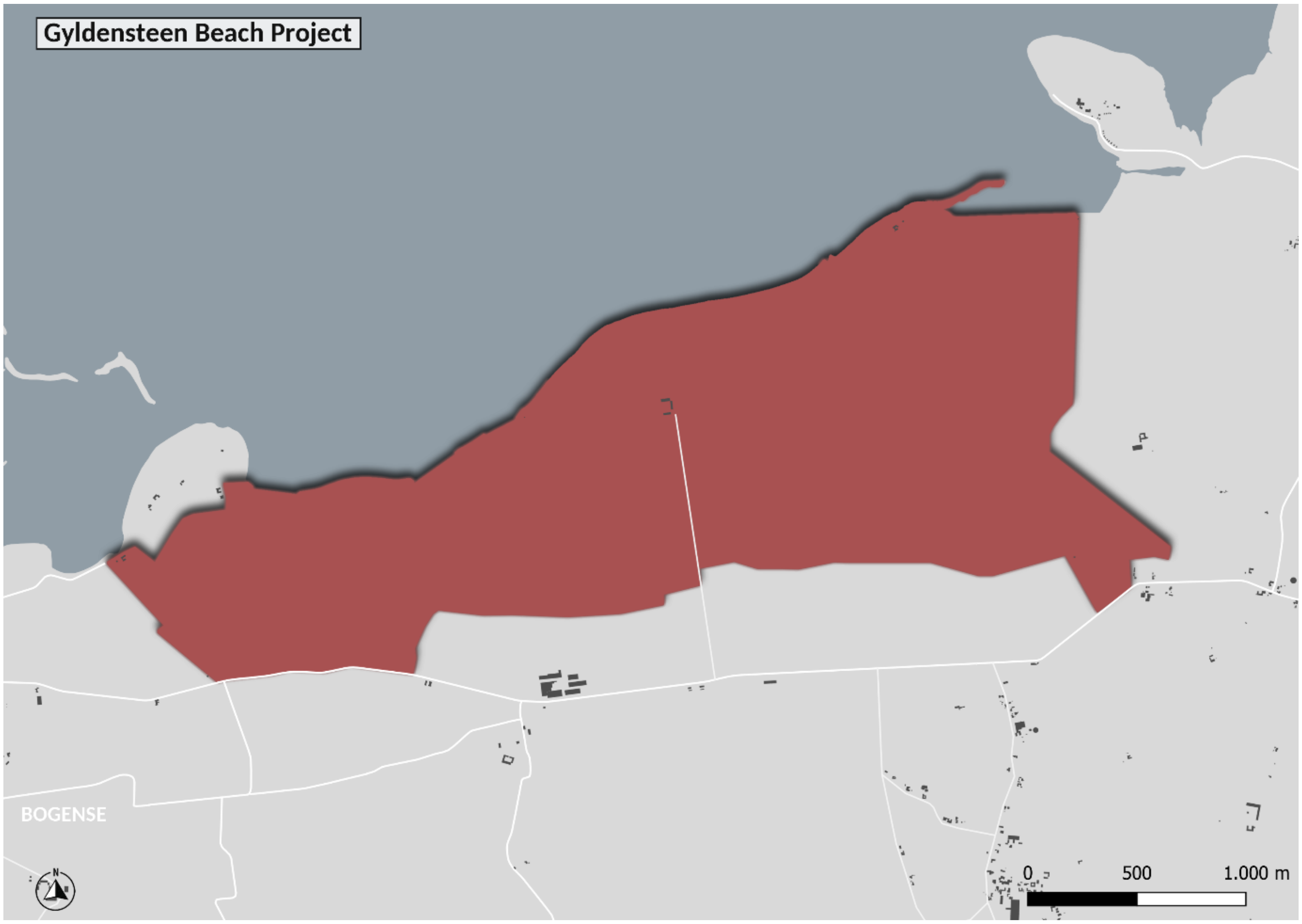

Fig. 20. Setting the context, aerial view on Gyldensteen Strand project (2023). Data from: Personal QGIS elaboration, developed with dataforsyningen.dk data

Case study description:

Gyldensteen Strand is a 616ha wide coastal protection area located 3km eastwards from the city of Bogense. The case study has been developed over the span of three years (from 2012 to 2014) and seeks to archive the local coastal resilience and to climate-proof the bordering town of Bogense. Recently, the analyzed project was designated as a Ramsar site and today it is part of a Special Protected Area (Bird Protection Area No. 76) and a Natura2000, area which together secure the safeguard and further development of local coastal habitats.

Historically, the case study and the surrounding coastal environments were characterized by shallow lagoons, salt marshes and marine areas but in 1871, due to the construction of a dikes and major land reclamation process, these areas were transformed into farmland. The dike system was modernized and reinforced in the 1960s, as new pump systems and dikes were implemented to protect agricultural lands from occasional floodings due to structural breaches induced by the sea. However, major storm surges in December 2013 significantly damaged the dikes and the local municipality, together with the current landowner (Aage V. Jensen Nature Foundation) decided to give the low-lying hinterland back to nature.

At the current state, Gyldensteen Strand is subdivided into three areas: to the westside, 214ha of land are covered by a shallow saltwater body, marshes and saline wetlands which mimic the local and historical lagoon environment. The central area (separated from the rest by the dikes built in the 1960s) is occupied by a 144ha freshwater lake, while the north-easter part of the case study is maintained as swamp environment with grazed meadows and minor freshwater ponds.

Finally, to secure the safety of Bogense and protect the surrounding agricultural lands, low-lying areas towards the south-western part of the project were reinforced by new 3m heigh dikes.

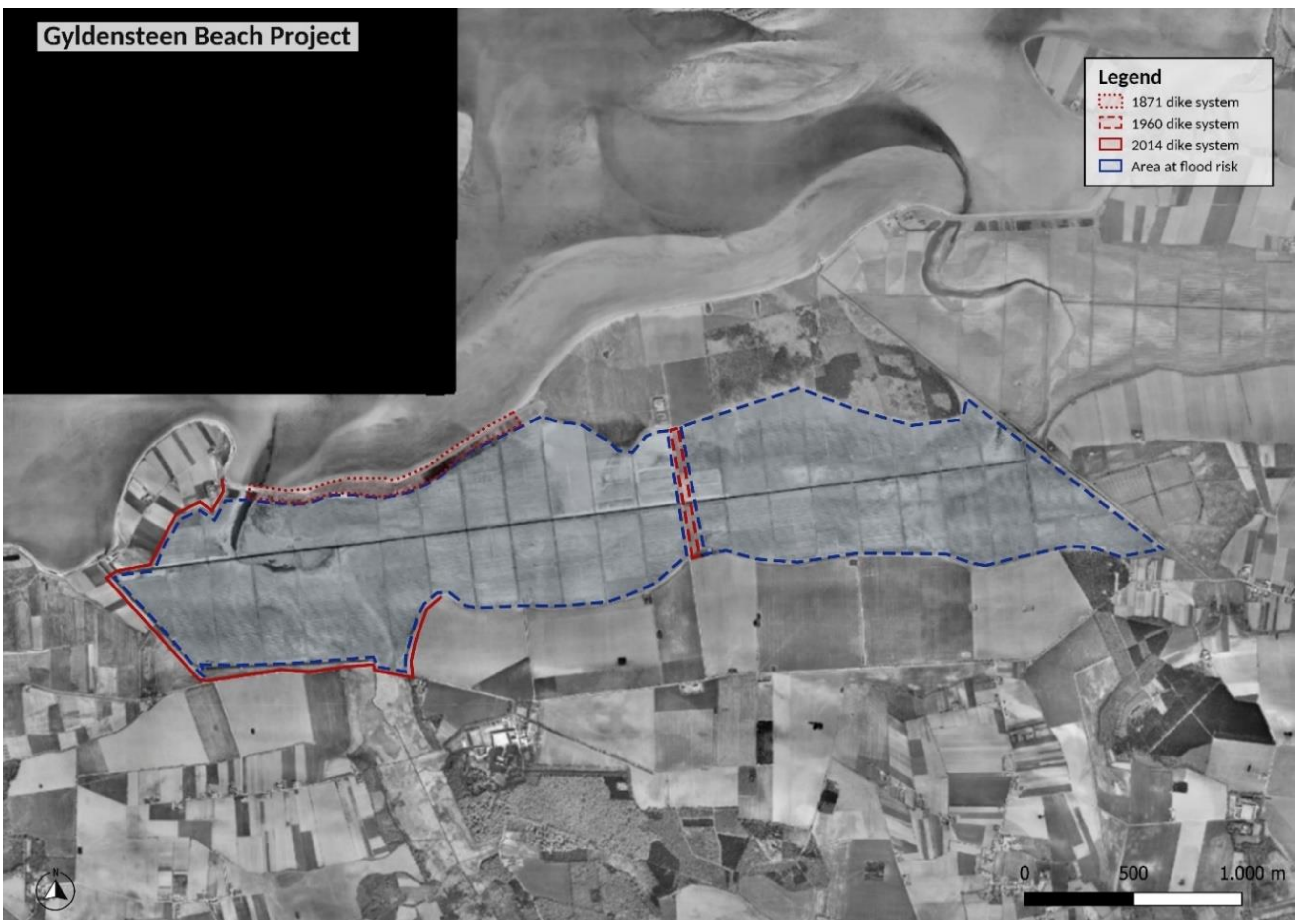

Fig. 21. Flood risk and history of coastal defense systems along Gyldensteen Strand project. Data from: Personal Photoshop elaboration, on 1954 kb.dk/danmarksetfraluften data

In the following section the analysis criteria are going to be developed for this case study, in order to gain a better understanding of the outcomes of the implemented solution, on the local socio-economic and environmental spheres.

Criteria analysis:

a) Have there been changes in the land-use typologies over time?

Gyldensteen Strand is a case study in which land-use typologies have changed significantly between the pre- and post-intervention scenario. Originally, most of the case study was occupied by shallow lagoons, salt marshes and other marine environments but, starting from 1871, dikes were constructed as part of a large land reclamation project to transform these areas into farmland. Occasional floods and dike breaches made crop cultivation a hard challenge and land was used for haymaking and cattle grazing until the 1960s as structural reinforcements took place and made the land stable. After 2014, as the Gyldensteen Strand project was completed, most of the area has been flooded and re-converted into the original natural habitat.

Human land uses today: No permanent structures have been developed inside the case study area. It is however worth mentioning that a pedestrian pathway, a cycling path and 5 parking lots have been created to facilitate access to the case study area without harnessing the protected environment, built along with 5 observation towers for birdwatching.

