CoCliCo

Research and Innovation Action (RIA)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003598

Start date : 2021-09-01 Duration : 48 Months

Futures services

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CoCliCo - Contract Number: 101003598

Project officer: Anna Natasa ASIK

Document title	Futures services
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Number of pages	29
Document type	Deliverable
Work Package	WP1
Document number	D1.5
Issued by	BRGM
Date of completion	2025-08-01 19:41:58
Dissemination level	Public

Summary

This deliverable is part of the Task 1.5 ?Future Services? as described in the DoA. It aims to describe added value of services and future development pathways and opportunities for the platform. This report explores the future development of climate services supporting coastal adaptation to sea-level rise. The report proposes a framework in which a core service, such as CoCliCo, informs downstream services at regional to local scales. The reports reviews the current landscape of climate services and notes a significant focus on risk assessment, while planning, implementation, and enabling conditions (e.g. governance, finance) remain under-addressed. Similarly, not all thematic areas and enabling conditions of adaptation are addressed by existing climate services. Future services should enhance integration between local and broad-scale tools, respond to thematic areas like health and biodiversity, and address long-term scenarios and uncertainty. Use cases in France, the UK (Fens) illustrate how high-resolution services combined with broad-scale platforms like CoCliCo can inform decisions. Recommendations stress the need to maintain the CoCliCo core, bridge knowledge gaps, and promote services that support robust, inclusive, and transformative adaptation pathways.

Approval

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2025-08-01 20:14:03	Paul SAYERS (SPL)
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Future services

Release Status: Final

Dissemination level: Public

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Date: 11/07/2025

Filename and version: D1.5 Future Services v1.docx

Project ID NUMBER 101003598

Call: H2020-LC-CLA-2020-2

DG/Agency: European Climate Infrastructure and Environment Executive Agency (CINEA)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101003598

Document History

Location

This document is stored in the following location:

Filename	D1.5 Future Services
Location	\COCLICO – WP1\ T1.5

Revision History

This document has been through the following revisions:

Version No.	Revision Date	Filename/Location stored:	Brief Summary of Changes
V01	Development draft	\COCLICO – WP1\ T1.5	
V1	Final version	\COCLICO – WP1\ T1.5	Incorporation of comments and additions

Authorisation

This document requires the following approvals:

Authorisation	Name	Signature	Date
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Future services should enhance integration between local and broad-scale tools, respond to thematic areas like health and biodiversity, and address long-term scenarios and uncertainty. Use cases in France, the UK (Fens) illustrate how high-resolution services combined with broad-scale platforms like CoCliCo can inform decisions.

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1. Introduction

The overarching goal of CoCliCo is to enhance decision-making in coastal risk management and adaptation by establishing an integrated core service dedicated to addressing sea-level rise risks. To achieve this, CoCliCo delivers an open-source web platform that assesses present and future coastal risks and their main drivers, tailors visualization and analysis to local decision-making contexts, and integrates high-quality, user-relevant geospatial information. Within the CoCliCo project, the platform is delivered as a demonstrator and validated in real-world settings (Technology Readyness Level 6 (TRL6) – D2.5).

Once migrated into a fully operational system (TRL9), the CoCliCo platform will be expected to support the development of a broader range of Future Services for coastal adaptation. For instance, the core platform and the data it gathers and generates offer opportunities to develop advanced tools supported by the CoCliCo workbench (D2.6). These future services can build upon the core platform's capabilities and datasets.

At the same time, the evolving global adaptation framework is generating new demands for coastal adaptation science. In particular, the UAE (United Arab Emirates) framework for global climate resilience adopted at COP28 has introduced new expectations and requirements.

This deliverable explores the added-value services and potential development pathways for downstream services based on the CoCliCo platform. Section 2 remains key challenges and features of climate services for coastal adaptation. Section 3 outlines how the global adaptation framework creates emerging needs for information and climate services focused on sea-level rise. Section 4 evaluates the current readiness of climate services to address these needs. Finally, Section 5 presents recommendations and opportunities for developing future coastal services to support effective adaptation.