Natural land uses today: Even if at the current stage the area is still accessible to humans, most places are protected and inaccessible to enhance a natural development of biodiversity, and to safeguard the protected coastal environment and the Natura2000 site.

b) Did the NbS bring socio-economic benefits to the local sphere?

Resulting Socio-economic benefits which the Nature-based Solution offers to the local sphere are many. First, the protected area is up to date an important touristic and recreational destination given its multiple habitat and landscape observation spots, its pathways through diverse and variety-rich coastal environments, or even Camping and Picnic areas. This value is further supported by the different accessibility options, in fact local inhabitants and tourists can reach Gyldensteen Strand by car (the area is provided with 5 public parking lots and 3 handicap parking lots), by public transportation (mainly by bus) or by bike or foot, given the close proximity to Bogense. To highlight the impact that the protected area had on the local economy, the park attracted over 90.000 visitors in its first 1,5 years, which corresponds to an average of 160 plus visitors/day (Faragò et., al., 2018).

Besides the above listed benefits, the case study functions as a protection and risk reduction measure and guarantees storm surge protection and flood protection to both the municipality of Bogense, and all the surrounding agricultural lands by introducing a 616ha of buffer zone between the sea and the municipality and its agricultural lands. Without the new Coastal protection system, agricultural areas would still be exposed to soil salinization and saltwater intrusion in the existing freshwater bodies, making agricultural cultivation a near to impossible task.

c) Did the NbS bring benefits to the local ecosystems?

As discussed above, first the re-development and then the protection of the historical natural landscape was one of the main goals to achieve over the Gyldensteen Strand lifespan. The complex organization of the case study into three unique natural biomes led to different positive outcomes. Located on the west side of the project, the 214ha of coastal lagoon are directly linked to the open sea to the north and are therefore strongly influenced by high and low tide events. Access to the sea enriches the shallow inlet with nutrients and food sources, essential for the self-sustainment of the newly developing fauna and flora and the maintenance of the surrounding salt marshes and wetlands. The central part of the case study is today occupied by 144ha of freshwater bodies and meadow areas covered by changing water levels during the year to mimic the natural coastal dynamics. This area, along with the most natural area to the north-east (characterized by bogs, swaps, meadows and dry grasslands) are helping to restore lost fresh-water animals and plants back to the local coastal environment.

In the end, the Nature-based Solution has been very important to support the existing Natura2000 site and guarantee its protection through the establishment of a Special Protected Area framework.

d) Can this NbS be considered a Resilient Solution?

Similarly to the already analyzed case studies of Køge Bugt and Seden Strand, Gyldensteen Strand project also orbits around coastal protection by adopting a combination of natural and semi-natural protection mechanisms. To tackle the increasing threats of climate change, sea level rise and more frequent storm surge events, the municipality of Bogense had to act to protect its agricultural lands and its settlement form the sea and implemented a new holistic Nature-based Solution.

The recently finished new defense system seeks to archive coastal Resilience through climate mitigation processes first, but also climate adaptation processes. Climate mitigation is supported by the Carbon Sequestration function of the flooded agricultural land, here the new developing coastal habitats function as effective carbon sinks, sequestrating carbon from the atmosphere into soil. To compare, the release of CO2 coming from the 214ha of agricultural land was approximately 12.300 metric tons per year, while it was only 3,200 after land reclamation (Thorsen et., al., 2016).
Recent studies on Gyldensteen Strand highlight the extreme efficiency of both the salty coastal lagoon and the freshwater bodies in the carbon sink process, especially the saltwater flooded agricultural lands which even retains any methane development in the area (Malmborg, 2020). On the other hand, the project functions as a natural barrier (supported as well by the new dike system) between the open sea and the human settlements and the agricultural land, guaranteeing a risk reduction to the surrounding low-lying hinterland.

e) Who financed the intervention costs of the NbS?

To enable the land transformation process and the project development, all the 616ha of previous agricultural land had been acquired by the Danish Aage V. Jensen Naturfond foundation in February 2011, from the Gyldensteen Estate. Since in Denmark the general rule for coastal protection is ‘’the landlord is responsible’’, the development expenses were covered entirely by the Danish Aage V. Jensen Naturfond foundation, as well as the monitoring and research expenses of the ongoing project for the first eight years of its lifespan (2014-2021).

f) Is the NbS to be considered a soft solution or hybrid solution?

Combining different types of solutions in the overall protection system, the Nature-based Solution can be considered a hybrid solution. In this case, new and hard engineered dikes have been constructed and are not well integrated in the natural context. These barriers are yes covered with natural elements like earth, grasses, bushes and other natural elements, but the dike structure itself is steep and does not allow proper grazing making the structure a hard structure. Besides the dike system, no other hard engineered solutions are put in place along the case study.

All other elements which are part of the coastal protection mechanism are soft elements. In fact, the 616ha of prior agricultural land now function as a buffer zone between the sea and the low-lying hinterland were the wave intensity during storm surges and extreme weather events is broken down. The area is currently a complex natural habitat made of different coastal environments, reaching from salt marshes to meadows, to wetlands, to grasslands, to woodlands, to dry grasslands, to bogs interspersed by different saltwater and freshwater bodies.

g) Did the NbS lead to further local/regional/national/international types of protection?

Gyldensteen Strand, and other 12.500ha of land around the municipality of Bogense were already protected under the Birds Directive from 1983 onwards and identified as the Natura2000 'Æbelø og kysten ved Nærå' site at international level. Today, the protection of the area is further supported by a Special Protected Area (Bird Protection Area No. 76), and a Reserve which includes the north-eastern side of the project.

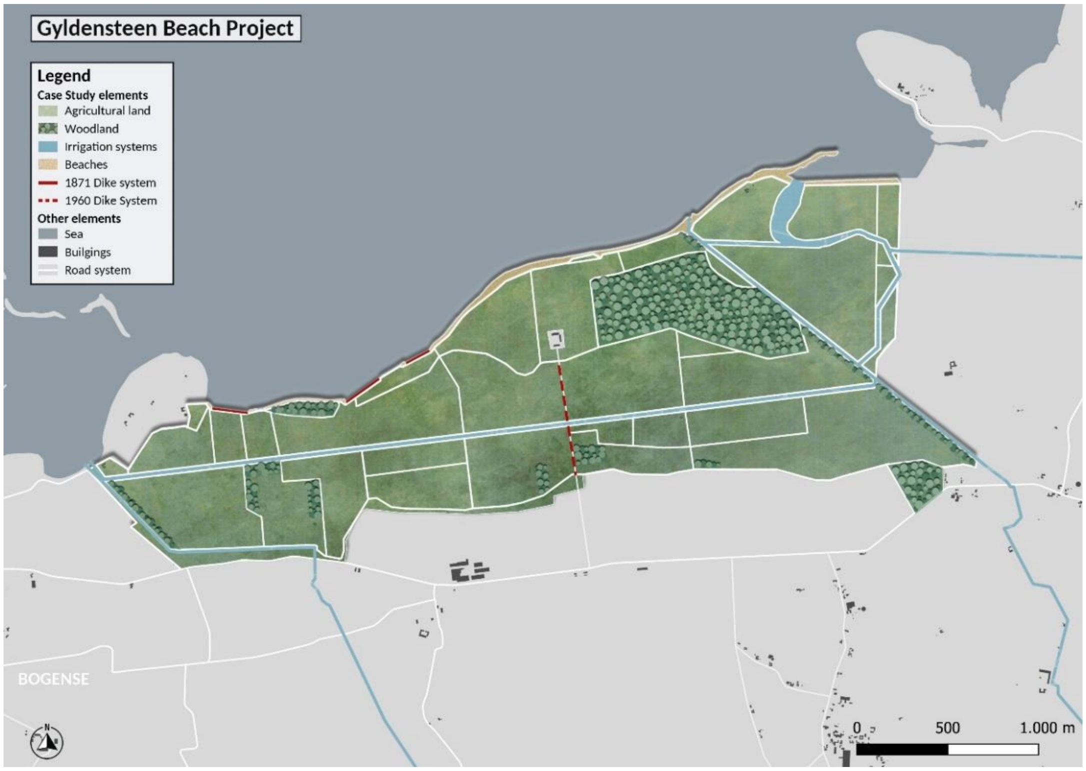

Fig. 22. Setting the context, the pre-intervention environmental status, Gyldensteen Strand (2010). Data from: Personal Photoshop and QGIS elaboration, on dataforsyningen.dk data

Fig. 23. Setting the context, the post-intervention environmental status, Gyldensteen Strand (2016). Data from: Personal Photoshop and QGIS elaboration, on dataforsyningen.dk data

3.5.4. Amager Strandpark case study

Fig. 24. Setting the context, aerial view on Amager Strand project (2023). Data from: Personal Photoshop and QGIS elaboration, on dataforsyningen.dk data

Case study description:

Amager Beach Park is a 60ha wide coastal protection system constructed along the island of Amager, in the southern part of the city of Copenhagen. The case study is made of a 2km long off-shore artificial barrier-island, connected to a coastal park on the mainland through three bridges. Today, the sea area between the artificial barrier-island and the mainland is coastal lagoon, while in the past the area was a shallow open sea space with shallow longshore sandbars. Planning of the project started in 1980, but the final construction itself took place only in 2004 and finished in 2005.

The construction of Amager Beach Park was financed at the first place to limit local coastal erosion phenomena, since beaches along the island were progressively disappearing due to sea level rise and increasing storm surge events. Low-lying coastal settlement, infrastructures and services were also threatened to the same extent, and therefore new protection measures were required to reduce their vulnerability. At the current stage, the project offers a mix of natural areas with marine landscapes to the northern part of the barrier-island (where grassland, sand dunes and dry meadows develop), while the southern area is predominantly furnished with recreational activities, touristic services, sport facilities and leisure areas (stretching from skateparks, playgrounds, football fields, museums, bars, restaurants and more). The mixed approach to coastal protection is a great example of combining artificial hard engineered defense structures with natural and ecosystem-based approach used to archive coastal resilience for a large territory.

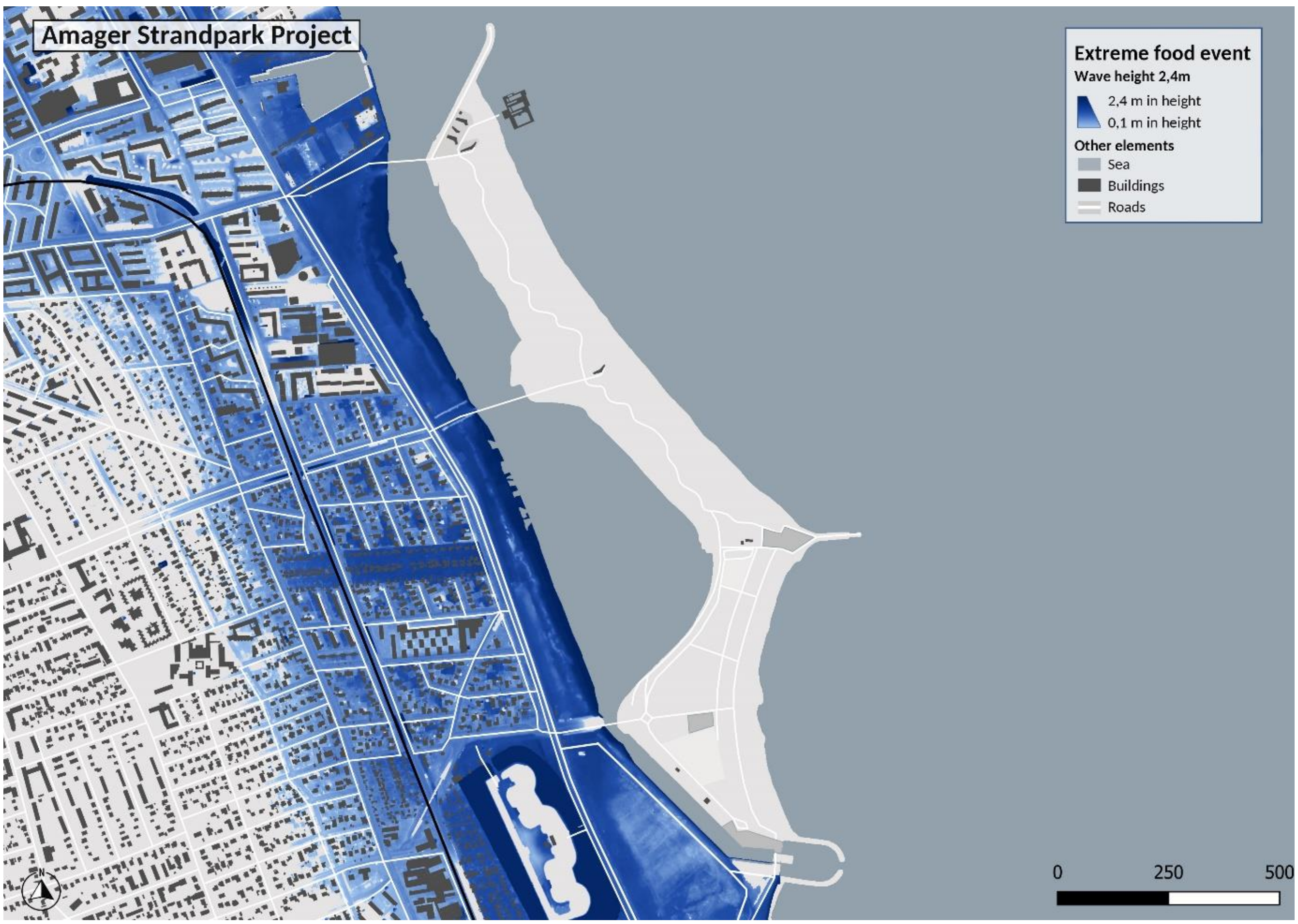

Fig. 25. Amager Strandparken, exposure to extreme events (water +2,40m AMSL) without NbS (2000). Data from: Personal QGIS elaboration, developed with dataforsyningen.dk data

In the following section the analysis criteria are going to be developed for this case study, in order to gain a better understanding of the outcomes of the implemented solution, on the local socio-economic and environmental spheres.

Criteria analysis

a) Have there been changes in the land-use typologies over time?

Amager Strandparken is an important case study where land-uses have changed considerably during the last 20 years. Prior to the Strandpark, the whole offshore coastal area was characterized by constantly transforming sand bars, not normally accessible to humans. To develop the area into a permanent defense system, an artificial reinforcement of the sand bars took place, supported at the foreshore by sand replenishment and beach nourishment.

Human land uses today: The area that until the early 2000s was a vulnerable natural area now is a recreational area, which hosts 6 permanently gastronomic activities (3 caffes and 3 restaurants) and, different sport facilities and workshops (from football fields to beach volleyball facilities, to skateparks and more). To attract residents and tourists, the Strandpark provides one major public park on the mainland part of the project, a Nature Center (Naturcenter Amager Strand), and 4.6km of public sand beaches where swimming, surfing and other water activities can be practiced. In terms of connectivity, the case study can be reached from Copenhagen via metro line (from Oresund, Amager Strand and Femøren St.), bus, bike, foot or car.

Natural land uses today: To support a climate resilient coastal defense system, the case study hosts many naturalized areas on the artificial barrier-island. The norther part of the offshore system is characterized by naturalized sand dunes, wetland patches and open grassland areas which mimic local natural coastal environments. On the other hand, the southern area of the barrier island (with a higher focus on recreational activities) is predominantly covered by meadows and grasslands, functioning as a recreational playground for human activities.

b) Did the NbS bring socio-economic benefits to the local sphere?

Amager Strandparken is to be considered a Nature-based Solution of great success in Denmark. The project is a unique protective coastal landscape made of hard and soft elements, and hosts sport facilities, playgrounds, leisure spaces, wide sandy beaches (…), along with different services stretching from restaurants and cafes to cultural centers and museums. Supported by its close proximity to Copenhagen and by a well-designed network of public transportation, the case study becomes accessible not only to local inhabitants of Amager, but also to dwellers living in the capital city or to visiting tourists which contribute to strengthen the local economy.

Other socio-economic benefits archived by the project are related to the project's nature. In fact, in the first place the artificial barrier-island functions as coastal defense system to protect the low-lying urban hinterland from floodings, sea level rise and storm surges. Second, the coastal defense system stabilizes the pre-existing beaches along Amager island, which in the past were affected by chronic coastal erosion dynamics and were at risk of disappearing. Both facts underline the benefits which the case study represent for the local environment, both in terms of cost reduction and adaptation.

c) Did the NbS bring benefits to the local ecosystems?

Until the completion of the Amager Strandparken project in 2005, the coastal area of Amager was poorly maintained, and its low-lying residential areas were threatened by chronic and progressive coastal erosion. To tackle current and future threats related to climate change and coastal flooding, the municipality of Copenhagen invested 25M euros in the construction of a new and resilient offshore coastal defense system. The construction integrates hard and soft design elements to establish a permanent coastal landscape, characterized in the northern section by wide sandy beaches, grasslands, reinforced sand dunes and salt meadows to mimic the historic local coastal environment. The southern part is dominated by grasslands, while the sea area between the barrier-island and the mainland has been naturally transformed into a saltwater lagoon, which today offers a mixed wildlife rich in biodiversity.
The mainland section of the project has been transformed only to a limited extent, here the southern area has been developed into a public park, while the coastline has been kept at its original state of sandy beach. Overall, the project presents positive outcomes both for the socio-economic sphere, and for the environmental sphere.

d) Can this NbS be considered a Resilient Solution?

Besides being a project known for its recreational values and the touristic appeal, Amager Beach Park was first planned, financed and developed to guarantee the safety of the local population living in the low-lying hinterland. Nature conservation and coastal environment protection were also important topics to be addressed by the project, given the progressive erosion of the beaches along Amager which, in the past, called for expensive annual interventions of sand nourishment.

Therefore, combining hard engineered structural elements and soft natural elements, the case study is able to archive coastal protection guaranteeing at the same time the resilience of the area implementing different climate adaptation and climate mitigation solutions. Most important Nature-based Solutions adopted by the project are the beach nourishment, the dune restoration, and the creation of wetlands (which function as natural buffer against erosion, storm surges and sea level rise), while promoting at the same time biodiversity and coastal habitat conservation. Climate change risks are addressed holistically by promoting sustainable development principles integrated with hard engineered solutions which are together able to enhance coastal resilience.

e) Who financed the intervention costs of the NbS?

The idea to develop a coastal defense system for Amager was developed starting from the 1980s and took about 20 years to be fully developed. Being sea level rise and storm surge events threatening to densely populated coastal areas, rich in services and in real estates, the municipality of Copenhagen funded the protection project instead of the local landowners, contributing with over 200 million Danish Kroner (equivalent to approximately 25 million Euros) to the project.

f) Is the NbS to be considered a soft solution or hybrid solution?

Amager Strandpark can be considered a hybrid-type Nature-based Solution, since different hard and soft elements were combined during the construction phase. Hard elements are all the concrete and clay reinforcements which were implemented to stabilize the original natural areas and consist of:

- three peers which reduce longshore coastal erosion (to the north, in the core and to the south)
- inner clay reinforcements of the sand dunes in the northern area, to avoid wind or water erosion
- structural reinforcements along the main barrier-island for an overall better structural stability

Along with the hard engineered elements, we can find many soft elements which support the Nature-based Solution approach and make the project Hybrid. These elements are:

- autochthon grass species planted on the sand dunes to enhance their stability
- open green areas which create natural habitats like meadows, marshes and wetlands
- the lagoon which mimic parts of the original state of the case study and serves as buffer area against flooding for the residential areas in the hinterland.
- wide open sand beaches which are, as the lagoon, part of the pre-existing natural habitat

g) Did the NbS lead to further local/regional/national/international types of protection?

No, the project did not lead to any sort of further protection of the case study area.

Fig. 26. Setting the context, focus on socio-economic changes in Amager Strandparken (2000-2023). Data from: Personal Photoshop and QGIS elaboration, on dataforsyningen.dk data

Fig. 27. Setting the context, the pre/post-intervention environmental status, Amager Strandparken. Data from: Personal Photoshop and QGIS elaboration, on dataforsyningen.dk data

3.6. Comparison matrix

To sum-up the results and understand the differences among the 4 selected Danish case studies, a comparison matrix has been developed (Fig. 28). On the vertical axis we placed the project names (Køge Bugt Strandparken, Seden Strand, Gyldensteen Strand and Amager Strandpark), while on the horizontal axis we displayed the seven criteria which have been selected for the comparison.