2. Climate services for coastal adaptation to sea-level rise

Coastal impacts of sea-level rise are a major challenge for climate change adaptation. CoCliCo results show that people exposure to flooding during storms is projected to increase by a factor of 2 by 2050, while associated costs could increase by one order of magnitude, thus confirming results from previous studies (Haasnoot et al., 2021; PIANC, 2020; Vousdoukas et al., 2020). Due to the high dependence on port activities of all the ports (Verschuur et al., 2022).

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One of the responses to anticipate future impacts of sea-level rise consists in developing coastal services for coastal adaptation to sea-level rise (Le Cozannet et al., 2017). Such services involve the provision and use of climate information supporting decision making on coastal adaptation to sea-level rise (Hewitt et al., 2012). Importantly, climate services are not limited to merely static infrastructure connecting adaptation practitioners to climate, sea-level and coastal science. Rather, they involve the dynamic and iterative process consisting in co-developing responses to coastal impacts in specific decision contexts (Brasseur and Gallardo, 2016; Vincent et al., 2018; Hinkel et al., 2019; Le Cozannet et al., 2017).

One major challenge in addressing the coastal impacts of sea-level rise is assessing coastal risks—both now and in the future—under a range of climate, socio-economic, and adaptation scenarios. These assessments are a crucial part of the iterative adaptation process and are typically supported by specialized climate services. To date, two main types of services have emerged in this domain:

- Broad-scale climate services, which operate at global, regional, or subnational levels, typically with spatial resolutions coarser than 50 meters (see D1.1 and D2.1 deliverables of CoCliCo). These services often use simplified representations of coastal processes due to their wide geographic scope. An example of such service is the sea-level rise viewer developed by the NOAA (https://coast.noaa.gov/slr/)
- Local-scale climate services, which are developed at the community or municipal level. These services often rely on broad-scale data as boundary conditions but are enhanced by high-resolution local inputs (e.g., digital elevation models with resolutions as fine as 1 meter) and in-depth knowledge of local coastal dynamics and decision contexts. An example of these services is high resolution modeling developed for coastal prevention or preparedness plans (e.g., Idier et al., 2020).

Both local and broad-scale climate services have distinct advantages and limitations.

For instance, broad scale climate services allow comparing multi-scales impacts with a unique and consistent framework. They can be particularly useful for identifying large-scale patterns, hotspots, or critical issues relevant to national or supra-national policy agendas. However, broad-scale services often struggle with accurately representing coastal hydrodynamics and flood dynamics due to their coarse spatial resolution. Key processes such as wave setup, which can influence total coastal water levels by several tens of centimeters—are typically oversimplified. In addition, coastal inundation modeling at broad scales often depends on data, such as the height and condition of coastal defenses, which usually require detailed local field assessments (Hinkel et al., 2021).

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In contrast, local-scale climate services can address some of these limitations by leveraging high-resolution data and localized expertise and providing more accurate flood simulations, for example. However, they face challenges too. These include persistent gaps in scientific understanding—such as accurately modeling coastal erosion under sea-level rise, or projecting the effects of long-term changes in bathymetry, coastline configuration, and coastal defenses on flood dynamics (D'Anna et al., 2020; Toimil et al., 2023, 2020). Furthermore, uncertainties in projecting future population distributions and estimating damage costs (e.g., through damage functions) introduce additional limitations (Hinkel et al., 2021).

Ultimately, both types of climate services offer imperfect but nonetheless essential information to support the urgent task of planning for coastal adaptation to sea-level rise. Depending on the user, its scope and scale of action, either local to regional or broad scale climate services, or both may be relevant: for local-scale concerns, a broad-scale climate services can give a comparative view and encourage action capitalising on pioneer projects. For national concerns or large portfolios of assets, some critical aspects or hotspot may arise. Rather than opposing the two, we raise the question: what specific information needs relevant to coastal adaptation can these different types of climate services respond to? How can they be interconnected? Where are existing climate services positioned within the vast ensemble of coastal adaptation needs?

3. An emerging framework for adaptation

Adaptation of human systems is defined in the IPCC glossary as the "process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC, 2022).The concept has emerged as a second pillar of climate policies supplementing climate change mitigation in the late 1980s and expanded since then as climate impacts have increased (Orlove, 2022).