Criteria of evaluation / Selected case studies	a) Køge Bugt Strandparken	b) Seden Strand Strandparken	c) Gyldensteen Strandparken	d) Amager Strandparken
1) Have there been any changes in terms of land use over time?	✓ Yes, new land was created, now designated as natural areas mixed with economic and recreational areas.	✓ Yes, the case study land use went from intensive agricultural land, to natural land.	✓ Yes, before the whole area was used as agricultural land now as natural land, with recreational areas.	✓ Yes, new land was created, nowdesignated as natural areas mixed with economic and recreational areas.
2) Did the NBS bring benefits to the socio-economic local sphere?	✓ Yes, tourism expanded at local and supra-local level, and recreational areas for residents were established.	✓ Yes, birdwatching spots and natural pathways made the area attracive and accessible to residents.	✓ Yes, unique landscapes and protected areas attract large quantities of tourists allover the year.	✓ Yes, added touristic values at local and super-local scale hosting important public beaches.
3) Did the NBS bring environmental benefits to the local sphere?	✓ Yes, wetlands, salt marshes, grasslands and dunes enhance erosion control and biodiversity.	✓ Yes, the NbS increased the bay water quality and restored historic coastal environments.	✓ Yes, it recreated the natural scenario, functions as carbonsink, attract rare and endangered birds.	✓ Yes, solves erosion and storm surge problems, and (in the northern part) increases biodiversity.
4) Did the NBS lead to new forms of coastal resilience?	✓ Yes, the NbS solved the coastal flooding and the strong coastal erosion problems.	✓ Yes, buffer areas and new sea-hinterland interactions reduced urban vulnerability to storm surges.	✓ Yes, works as natural barrier for urban and agricultural areas during extreme weather events.	✓ Yes, coastal erosion dynamics are controlled and the hinterland is secured from storm surges.
5) Was the project funded by the local landowners?	✗ No, funded and maintened by inter-municipal and inter-regional agreements.	— Partially, funded by the municipality, the EU and the private land-owners.	✓ Yes, funded by the land-owner Aage V. Jensen Naturfond foundation.	✗ No, funds were provided by the municipality of Copenhagen.
6) Can the case study be classified as a soft Nature-based Solution?	✗ No, the mix of soft and hybris elements (reinforced dunes, groins) make it a hybrid solution.	✓ Yes, all the designed elements are soft design elements. Therefore, the project is a Soft solution.	✗ No, hard engineered elements (as the southern dike system) characterize the project as hybrid .	✗ No, hard engineered design elements (as the three groins) make the solution a hybrid type of solution.
7) Did the NbS lead to new coastal legislative protection measures?	✗ No, further environmental protection laws or directives are absent.	✗ No, further environmental protection laws or directives are absent.	✓ Yes, new Natura 2000 site, and new Bird Protection Area No.76.	✗ No, further environmental protection laws or directives are absent.

Fig. 28. Comparison matrix, a case study analysis through seven comparison criteria. Data from: Personal elaboration

In this Thesis we decided to develop a comparison matrix to allow the readers to systematically assess the pros and cons for each option (case study, and criterion) and make an informed conclusion at the end. Our comparison matrix can be read in two ways. First, if the matrix is red along the vertical axis, the reader gains an insight on the success (or not success) of the chosen case study in archiving or fulfilling the selected criterion to its left side. The results of this analysis are summed-up below (paragraph 3.7.1.). Second, if the matrix is red along the horizontal axis, the reader can draw a line on the overall importance of the selected criteria, among the 4 selected Coastal Nature-based Solutions. These results on the other cand can also be found below (paragraph 3.7.2.).

Note: if a cell of the comparison matrix is filled with a green (**V**) the option is verified or fulfilled; if a cell is filled with a red (**X**) the given option is not fulfilled or not verified; while if a cell is filled with a grey (**-**), relevant comparison data for the given criterion is missing or not sufficient for a conclusion.

3.6.1 Summing up the outcomes (criteria/case study)

1) Have there been any changes in terms of land use over time?

- (a-1): **Yes**, the project was developed on a new piece of land, currently designated as natural areas mixed with economic and recreational areas. (Køge Bugt Strandparken)
- (b-1): **Yes**, pre-intervention most parts of the case study area were used as agricultural land, now there areas are almost exclusively kept as natural land.
- (c-1): **Yes**, before the interventions took place the whole area was used as agricultural land. Now, the land is designated as natural land, with some recreational areas.
- (d-1): **Yes**, the project was developed on a new piece of land, currently designated as natural areas mixed with economic and recreational areas.

2) Did the NbS bring socio-economic benefits to the local sphere?

- (a-2): **Yes**, the coastal environment experienced growth in terms of tourism both at local and supra-local level, and established successful recreational areas.
- (b-2): **Yes**, the project added new birdwatching spots and natural pathways to the area, therefore facilitating the overall accessibility to the site at local scale.
- (c-2): **Yes**, once completed the case study was able to attract large quantities of tourists every year from all over the country thanks to its unique characteristics.

- (c-2): **Yes**, Amager became a key touristic destination for both local inhabitants and super-local tourists hosting one of the most important public beaches in Copenhagen.

3) Did the NbS bring environmental benefits to the local sphere?

- (a-3): **Yes**, implementing wetlands, salt marshes, grasslands and dune-belts contributed significantly to coastal erosion control and biodiversity protection.
- (b-3): **Yes**, the implemented NbS did increase the water quality of the bay, and helped to restore the lost historic coastal environment in the protected Natura2000 area.
- (c-3): **Yes**, this project was able to recreate the original coastal scenario of the XIX century, to lower CO2 emissions and to attract rare and endangered bird species.
- (d-3): **Yes**, the project solves the coastal erosion and storm surge problem, and especially its northern part (more natural) saw an increase in biodiversity.

4) Did the NbS lead to new forms of coastal resilience?

- (a-4): **Yes**, originally the case study was highly exposed to coastal flooding and subject to strong coastal erosion dynamics, now these problems have been tackled.
- (b-4): **Yes**, by adding new natural buffer areas and changing the interaction between sea and hinterland, the project reduced the overall urban vulnerability to storm surges.
- (c-4): **Yes**, during extreme weather events, the project successfully works as a natural barrier for bordering urban and agricultural areas, thus reducing coastal vulnerability.
- (d-4): **Yes**, implementing the project lead to coastal erosion control (reduced to historical minimums) and urban areas in the hinterland have been secured from storm surges.

5) Was the project funded by the local landowners?

- (a-5): **No**, the development has been funded and its maintenance costs are currently covered by an inter-municipal and inter-regional agreement.
- (b-5): **Partially**, this project received fundings from both the municipality of Odense, from the European Union and from private affected land-owners in Senden.
- (c-5): **Yes**, in this case fundings for the project development have been allocated by the Danish Aage V. Jensen Naturfond foundation, owner of the project area.
- (d-5): **No**, funds have mainly been provided by the municipality of Copenhagen and not by the affected local land-owners given the massive size of the project.

6) Can the case study be classified as a soft Nature-based Solution?

- (a-6): **No**, in this case the case study is characterized by the implementation of soft and hybris design elements (reinforced dunes, groins) which make it a hybrid solution.
- (b-6): **Yes**, all the project elements which have been designed for this Coastal NbS are soft design elements. Therefore, the case study is classified as Soft solution.
- (c-6): **No**, the use of hard engineered protection elements (as the new southern dike system) characterize the project as hybrid NbS and not as soft solution.
- (d-6): **No**, reinforcing the project with hard engineered design elements (as the three groins) makes the solution a hybrid type of solution.

7) Did the NbS lead to new coastal legislative protection measures?

- (a-7): **No**, the project did not lead to any new types of environmental protection laws.
- (b-7): **No**, the project did not lead to any new types of environmental protection laws.
- (c-7): **Yes**, the coastal area which in the past was used as agricultural land is up to protected by a Natura 2000 site, and under the Bird Protection Area No.76.
- (d-7): **No**, the project did not lead to any new types of environmental protection laws.

The final thoughts and the final comparisons are going to be developed in the Conclusion chapter of this Thesis

The project

Italy as case study

4. Italy as case study

Excluding Greenland and the United Kingdom from the ranking, the ***coastline of Italy is the third longest in the European continent*** (Sen Nag, 2018) counting approximately 7.500km of Shoreline along the Ionian, the Adriatic, the Ligurian and the Tyrrhenian seas. The Italian coasts are classified according to their geologic and morphologic characters into (i) ***high coasts***, elevated rocky coasts with articulated and jagged shapes (more common in Sardegna and Sicilia, and along the Tyrrhenian regions Liguria, Toscana and Campania) and (ii) ***low coasts***, often wide and low-lying sandy or rocky coasts (these coastal conformation are more common than high coasts and can be found almost in every region, for the exception of Valle d'Aosta, Piedmont, Lombardy, Trentino-Alto Adige and Umbria) (ISPRA, 2011).

Coastal areas are evolving and dynamic ecosystems where natural and anthropic processes meet and interact, constantly changing the local geomorphological, physical and biological structures of the coast. Similarly to the other coastal areas across the EU, also ***Italy's coasts are massively threatened by Climate Change due to a high presence of human settlements, economic activities and agricultural lands*** which experienced a development boom from the 1960s onwards. In a recent publication of the Italian institute of national statistics (ISTAT, 2022), it is stated that currently ***34.4% of the entire national population lives in coastal municipalities*** (coastal municipalities are either directly on the coast or have at least 50% of their municipal surface less than 10km from the shoreline), ***densely concentrated in less than 18.8% of the entire municipal surface***. Furthermore, between 2006 and 2020 the levels of ***soil consumption*** along Italian coastal areas has ***increased by 6% and today 420 thousand hectares of coastal area are sealed*** (equal to ***27% of the entire national consumed soil***) (Legambiente, 2023).

Overall, coastal ***anthropization significantly altered the natural coastal environments in Italy***. On the one hand by limiting sediment flows from water bodies to the sea, on the other by changing underwater sea-currents with hard engineered structures which unwantedly and artificially ***boosted coastal erosion processes*** (Guadagno et., al., 2023) further exacerbated today by sea level rise and extreme weather events. As Fedrizzi (2019) pointed out, ENEA estimates that without an immediate implementation of mitigation and adaptation processes, about ***5500 km^2 of coastal area in Italy are going to be submerged by the end of the century***, particularly affecting the North-Eastern national coastline, the Pescara river outlet (Abruzzo Region), Lesina and Taranto (Puglia Region), wide parts of Versilia, Cecina, Follonica and Piombino (Toscana Region), the Fondi plain (Lazio Region) and the coasts of Cagliari (Sardegna Region) as can be observed above (Fig. 29).

Fig. 29. The Italian coastal areas at high flood-risk. Credit: ENEA

The current state of the Italian coastline is better framed by ISPRA (Istituto superiore per la protezione e la ricerca ambientale), which focuses its research on the evolution of sandy low coasts along the national borders between 2006 and 2020. According to the study, out of 3.400km of natural sandy coast (particularly affected by coastal erosion) ***1.000km are under progressive erosion***, ***1.400km are in stable conditions and 1.000km are in deposition*** (growth) (ISPRA, 2020). However, the report does also include all artificial defenses and sand replenishment processes implemented along the coastline in the study, and therefore provides data which do not exactly represent the 'real' coastal scenario (especially for stable and in deposition coasts) which, over the past 50 years, has lost between 35 and 40 million square meters of coast of about 45 billion Euros in economic value (Galdo, 2024). Since the 1970s, municipalities in Italy tried to limit coastal damages adopting hard engineered coastal defenses (often very expensive), which led to the implementation of -up to date- more than 10.500 grey structures along the Italian coastline, approximately 3 structures each 2km of coast (Legambiente, 2023). The installation of hard engineered protection measures cost the Italian State and Regions approximately 100 million Euros yearly but rarely solve the coastal erosion problems or solves them by shifting them to other coastal areas (Pranzini, 2020) due to further anthropizations of the coastline.