Unlike mitigation - which can be assessed by the reduction of greenhouse gas emissions - adaptation lacks clear and universally accepted metrics and criteria of success (Orlove, 2022). Progress on mitigation can be monitored through the reduction of greenhouse gas emissions and its success evaluated against the objective of the Paris agreement objective to stabilize climate change well below 2°C global warming levels. In theory, from an economic point of view, the success of adaptation could be measured by quantifying the losses and damages avoided by adaptation measures. Yet, this quantification is highly challenging because it would require an accurate evaluation and attribution of losses and damage due to climate change in the real world and in a counterfactual world without adaptation. In reality, losses and damages are often supported by households, businesses and public

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organisations without any specific reporting. In addition, adaptation is not yet satisfactorily monitored today, especially for the huge number of autonomous adaptation measures implemented locally or informally.

Given the lack of a unified method for evaluating adaptation progress, multiple multi-criteria approaches have been developed to evaluate adaptation (Magnan et al., 2023; United Nations Environment Programme, 2024). Here we refer to the framework developed within the climate negotiations on the global adaptation goals and agreed at COP28 (UNFCCC, 2024). This framework, known as the Global Framework for Climate Resilience, establishes 7 thematic areas and 4 adaptation steps that countries are required to report on by 2030. The framework is further supported by several enabling conditions such as finance or governance, which are essential to ensure the credibility and effectiveness of adaptation polices (Figure 1).

Because of its authoritative nature (countries will have to report about their progress by 2030), we use this framework to assess whether existing and future services for coastal adaptation adequately inform adaptation decisions today. As suggested in the draft outline of the 7th IPCC report, we complete the steps of adaptation policy planning. It includes 4 steps: risk assessment, planning, implementation and MEL (Monitoring, evaluation and learning), with a scoping phase aiming at identifying the broad challenges and objectives of adaptation as well as the information available in the early stage of adaptation strategy development.

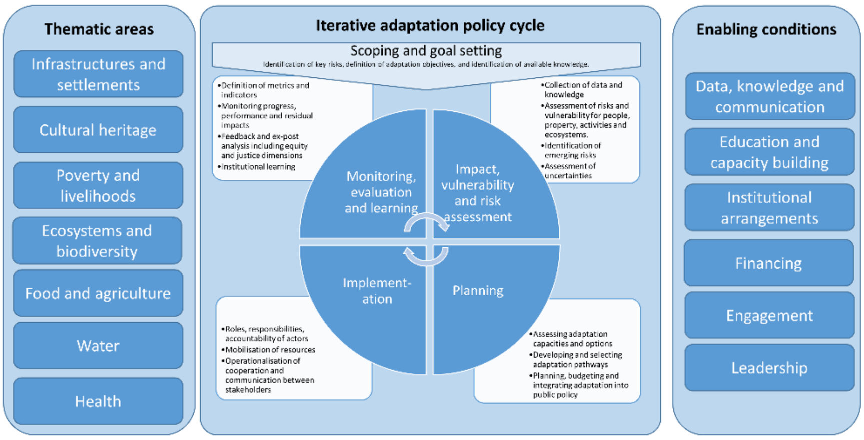

Figure 1: dimensions of adaptation, based on the UAE Global Framework for Climate Resilience, the UNEP adaptation gap reports and the report of the scoping meeting of the 7th assessment report of the IPCC (IPCC, 2025; UNFCCC, 2024; United Nations Environment Programme, 2024).

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Although adaptation to sea-level rise presents distinct challenges, the analytical framework outlined above remains applicable. Adaptation to coastal risks related to sea-level rise is considered as a distinctive adaptation challenge in the 6th assessment report of the IPCC due to the superimposition of extreme events with a slow-onset process that will continue for centuries after global warming levels have been stabilized (IPCC, 2022). As a consequence, measuring the success of adaptation is even more difficult because committed losses and damages may remain substantial even after implementation of adaptation, as meters of sea-level rise are already locked in at current levels of global warming (Le Cozannet et al., 2023). Rather than aiming to establish a new and stable state in which coastal zones are permanently resilient to climate change, the priority is to create dynamic, flexible governance processes that enable continuous adaptation over time (Conway et al., 2019). This specific issue of coastal adaptation explains why frameworks such as adaptation pathways are especially relevant for stakeholders concerned with sea-level rise (Haasnoot et al., 2013; Ranger et al., 2013). While these specific challenges must be taken into account at each step of the adaptation policy cycle, they do not require adjustments to the general framework proposed above. Therefore, it can be used as a reference to map the scope of existing climate services.

4. Current climate services for coastal adaptation to sea-level rise

4.1 The current landscape of services supporting coastal adaptation in Europe and globally

The development of broad scale climate services in Europe is strongly driven by the Copernicus programme, which is building a comprehensive Earth observation capacity for Europe. Although no service is currently dedicated specifically to coastal adaptation, various Copernicus services provide valuable data and insights to support the assessment of coastal risks and inform adaptation strategies (Melet et al., 2021). For example, the Marine service provides observations and forecasts of sea levels and waves. The land service provides digital elevation models and information on vertical ground motions, which may either mitigate or enhance climate-induced sea-level rise (Thiéblemont et al., 2024a). Climate modelling results that can be used to anticipate changes of sea levels, surges, waves and precipitations and the Emergency service provides support to coastal disaster preparedness. The information relevant to broad scale climate services supporting adaptation to sea-level rise in Europe is therefore not yet available through a single clearing house, but it can be noticed that

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the concept of a coastal data hub has been proposed to better serve coastal users in Europe (Melet et al., 2021).

Several broad scale climate services relevant for coastal adaptation to sea-level rise have been identified with the CoCliCo Project (Derval et al., 2022). This report shows that climate services relevant to coastal adaptation to sea-level rise in Europe are diverse and stem from a wide range of initiatives—organizational, international, sectoral, and financial. While many platforms exist, often offering interactive tools or expert products, their users and real-world applications beyond science remain unclear. The structured comparison conducted within this report shows significant variation in content, accessibility, and target audiences of existing broad scale climate services for adaptation to sea-level rise. Critically, there is still a major gap: existing services lack the capacity to provide integrated, decision-relevant information that combines climate, socio-economic, infrastructural and adaptation scenarios at the pan-European scale.

Coastal climate services for adaptation to sea-level rise include a number of activities that do not necessarily identify themselves as climate services, but correspond to the commonly accepted definition of "activities supporting adaptation to and mitigation of climate change" (Le Cozannet et al., 2017). Mapping all these activities is not possible due to their heterogeneity, but some of their characteristics can be identified from previous reviews. In particular, a systematic review published by Cabana et al. (2023) has examined how coastal research is currently positioned. This review shows that the majority of studies have focused on the initial phase of the iterative adaptation policy cycle, that is, the initial impacts, vulnerability and risk assessment, with minimal attention to the implementation phase. Enabling conditions are little addressed or exposed, especially the question of funding. Finally, the majority of studies address questions related to urban and coastal management, suggesting a dominant focus on infrastructures and settlements, which can include some consideration of coastal ecosystems, especially where they support nature-based solutions. Although many activities may not be reported in the published literature, this review suggests a stronger focus on a few thematic areas (infrastructure and settlements, and to some extent ecosystems and biodiversity), on the impacts, vulnerability and risk assessment phase of the iterative policy cycle and too little attention to enabling conditions besides the development of knowledge, information and data.

In this context, the structure of future climate services for coastal adaptation to sea-level rise could follow the model shown in Figure 2. Building upon Copernicus, a broad-scale coastal climate service would provide the foundational information needed to build Europe-wide capacity for coastal adaptation. The CoCliCo platform is a TRL6 (Technology Readiness Level 6) demonstrator of such service, that is, a demonstrator validated in relevant decision contexts. This core service could deliver information

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directly to users or serve as a resource for researchers and value-added companies already supporting coastal adaptation, even if they do not identify themselves as climate service providers. Between these levels, downstream services could be developed, tailored to the needs of specific users—such as cities, infrastructure managers, or national risk assessors—by building on and contextualizing the core information.