Another great danger to the Italian case study is represented by the increasing extreme weather events. A recent study published by the European Environment Agency (EEA) highlights the progressive increase in extreme weather events across Europe, which between 1990 and 2021 caused economic losses of approximately 560billion Euros, and the death of 195.000 lives (EEA, 2023). According to this study, ***Italy*** is ranked as ***third country in Europe in terms of climate-change related losses*** where ***92 million Euros of damages*** were registered and ***22.000 people died*** over the analyzed 31 years (Brambilla, 2023). Furthermore, ***over 40% of the extreme weather events*** which occurred between 2010 and 2023 ***occurred in coastal municipalities*** which highlight their current vulnerability and exposure to Climate Change threats (Di Stefano, 2023). To provide researchers and policymakers with better understanding on how climate change will increase coastal floodings in Europe, the IPCC has developed two maps (Fig X).

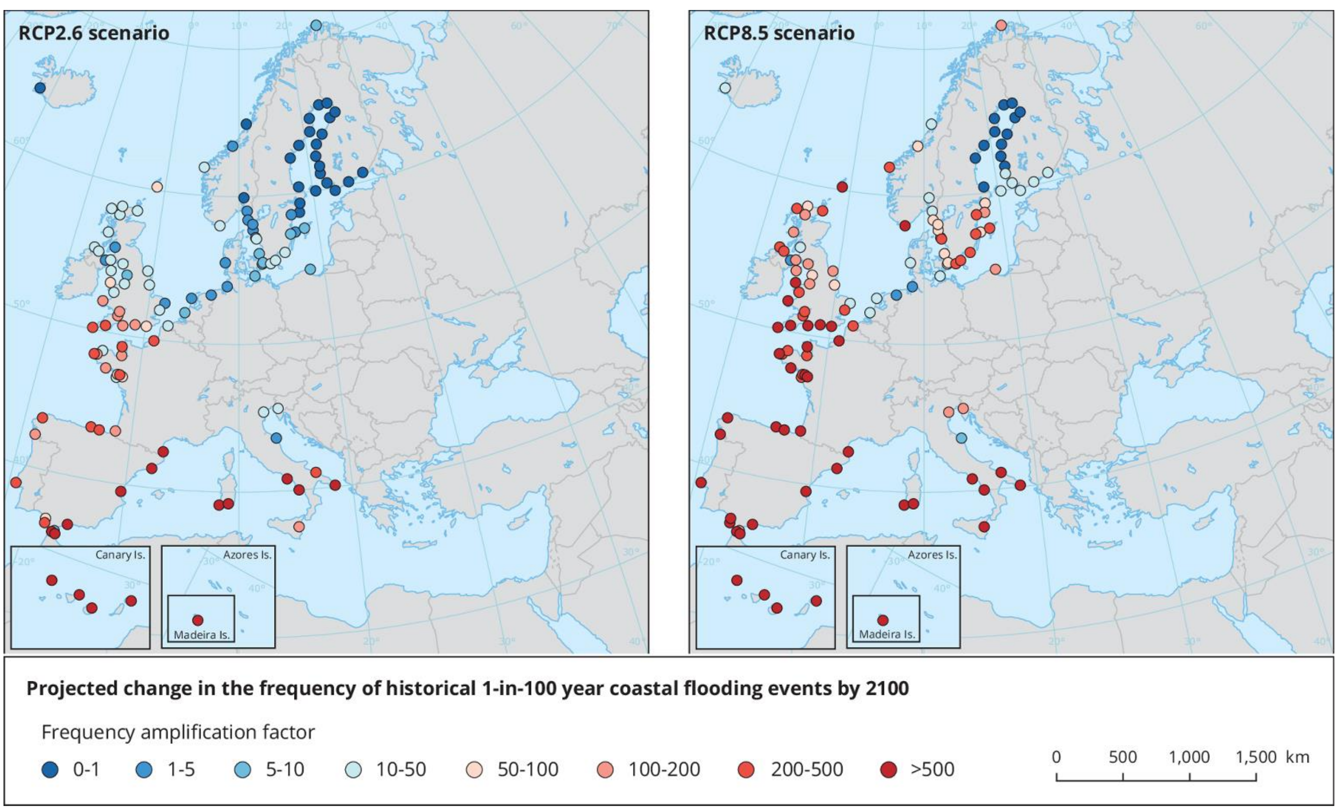

Fig. 30. Projected change in frequency of historical 1-in-100 years coastal flooding events by 2100. Source: Figure 4.12 of the IPCC Special Report on the Ocean and Cryosphere (SROCC).

These two maps show the estimated multiplication factor, by which the frequency of flood events will change between 2010 and 2100 due to sea level rise under the RCP2.6 (low emission scenario where we quit emitting GHG today) and RCP8.5 scenarios (we keep emitting GHG gases as we do currently). As can be observed from both scenarios, the whole mediterranean coastal area will experience a significant increase in frequency of extreme coastal-flooding events (1-100 year events) which, given the already high coastal vulnerability of Italy will increase even further its current levels of exposures.

4.1. Framing the Italian coastal planning system

The first national law in Italy which seeks the protection of coastal areas is the law n.542, 14th of July 1907 ''*Legge per la difesa degli abitati dall'erosione marina*''. This law had a particular focus on the protection of coastal human settlements from coastal erosion dynamics but did not focus on the protection of vulnerable coastal beaches or coastal ecosystems (Guadagno et., al., 2023). The law set also the baseline for the development of large hard engineered coastal defense systems, since at the time different national beaches suffered from major coastal erosion processes.

With the d.p.r. 616 (decreto del president della Repubblica) 24th of July 1977, many responsibilities in the field of coastal protection have been rescaled and have been shifted from the national level down to the regional level of competence. If on the one hand the State keeps an administrative role over national navigation routs and national security protection measure, regions are now empowered with the administration of touristic and recreational interventions in coastal areas, and with the protection of regional environmental values (MATTM-Regioni, 2018). Only with the law n.179, 31st of July 2002 coastal defense becomes entirely of Regional competence. Another important legislation which surely left a mark on the Italian coastal system is the law n.494, 4th December 1993 in which the Regions became responsible for the administration of beach concessions by preparing a coastal land use plan.

Further important changes in the coastal protection field in Italy happened only with the D.lgs n.49, 23rd February 2010, as Italy started to introduce the European directives on the assessment and management of flood risks (2007/60CE). With the new D.lgs, Italy identified all the vulnerable coastal areas exposed to coastal floodings, in order to tackle the negative outcomes on human wellbeing, on goods, on the environment, on the cultural heritage and on all the coastal economic and social activities. It is however important to note that it will take until December 2015 to draft and adopt the first set of Flood-Risk Management Plans (Piani di Gestione del Rischio Alluvioni) (MATTM-Regioni, 2018).

The D.lgs n.201/2016 provides a new planning framework for coastal management where the sustainable growth of coastal economic activities, the sustainable management of coastal areas and the sustainable use of coastal resources are structural key elements, systematically developed following an ecosystem approach. The goal is to introduce new coastal dynamics which, differently from the past, can guarantee mobility of the coastline and favor an overall coastal resilience (MATTM-Regioni, 2018).

From a political and governmental perspective, in Italy the protection and the management of coastal areas is carried out at multiple levels to ensure an integrated and coordinated approach between the national government, the regions, the provinces and the municipalities.

At the upper level of coastal governance there is the National Government in which the Ministry for Ecological Transition (Ministero della Transazione Ecologica, MITE), the Ministry of Infrastructure and Sustainable Mobility (Ministero delle Infrastrutture e delle Mobilità Sostenibili, MIMS) and the Higher Institute for Environmental Protection and Research (Istituto Superiore per la Protezione e la Ricerca Ambientale, ISPRA) are the most relevant players. While ISPRA is responsible for providing technical and scientific support for coastal protection and planning, the MITE is responsible for the development of proper environmental policies and coastal protection measures and the MIMS manages coastal infrastructures and maritime works.

Below the National Government, in terms of relevance and responsibilities, there are the Regions. In the field of coastal protection, the Italian Regions are responsible to plan, produce and manage Regional Management Plans like the Integrated Coastal Zone Management ICZM (in Italian Gestione Integrata della Zona Costiera, GIZC) with the goal to support and guarantee a regional sustainable development along the coastal area, protecting coastal ecosystems, coastal landscapes, cultural heritage and support the development of a sustainable economy (MASE, 2023). Besides the ICZM, each Region is allowed to develop and adopt their own specific coastal management and coastal protection laws, as long as they follow the National and the European directives (MATTM-Regioni, 2018).

Inside each Region, Provinces and Metropolitan Cities act as coordinators between municipalities and provide technical and administrative support for coastal management projects.

At the lower end of the coastal management and governance system there are the municipalities.
Municipalities implement Regional coastal management and protection directives at local level in their urban plans and manage the maritime domain concessions and economic activities related to beach tourism in compliance with the upper prescriptions and directives.

As can be understood above, in the Italian coastal government system coordination mainly happens on a vertical axis where National and Regional guidelines guide coastal development at local level. In fact, the national government (following indications from the European Union) provides guidelines and directives that regions must follow in managing their coasts. Regions, in turn, develop regional plans that municipalities must implement. This way, coastal planning becomes a holistic approach at national scale. Currently the most recent and important National guidelines are gathered in the National Adaptation Plan to Climate Change adopted last December (2023) which, as its name underlines, is strongly grounded on climate adaptation and climate mitigation processes to tackle the negative effects of climate change.

However, it is also important to specify that coordination in coastal planning can also happen on a horizontal axis, especially as coastal municipalities (or even coastal Regions) can collaborate through consortia or inter-municipal/regional agreements and projects to manage coastal areas that extend beyond administrative boundaries. Same can be said about international coastal managements projects, since Italy is part of different projects with other Mediterranean countries and European Union initiatives aimed at protecting and managing connected coastal and marine environments such as:

- ***Interreg Mediterranean Programme.*** Two relevant Interreg projects in which Italy takes part of are the Interreg Mediterranean CO-EVOLVE project and the Interreg Mediterranean PHAROS4MPAs project. The first project involves the participation of Italy, Spain, France, Greece and Croatia and aims to support a symbiotic development of the socio-economic sphere and the natural sphere in touristic coastal areas along the Mediterranean sea (Interreg, CO-EVOLVE). The second project involves the participation of Italy, Croatia, Cyprus, France, Greece, Slovenia and Spain in the intent to conserve marine biodiversity and natural ecosystems in populated coastal areas along the Mediterranean Sea (Interreg, PHAROS4MPAs).