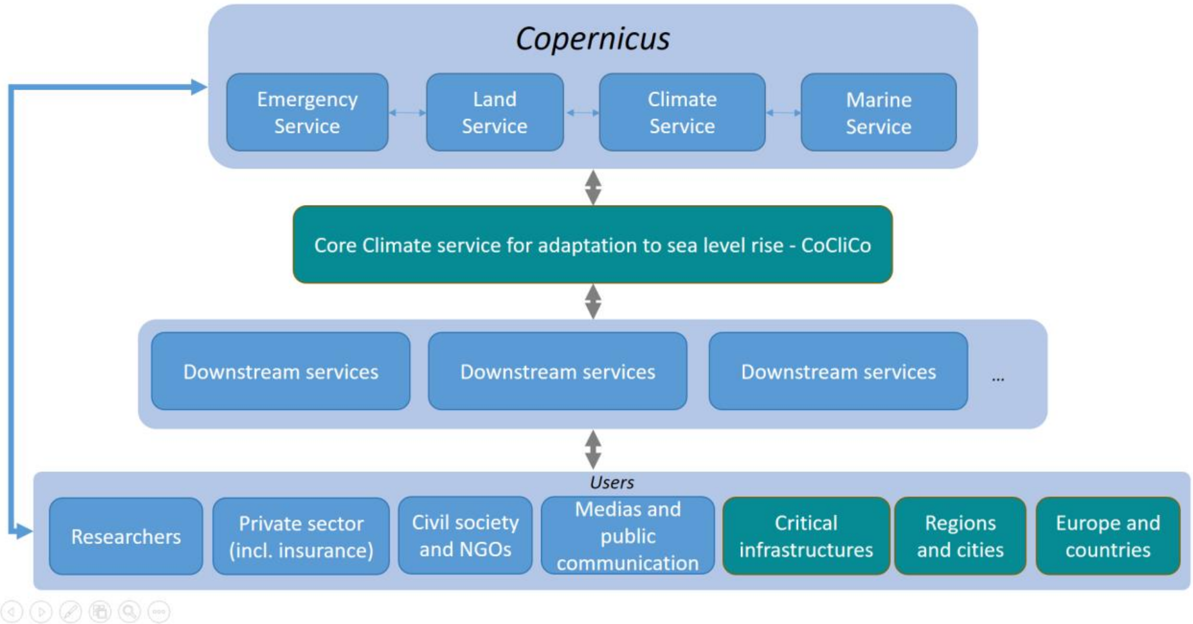

Figure 2: a model for future climate services supporting coastal adaptation to sea-level rise.

As shown in Figure 2, the interactions between the different layers of climate services are bidirectional. Users are not only recipients of information—they also provide feedback that shapes the evolution of services. Similarly, downstream services typically draw on the core service for data and boundary conditions, but they also play a crucial role in shaping the content and priorities of the core service. By articulating specific needs and use cases, these downstream services help ensure that the data, scenarios, and tools provided at the core level are better aligned with the diverse requirements of end users.

4.2 Current positioning of CoCliCo across the adaptation dimensions

The analysis in Section 3 provides an initial assessment of how existing climate services for coastal adaptation to sea-level rise are positioned across the adaptation dimensions. This is summarized in Figure 3. Figure 3 shows that current climate services primarily support the early stages of the iterative adaptation policy cycle. As previously discussed, thematic areas and enabling conditions are unevenly

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addressed. Yet, we consider that sectors such as food and agriculture, as well as water, are at least partially covered—thanks to a small but notable number of studies on fisheries and water management identified by Cabana et al. (2023).