- ***EU Life Programme.*** The EU Life programme are key tools of the European Union which seek to support environmental, nature conservation and climate action projects among its member states. Italy is involved in many of these projects, the most known one are LIFE REMEDIA, LIFE PRIMES, LIFE GreenChainSAW and LIFE MASTER ADAPT (LIFE programme)

4.2. The National Adaptation Plan

On December 21st of 2023, Italy adopted the final form of its National Adaptation Plan to Climate Change (Piano Nazionale di Adattamento ai Cambiamenti Climatici, PNACC) whose development started in 2015 as the National Adaptation Strategy to Climate Change (Strategia Nazionale di Adattamento ai Cambiamenti Climatici, SNACC) was adopted. The PNACC is designed to support and guide national, regional, and local authorities in the development and the implementation of climate adaptation strategies to reduce the vulnerability of the exposed socio-economic and natural spheres in order to guarantee a better national resilience.

The document provides a list of 361 climate adaptation measures and actions to be implemented at national and regional scale, subdivided into three categories: Soft measures, Green measures and Grey measures. Soft measures focus on the development of institutional and organizational actions (especially on governance), Green measures involve the implementation of Nature-based Solutions and ecosystem approaches, while Grey solutions are traditional hard engineered infrastructural or technological interventions. Besides the positive trend which the PNACC represents in the national agenda towards a more sustainable and resilient future, it is important to highlight an important problem in its current approach given the fact that most of the adaptation action and measures which the Plan provides are classified as soft actions (274), and only a minority are structural implementation as for instance Green actions (46) and Grey actions (41) (Del Bianco, 2024). Moreover, the financing of these actions and measure require great funds which are largely provided by the European Union in this case (e.g. through the LIFE Programme, the European fund for Regional development, Urban Innovative Actions, Horizon Europe and other); however, only a minority of all the actions and measures listed in the PNACC are currently covered by the EU. In fact, the European Union funds are designated to its member states on a competitive basis where only the best projects become financed. This represents a big problem for Italy, since the design of Climate Change actions and measures is still in its embryonal development phase.

4.3. A proposal for Marina Romea, Ravenna

As stated in the introduction and supported by the Danish case-study analysis, Coastal Nature-based Solution are strong and effective design elements which should be adopted at scale to tackle the negative effects of climate and enhance the overall resilience of coastal environments. Besides being Italy on the move towards a holistic introduction of Nature-based Solutions along its national vulnerable coasts (as can be seen in the national guidelines of the National Adaptation Plan), the planning and the development of NbS is happening at low speed. High maintenance costs of traditional hard engineered structures and their diagnosed low effectiveness in current and future scenarios however calls for immediate action. In the following section of the Thesis, we are going to analyze a specific vulnerable coastal case study which suffers from chronical coastal erosion and storm surges, in order to develop an *ad-hoc* Nature-based Solution grounded on the lessons learned from the Danish case study.

Among the many vulnerable coastal areas in Italy, the Thesis focuses on Marina Romea in the municipality of Ravenna (Emilia-Romagna) for the following reasons. First, from a geologic and morphologic perspective the beaches along the Marina similar to the beaches in the Danish case studies (sandy low-beaches), and are also particularly affected by coastal erosion dynamics. This problem is further exacerbated by high levels of anthropic pressure (due to the presence of new residential areas, beach clubs and roads) which make the area prone to subsidence, and thus more exposed to sea level rise. At this point in time, Marina Romea is protected from sea-threats by an artificial pine-tree forest (whose existence is compromised by saltwater infiltration in the ground waters) and by a progressively disappearing dune-belt system (threatened by continuous anthropic beach modifications and touristic pressures). These two elements have been recognized internationally as unique coastal environments and have been designated as protected areas and Natura 2000 sites (IT4070003, IT4070004 and IT4070005). It is also relevant to highlight that coastal erosion is currently managed by grey solutions installed along the coastline (three groins, orthogonal to the coastline) which however do not solve the problem, but rather exacerbate it by compromising the natural flow of sediments coming the Lamone river at the northern end of Marina Romea. Finally, this specific case study has also been selected for two more reasons: first, the higher levels of confidence which I have with the case study, being I myself from the Emilia Romagna region. Second, because the municipality of Ravenna recently took part in a not yet initiated European co-funded project (2024-2026 ACTION – Increasing coastal ecosystem resilience to climate change) to find and develop a new coastal defense solution for the above listed problems along Marina Romea. Our goal is therefore, again, to develop a new and innovative coastal protection system, grounded on adaptation and mitigation principles learned from the analysis of Danish case studies.

4.3.1. The current state of art

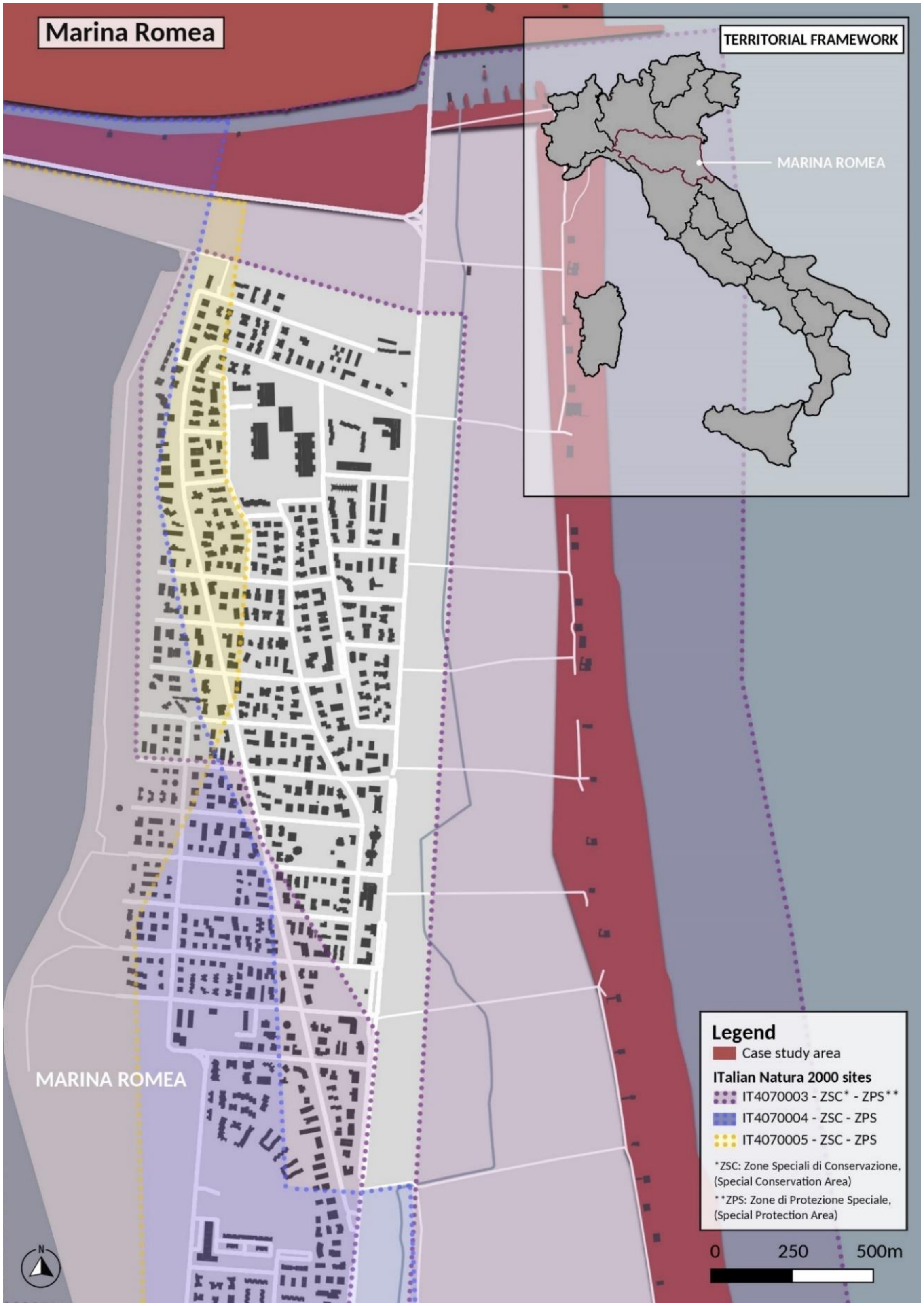

Fig. 31. Setting the context, view on Marina Romea: project area and environmental laws (2023). Data from: Personal Photoshop elaboration, on geoportale.regione.emilia-romagna.it/ data

Marina Romea is a coastal hamlet of the municipality of Ravenna, located 15km north-east from the main city of Ravenna and is framed by the mediterranean sea on the East side, the Lamone river to the North and a large lagoon system connected to the sea to the western and southern part of the urban area. Until the 1950s, the today urbanized area of Marina Romea was used as farmland, surrounded by the already existing pine-tree forest, by wetlands, salt marshes and a wide dune-belt system along the coastline. With the advent of urbanization and a growing touristic interest for the Ravennate coast, the original natural environment changed drastically, and the settlement of Marina Romea was built along with many beach clubs given in concession by the state for touristic purposes.

Growing anthropic pressures and new infrastructural loads lead over time to a progressive subsidence of the terrain and, as a result, it significantly increased the local vulnerability to sea level rise, storm surges and coastal erosion processes. Estimates of Ravenna's disaster contingency plan (Piano di Protezione Civile Comunale – Comune di Ravenna, 2009) state that in Marina Romea approximately 3 km^2 of urbanized area and 1.354 residents (not tourists) are at risk of extreme sea-weather events, and urgent countermeasures must be taken to avoid negative repercussions. But the progressive subsidence of the terrain is not the only factor which influences the coastal vulnerability of the hamlet, other key element which must be taken into consideration are the sustained disappearance of the historical natural dune-belt system which by nature would tackle storm surge events and erosion, as well as the change of land use destinations from wetland (buffer zone between sea and hinterland) to agricultural or uncultivated land. As highlighted in the Køge Bay Beach Park project and in the Amager Beach Park project (chapter 3), dune-belt systems are great answers to coastal erosion problems and storm surge events, functioning both as natural barrier element, and as temporary sand reservoirs which over time naturally accumulate and re-distribute sand volumes when needed. Moreover, the maintenance costs of these sorts of solutions are significantly lower compared to traditional ones due to their self-maintaining nature.