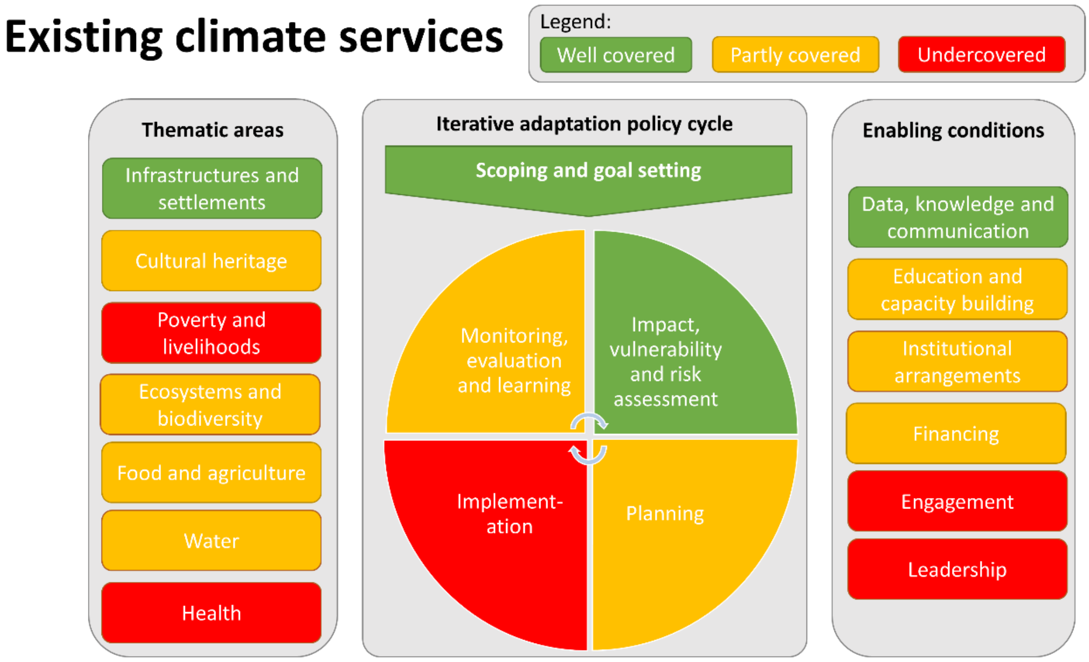

Figure 3: positioning of existing climate services across the dimensions of adaptation identified in section 3.

The core service of CoCliCo focuses on flood risk assessments, and as such, it addresses a more focused scope compared to some other climate services considering for example other dimensions of adaptation (e.g. planning, with the delivery of adaptation pathways) or thematic areas (e.g. poverty and livelihood, addressing the equity and justice challenges in coastal impacts and adaptation). Figure 4 illustrates the main adaptation dimensions targeted by this service. Given its broad-scale coverage at the European level, CoCliCo is naturally positioned within the early phases of the iterative adaptation cycle—specifically the pre-assessment, scoping, and goal-setting stages. It may also serve as a useful source of information for more detailed risk and impact assessments in cases where local data or resources are lacking. However, in general, such detailed assessments are expected to rely on high-resolution, locally owned digital elevation models (DEMs), improved representation of wave setup and flood dynamics, and other localized parameters to produce accurate flood maps. This points to the potential role of a future downstream service: using CoCliCo's broad-scale outputs as boundary conditions for localized risk assessments.

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CoCliCo is primarily designed to assess flood risks for human settlements and infrastructure, and potentially cultural heritage sites. However, the human-biophysical interactions modeled in the platform are currently limited to crossing hazards with people exposed and infrastructures. They do not currently include the processes relevant to thematic areas such as ecosystems and biodiversity (e.g., to evaluate the ecological benefits of different adaptation options), or health, e.g. to better understand the differentiated physical and mental health impacts of marine flooding across age groups, genders, and other social factors.

In terms of enabling conditions, CoCliCo clearly contributes to the data, knowledge, and information dimension. It also partially addresses the finance dimension by providing indicative cost and cost-benefit analyses for various adaptation options, and supports education through user guidance and learning resources embedded in the platform. However, other enabling factors—such as leadership and institutional capacity—are not covered.

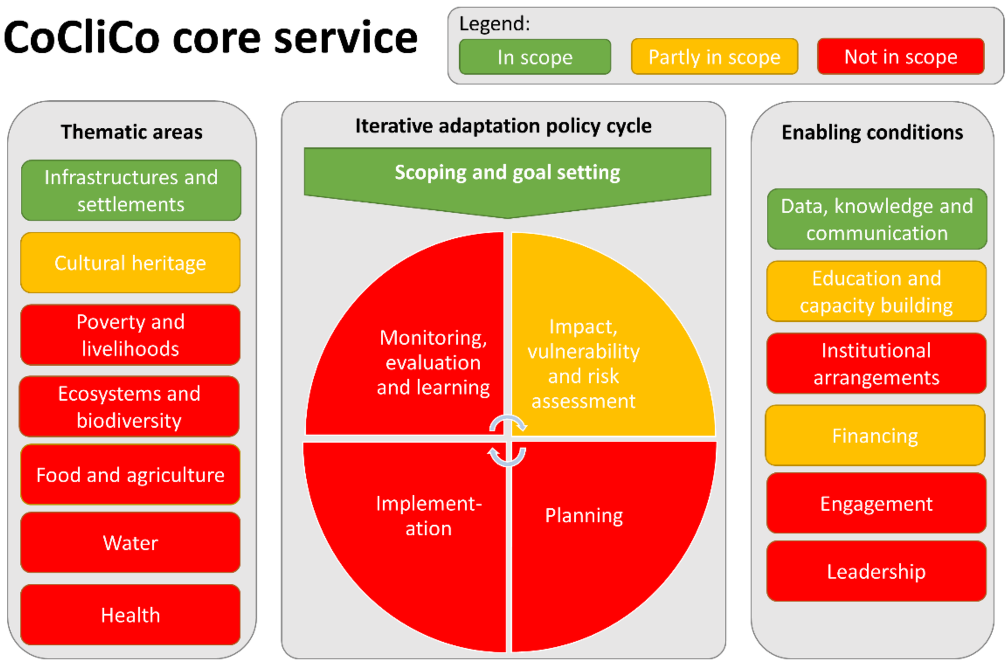

Figure 4: positioning of the CoCliCo core service across the dimensions of adaptation identified in section 3.

Based on our experience, engagement and leadership in the field of adaptation seem to be significantly underrepresented in existing services. While flood risk assessments services such as CoCliCo are not intended to contribute directly to these dimensions,

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it could be argued that to some extent, policy briefs and science–stakeholder interactions may offer some support in this area. Given the critical role that leadership and engagement play in the success of adaptation efforts, future research should specifically aim to address this gap.

5. Future coastal services supporting adaptation to sea-level rise

A significant portion of future climate services is expected to emerge within the downstream layer illustrated in Figure 2. The following section presents a typology of these services, organized according to their role within the iterative adaptation policy cycle, and illustrates them with concrete examples drawn from CoCliCo's use cases developed during the project.

5.1 Scoping and goal settings

Climate services supporting the scoping and goal settings of adaptation to sea-level rise support the initial assessment of the decision context and the solution space, broadly defined as the constraints and opportunities for adaptation (Haasnoot et al., 2020; IPCC, 2025). For example, they may either provide an initial set of information to identify the social, economic and environmental settings, key climate risks to adapt to, current development projects, current decision mechanisms and identify how these key risks have been addressed in other contexts. They may also help determine the information available to perform the more detailed assessment of key risks and adaptation options, and support stakeholders in organizing and structuring the adaptation policy cycle.

Broad scale climate services do not provide all the support needed for adaptation, but they are essential at the initial stage. Indeed, a key challenge here is to go over a wide range of climate and socio-economic scenarios in order to explore as many options as possible. For example, CoCliCo can here provide key support as it spans a wide range of climate and socio-economic scenarios, ranging from stabilization of climate change below 2°C as agreed in the Paris Agreement, to high emissions pathways assuming a rollback of climate policies, continued fossil fuel development, and the onset of a collapse of some sectors of the Antarctic ice sheets. These scenarios also allow exploring different patterns of population migrations toward urban and coastal areas (Merkens et al., 2016). In addition, broad scale climate services may help explore a larger set of timescales than previously considered, e.g. until 2100 or 2150 depending on the user story in CoCliCo. Indeed, a key message to be conveyed to stakeholders at this initial stage is that far from being static, the solution space evolves

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over time, both due to sea-level rise and climate change – which reduces the opportunities – and human actions – which may either expand or reduce opportunities depending on the adequacy of responses (Haasnoot et al., 2020).

Local climate services available in the specific area of interest can be extremely valuable, as they help to understand the capacities built already and the adaptation options in place. However, they should be considered carefully because they may only address a subset of the problem – for example only erosion and not flooding - or be strongly constrained in terms of scenarios exploration. For example, much of the information available today in France assumes that sea levels will reach 60cm in 2100, and do not explore farther timescales or higher scenarios that are equally plausible (Le Cozannet et al., 2025). Overly focusing on such local studies may miss the opportunity to explore the entire solution space and its constraints. It may also mislead adaptation efforts, as relying on a limited subset of scenarios can underrepresent the deep uncertainties inherent in climate and socio-economic futures. This, in turn, may lead to decisions that appear optimal within a narrow framing but fail to remain robust across a wider range of plausible futures.