As highlighted in the environmental analysis carried out by INTERREG for an upcoming EU co-funded project in the Ravennate area (Interreg, 2024), unique and local coastal environments like wetlands, natural dune-belt systems and the pine-forests are at risk or are already disappearing due to human pressures and outstanding elements of disturbance in coastal areas are beach clubs. These touristic assets change the natural coastal morphology by occupying, moving and sealing large chunks of soil, and by removing trees, shrubs and grasses which normally would stabilize natural systems, in order to make beaches more attractive to tourists (Giudizio, 2024). Finally, the presence of grey coastal defense (in this case groins) compromise the natural flow of sediments coming from the Lamone river which normally would accumulate along the beaches of Marina Romea and counteract erosive processes.

Fig. 32. Setting the context, the pre-intervention environmental status, Marina Romea (2024). Data from: Personal Photoshop elaboration, on geoportale.regione.emilia-romagna.it/ data

Taking into account the lesson learned from the Danish case study and the outcomes of an in depth environmental analysis of the coastal system in Marina Romea, our project wants to address the following problems:

- *Reduce anthropic pressures on the natural environment*

The first step in this regard is to change the amount of total beach concessions. Currently 80% of the beaches in Marina Romea are occupied by beach clubs, the goal is to reduce them down to 50% in line with the proposal of Legambiente (Legambiente, 2023). An interesting note on beach concession is that in 2019 the state earned 83Million Euros in taxes from beach concessions, but at the same time had to invest 115Million Euros in sand nourishment processes to guarantee their accessibility over the next year (La Redazione, 2021), highlighting the ineffectiveness of the current approach.
Our idea in the project is to remove beach clubs where they are too densely clustered, and thus support a homogeneity in the succession of natural and anthropized areas, also to support the next project step.

- *Restore and reinforce the disappearing dune-belt system*

As introduced before, high levels of human pressures (e.g. the development of new residential areas, beach clubs, impermeable roads…) strongly alter the natural coastal environment, and especially the dune-belt system which naturally would develop along Marina Romea's is progressively disappearing at the current stage. Our project seeks to reinforce the disappearing dune-belt as happened in the Køge Bugt case study (Chapter 3) and promote the restoration of these crucial coastal defense systems in the fight against Climate Change. New sand masses are going to be added where beach clubs are removed, reinforced and stabilized with dune vegetations (grasses, shrubs and small trees) which are natural in the area.

- *Channel the access to the coast through natural pathways*

The next step in our project is to re-organize the coastal infrastructure which crosses the pine-tree forest and the dune-belt system, channeling tourists along specific pathway to avoid the deterioration of the new natural environments and minimize their disturbance. To support this step, and make the infrastructure elements more sustainable it is also essential to change the paving materials of the pathways, designing and implementing low impact and nature friendly elements like wooden Boardwalk, Living Pathways, Mulch Pathways or other permeable pavers (like gravel and stones) which fade into the coastal landscape. Providing new pedestrian pathways to access biodiversity rich natural environments could also support the development of co-benefits for the socio-economic sphere, promoting alternative forms of tourism (slow tourism) as it happened in the Bogense case study (Chapter 3).

- *Re-shape the Lamone creating new meanders*

In line with the literature review on the causes of coastal erosion, and in line with the outcomes of the analysis of the Seden Strand case study (chapter 3), changing the natural shape of rivers has strong influence on the overall waterflow speed which (as in this case) exacerbates coastal erosion mechanisms. The goal of the project is to work on the current shape of the Lamore river (which at this point in time moves seawards in a straight line), and re-shape it into a more natural form with large, vegetated meanders, in order to reduce the overall water speed at the outlet, and facilitate a natural accumulation of sediment masses along the bordering beaches. To support a natural development of the river outlet, and enable a natural flow of sediments, we also removed the existing hard engineered groin systems (highlighted in dark red in Fig. 32) which have been identified as disturbance elements, unable to cope with current and future climate threats.

- *Re-create natural coastal buffer areas along the Lamone river*

The interaction between sea and rivers can become a dangerous factor during extreme weather events when storm surges coming from the sea overlap with high water levels in the rivers due to heavy rain precipitation. The combination of these factors often leads to river outflows and inundations in the proximity of the river outlet. To avoid the flooding of the residential area to the northern side of Marina (where the coastal forest is smaller, and where the dune-belt ends), the project wants to re-create historical wetlands with salt marshes and grasslands as in the Seden Strand case study (chapter 3), able to cope with the predicted threat. These natural environments are known for their ability to temporarily store large water volumes, and for their resistance to the infiltrations or the accumulations of saltwater masses.

- *Enhance the status of the natural reserves*

Marina Romea is surrounded by unique and singular coastal environments which in many cases are protected and safeguarded by specific limitations like the above listed IT4070003, IT4070004 and IT4070005 constraints. By supporting a holistic naturalization of the case study area, the existing protected areas gain even more variety in terms of biodiversity and can archive the guidance of Natura2000 protected areas.

4.3.2. A design idea for the future of Marina Romea

Fig. 33. Designing the context, the possible future environmental status of Marina Romea. Data from: Personal Photoshop elaboration, on geoportale.regione.emilia-romagna.it/ data

Conclusions

5. Drawing a line from the lesson learned

In light of the analysis conducted so far, this chapter lists some recommendations for transferring successful Coastal Nature-based Solutions from the Danish case study to the Italian case study.

5.1. Restatement of the Thesis Objectives

Italy's coastline is particularly exposed to unpredictable and constantly changing climate change threats (e.g. sea level rise, coastal erosion and storm surges), but at the same time the country is not provided with proper coastal defense measures able to cope with these threats. Coastal Nature-based Solutions are internationally considered great solution for vulnerable and exposed coastal environments, and over the past few decades Denmark became a global frontrunner in this field by studying, developing and pioneering many successful projects. Given the important success of these solutions, this Thesis aims to answer the leading research question '*can effective Coastal Nature-based Solutions be transferred to the Italian case study, learning from Denmark as European front-runner in the coastal protection field?'*.

In this regard, first it has been necessary to understand and frame the concepts of *Nature-based Solutions* (NbS) and *Coastal NbS* in the contemporary Global and the European scientific and political debate through a state-of-art review. Consequently, the focus has been shifted towards Denmark, of which we analyzed the national and the international coastal policy-framework, its model of coastal governance and finally its main national and international coastal protection projects in which the country is currently involved with. Once defined, the analysis moved onto the study of specific Danish Coastal NbS case studies which pioneered and marked a national success in the sustainable coastal protection field, and afterwards results have been compared through a comparison matrix to gain an in depth understanding on the reasons behind their success. A total of seven criteria have been selected for the comparison matrix, and focus on changes in land-use patterns, on the development of new socio-economic and environmental co-benefits, on the degree to which territorial resilience has been archived, on the funding processes behind the implementation, on the typology if implemented NbS (hybrid vs soft) and on the extent to which these solutions lead to environmental protection measures. The development of a comparison matrix is fundamental to draw a line for our final evaluations, and support a possible uptake of successful solutions to another similarly exposed and vulnerable case study, the Italian case study. Finally, since the political and the governmental environments of the two countries are quite different, a further analysis of the Italian system has been carried out to help in the final evaluation, and develop a coherent final project.

Our study revealed that Danish Coastal NbS are mainly implemented along sandy low-beaches due their high levels of exposure to climate change threats, especially to coastal erosion, sea level rise, storm surges and coastal floodings. All analyzed case studies are characterized by a strong focus on the restoration and/or on the development of natural coastal environments (e.g. wetlands, salt marshes, grasslands, dune systems), which function as natural barrier between the sea and its hinterland. Together, these elements offer significant benefits of local erosion control, biodiversity enhancement, and the protection of coastal settlements, becoming great alternatives to traditional hard-engineered solutions often unable to cope with current and future climate change threats and unable to guarantee additional co-benefits to the socio-economic or natural spheres. However, besides involving similar design-elements to reach territorial resilience, all analyzed Coastal NbS are unique because they answers specific place-dependent needs and problems. It is therefore crucial to carry out an in-depth study of a local environment before designing and implementing new Coastal NbS, since their final success depends on it. All analyzed Coastal NbS in Denmark are developed in sandy low-beach environments, very similar from a morphologic and geologic point of view to the wide and open sandy low-beaches present along the Emilia-Romagna coastline. From our point of view, transferring Coastal NbS grounded on the lessons learned from the Danish case study to the Italian case study is likely to bring similar outcomes (mitigate coastal erosion and enhance the overall territorial resilience) if the local natural and socio-economic characters are properly studied and taken into the equation.

5.2. Considerations on the political framework

During the development of this Thesis, we learned that to successfully pioneer effective Coastal Nature-based Solutions we first need to approach the coastal governance, management and protection discourse in a holistic way. Differently to Italy, Denmark's has integrated Coastal NbS into its national and regional coastal protection policies, thus providing a supportive framework for their implementation at international and national level. Furthermore, besides encouraging the use of Coastal NbS through different policies, Denmark does also constantly invest resources and funds into their study, their research, their development, their implementation, their maintenance and their monitoring over time to obtain more reliable data and better future results. This is also facilitated by a strong collaboration between policymakers, research institutes, universities and the National Government organization responsible for coastal planning, the Danish Coastal Authority. Besides the positive policy trend which lately has been registered in Italy, involving climate change adaptation actions at national scale for coastal protection, Coastal Nature-based Solutions are still not explicitly mentioned as solutions, neither implemented at the expected scale, nor at the expected speed along the national borders. However, Italy by adopting effective and comparable Coastal NbS from the Danish case study would not only addresses immediate coastal protection needs, but would also promote sustainable development and biodiversity conservation along its unique coasts in line with the EU's climate adaptation strategies and directives. In this regard, Italy should further strengthen its policy framework to support the development and the research of Coastal NbS, by including Coastal NbS into national coastal protection strategies, providing as well financial incentives, and aligning regulations to facilitate their adoption ad different levels. While our research provides a comprehensive framework which supports the implementation of Coastal NbS in the Italian case study, it is limited by the availability of long-term environmental data for some of the more recent analyzed projects, and by the availability of the specific socio-economic conditions of the study areas. Moreover, all the analyzed NbS are developed in sandy low beaches since these are the most vulnerable coastal conformation to sea level rise, storm surges and coastal erosion dynamics. However, there are also other coastal environments which suffer significantly from Climate Change, and a wider study is needed to validate our findings across different vulnerable coastal regions in Italy.

We recommend that policymakers and urban planners prioritize Coastal NbS in coastal management plans and allocate funding for pilot projects in vulnerable areas, since the European Union is strongly supporting and investing into Climate Change adaptation measures when these are well designed. Moreover, huge quantities of data are required to consistently backup the positive outcomes of NbS, therefore NbS need to be designed, developed monitored at scale. Additionally, practitioners should engage local communities in the planning and implementation processes to ensure the success and sustainability of these solutions over time. Future research should focus on long-term monitoring of NbS effectiveness in different coastal environments and explore innovative funding mechanisms to support large-scale implementation. Comparative studies between Italian, Danish and other case studies would definitely further enrich the understanding of Coastal NbS adaptation across diverse contexts.

5.3. Recommendations for the transfer Coastal NbS

Another important takeout from the Danish experience is that, besides supporting the development of coastal spatial resilience (defending vulnerable residential areas, socio-economic assets and/or natural environments from climate change threats) through climate mitigation and climate adaptation processes, Coastal NbS do provide many co-benefits to the local, and sometimes supra-local sphere. One explanatory example among the selected case studies is the re-naturalization of coastal environments, previously altered by human pressures. For instance, restoring historical natural areas along intensive agricultural fields lead to better water quality in the sea due to lower amounts of fertilizers transported to the sea (rich in dangerous nutrients like Nitrogen and Phosphorus), and on the other hand natural areas have strong carbon sink properties which help to secure and absorb GHG emissions from the atmosphere. Natural areas do also enhance the development and the enrichment of local biodiversity which in Denmark has been exploited to develop new forms of slow and sustainable tourism, grounded on birdwatching activities, landscape exploration or on natural laboratories. All together these co-benefits provided by implemented Coastal NbS lead to substantial, and immediate, socio-economic benefits to the local sphere.

Key outcomes of the Thesis are related to the interpretation of the comparison matrix developed in Chapter 3, to analyze and compare the explored Danish best practices. From the seven chosen criteria we can draw the following conclusions and recommendations for the Italian case study:

Are land-use changes important to the success of Coastal NbS?

From the analysis of the selected Danish Coastal Nature-based Solutions, we can conclude that *'changes in land-uses are crucial aspects for achieving coastal resilience'*. In fact, all the chosen projects work on the restoration or the preservation of natural habitats (e.g. wetlands, dune-belts, salt marshes, grasslands, or swamp systems) which act as buffer areas against storm surges, floodings and/or coastal erosion. Furthermore, adjusting land use practices to give space back to nature (and prioritize and protect these natural areas) helps enhance their ability to provide in exchange essential ecosystem services to the local coastal environments. Finally, but not therefore less important, integrating NbS into land use planning can mitigate the impacts of urban development and agricultural activities that typically exacerbate coastal vulnerabilities in close proximity to the sea. Therefore, strategic land use changes seem to be a fundamental element to maximize the effectiveness of Coastal NbS and ensure resilience against climate change impacts.

Do overall Coastal NbS bring socio-economic benefits to the local sphere?

The above analysis speaks clearly, each implemented Coastal NbS provides socio-economic benefits. Fist, Coastal NbS have proven to enhance the overall protection of coastal environments by reducing significantly the risk of flooding and coastal erosion. Therefore, NbS do directly or indirectly safeguard coastal populations, their economic activities, agricultural areas or different types of property values by reduce their repair and/or maintenance costs. Second, all case studies were able to somehow boost the local economies by providing new touristic attractions, unique recreational spaces for residents and/or tourists, unique natural environment and more. Overall, we can say that '*Coastal NbS proved to contribute positively to economic stability and growth while fostering a healthier, more resilient coastal environment'*.

Do overall Coastal NbS bring environmental benefits to the local sphere?

By helping to restore, maintain and enhance natural ecosystems which play crucial roles in maintaining biodiversity and supporting wildlife habitats (e.g. wetlands, dune-belts, salt marshes, grasslands, or swamp systems), without doubts Coastal NbS bring substantial environmental benefits to the local sphere. Moreover, these solutions can help to filter and improve the water quality of coastal water bodies (rivers, lakes, lagoons and bays) by reducing and absorbing the pollutants or exceeding nutrients which industrial activities or agricultural lands produce during their lifetime. Furthermore, their carbon sink function (given by the high levels of new coastal vegetation which gets implemented) also mitigates climate chance effects and contribute to the global carbon reduction goals. Thus, from the study of the selected Danish best practices we learn that *'the implementation of Coastal NBS leads to healthier and sustainable coastal ecosystems, more resilient to the impacts of climate chance'*.

Do overall Coastal NbS lead to a greater coastal resilience?

In line with the outcomes of point 2 and 3 (socio-economic and environmental benefits) we can affirm that, by enhancing the natural buffering capacity of coastal ecosystems which absorb and dissipate wave energy, Coastal NbS are able to cope with extreme weather events (e.g. storm surges and coastal erosion) and stabilize the integrity of the coastline. Compared to grey solutions, NbS promote biodiversity and ecosystem health which are critical for their adaptive capacity to environmental disturbances. Furthermore, the flexibility and adaptability of these solutions allows them to respond dynamically to changing climatic conditions, ensuring long-term protection in contrast to hard engineered solutions. Thus, we can conclude by saying that overall '*Coastal NbS significantly strengthens the ability of coastal areas to withstand and recover from adverse effects of climate change, and ensure coastal resilience'*.

Can Coastal NbS be implemented by local landowners?

Denmark is a specific case study which, as discussed above, commonly sets landowners of coastal areas as responsible for the protection and the maintenance of their own piece of coastal land. However, due to a long coastal protection tradition grounded on grey infrastructures, these landowners are more likely to implement hard engineered solutions such as seawalls and groynes (perceived as reliable and immediate solutions against coastal erosion and flooding) rather than the new and uncertain NbS. Moreover, Coastal NbS are commonly implemented on large coastal areas (seeking to archive territorial, rather than local resilience), and therefore involve high design, investment and maintenance costs which rarely are accessible to local landowners. We can conclude by saying that inter-municipal, inter-regional or international fundings are definitely preferrable to develop Coastal NbS, rather than landowner investments.

Are soft-designed Coastal NbS more effective?

Our analysis leads to the conclusion that both soft-designed and hybrid-designed Coastal NbS have positive outcomes on the local environment, it is not possible to draw a clear line in favor of one solution over the other. Overall, hybrid Coastal NbS might be considered somehow superior to purely soft NBS because they combine the benefits of both natural and engineered systems, resulting in enhanced effectiveness and resilience. But further research is needed to confirm this point and make it a statement, also because (if poorly integrated) hard engineered solutions can negatively affect the natural environment.

Is it important for Coastal NbS to have supporting legislative protection measures?

From what has been analyzed before in the thesis, we can affirm that overall Coastal Nature-based Solutions can be implemented without the need of a supporting legislative framework. However, having a robust legislative environment can significantly enhance their effectiveness, sustainability, and integration into broader coastal management strategies. Therefore, we can conclude by saying that this step is case dependent and needs further studies to be better understood.

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Glossary

Adaptation

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.
IPCC, 2021
apps.ipcc.ch/glossary/

Biodiversity

biological diversity means the diversity of life in all its forms (species, genetic variations within one species, and ecosystems). The importance of biological diversity to human society is very high, an estimated 40% of the global economy is based on biological products and processes. Poor people, especially those living in areas of low agricultural productivity, depend especially heavily on the genetic diversity of the environment.
CBD Toolkit Glossary,
cbd.int/cepa/toolkit/2008/doc/CBD-ToolkitGlossaries.pdf

Climate change

refers to any change in climate over time, whether due to natural variability or human activity. This usage differs from that in the UN Framework Convention on Climate Change, which defines it as: “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time period”.
IUCN Glossary,
iucn.org/sites/dev/files/iucn-glossary-ofdefinitions_en.pdf

Coastal erosion

is the outcome of a process, or a series of natural or induced processes, which change the coastal morphology and lead to the loss of sediment volume in a given timespan and in relation to a specific sea level height.

TNEC

erosionecostiera.isprambiente.it/files/linee-guida-nazionali/TNEC_LineeGuidaerosionecostiera_2018.

Ecosystem

According to the Agreement on Biological Diversity, an ecosystem is understood as a dynamic complex of vegetable, animal and microorganism communities and their nonliving environment that interact as a functional unit. Ecosystems may be small and simple, like an isolated pond, or large and complex, like a tropical rainforest or a coral.
IUCN Glossary,
iucn.org/sites/dev/files/iucn-glossary-ofdefinitions_en.pdf

Ecosystem services

The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth.
Millennium Ecosystem Services,
millenniumassessment.org/documents/document.776.aspx.pdf

Environment

It refers to all living and non-living components and all the factors, like the climate, that surround an organism. It is frequently confused with the word ecology, which is the science that studies the relations of living beings with each other as well as with all the non-living parts of an environment.
IUCN Glossary
iucn.org/sites/dev/files/iucn-glossary-ofdefinitions_en.pdf

Global warming

The estimated increase in Global Mean Surface Temperature averaged over a 30-year period centered on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue.

IPCC, 2021
apps.ipcc.ch/glossary/

Hard engineering strategies

are traditional management process for erosion/flooding, which enhance the coastline in concrete, stone and steel. The aim is to directly stop physical processes altogether (e.g. erosion or mass movement) or alter them to protect the coast. Hard engineering (groynes, sea walls, rip rap, revetments, offshore breakwaters) are economically costly and deliberately alter physical processes and systems.
EDEXCEL
geographyrevisionalevel.weebly.com/211a-hard-engineering.html

Mitigation

A human intervention to reduce emissions or enhance the sinks of greenhouse gases.
IPCC, 2021
apps.ipcc.ch/glossary/

Resilience

The capacity of interconnected social, economic, and ecological systems to cope with a hazardous event, trend, or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation
IPCC, 2021
apps.ipcc.ch/glossary/

Scaling up

"Expanding, replicating, adapting, and sustaining successful policies, programs, or projects in geographic space and over time to reach a greater number of people. "It is important to define up-front the ultimate scale to which an intervention should or could be taken, given the needs of the target population and the nature of the intervention. It is also important to realistically consider the time horizon over which the scaling process needs to extend to achieve the desired ultimate scale. Hartmann and Linn found that successful scaling up of programs to national scale can take ten to fifteen years, or longer.

Taking Innovations to Scale: Methods, Applications and Lessons
usaid.gov/sites/default/files/documents/1865/v5web_R4D_MSIBrookingsSynthPaper09

Sustainability

It refers to the adequate access, use and management of the natural resources, to ensure that the men and women of present and future generations are able to meet their basic needs on an uninterrupted basis. Pattern of behavior that guarantees for each of the future generations, the option to enjoy, at the very least, the same level of welfare enjoyed by the preceding generation. Intergenerational equity of development.
IUCN Glossary
iucn.org/sites/dev/files/iucn-glossary-ofdefinitions_en.pdf