A future downstream service based on CoCliCo at this stage could help stakeholders contextualize and understand the core service, how it can inform decisions and what its limitations are. This downstream service could take the form of consultancy realized by researchers, engineers, or coastal consultants. As the CoCliCo platform only covers a subset of thematic areas and enabling conditions relevant to adaptation, it is important for the providers of this service to go beyond CoCliCo alone and include under-covered topics such as health and water or enabling conditions such as institutional arrangements and engagement. For example, an extremely important aspect of this initial stage is to build trust. As shown by the difficulties in adopting the coastal risk adaptation plans in France, coastal adaptation projects can fail if they are misaligned with development priorities and have not engaged with all relevant stakeholders, including people at risks and opponents to coastal adaptation (Le Cozannet and Cazenave, 2024). This suggests that the key expertise of consultants providing the relevant downstream service at this stage should be in social science with a clear understanding of the biophysical and social boundaries of the solution space.

5.2 Impacts, vulnerability and risk assessments

Climate services that support the assessment of impacts, vulnerabilities, and risks must integrate diverse sources of information. This includes data on climate and marine forcing factors (e.g., sea-level rise, waves, and storm surges), coastal hazards (e.g., erosion, flooding, and salinization), the exposure and vulnerability of elements

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at risk (e.g., populations, infrastructure, and ecosystems), and ultimately, the resulting risks, which can be quantified using metrics such as expected annual damages.

This area of work particularly benefits from effectively interlinking broad-scale and local-scale climate services in ways that is suitable to each local context. In ports, cities, regions, or countries with high adaptive capacity, local data and models are often available, enabling detailed assessments. In such cases, broad-scale climate services play a crucial role by providing the boundary conditions necessary to drive local models. Conversely, in areas with lower adaptive capacity, broader-scale assessments may be the only available option. In these contexts, it is essential to account carefully for the limitations and uncertainties inherent in broad-scale information.

Broad-scale models may as well contribute to the development of a common "cultural knowledge" (Crona et al., 2013) on climate change across various regions, here Europe, where people share some similar sets of perspectives on climate change despite different national political and policy responses (Lorenzo and Hulme, 2009).

When interlinkaging the broad and local scales, it is necessary to understand how higher resolution assessments add value to the broad scale, and if they can add a cascade of uncertainty. For flood risk assessment, state of the are broad scale modelling can provide precise and accurate boundary conditions until the point when waves have broken, typically at 20m depth (Filippini et al., 2024). Beyond that point, the wave setup generates variations of the instantaneous total water levels that are substantial and are usually not accurately represented by empirical formulas. To ensure realistic flood modeling, broad-scale inputs should be used only up to the wave-breaking zone. From there onward, more detailed local surge models should be employed to accurately represent the storm surge contribution to total water levels. This transition is critical for producing meaningful and context-relevant flood risk assessments and defines where a downstream local climate service will add significant value.

Going further in the chain of computation leading to risk assessments, the identification of assets at risks may be more precise locally than those provided at broad scale, but one key limitation will be the damage functions (Hinkel et al., 2021). These functions carry intrinsic uncertainties that are difficult to reduce, even with detailed local data and limit the accuracy of risk assessments. Downstream local services must consider this limitation that the flood hazard may be extremely precise and therefore help assess precisely the exposure to flood risks, but that deep uncertainties will remain when computing risks due to the lack of precise vulnerability functions. Research in this area is being performed, but one cannot expect reducing too much of the uncertainties due to the large proportion of households contents in the total losses observed after coastal flood disasters (André et al., 2013).

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For coastal erosion and shoreline retreat, the situation is different: a key issue preventing from achieving accuracy is not only the resolution of data but the structural uncertainties of shoreline retreat models (Le Cozannet et al., 2019). Local data can help better characterize current erosion trends and the impacts of storms and seasonal variability on shoreline mobility. They can also improve understanding of constraints related to geology, lithology, and human infrastructure. However, significant uncertainties will remain regarding how shorelines will respond to sea-level rise. Furthermore, erosion and flooding are not separate hazards but interact with one another, introducing significant uncertainties into flood projections (Toimil et al., 2023). In this area, downstream services may therefore both focus on improving projections considering the local context but also raise attention to the need for decisions frameworks able to handle deep uncertainties, such as robust decision making.

The two previous paragraphs explain how the CoCliCo core service can be developed further by downstream services to better serve users at the impact, vulnerability and risk assessment step of the adaptation policy cycle. However, there are others, which are relevant to coastal adaptation and not covered in CoCliCo. This includes in particular extreme precipitations and runoff events, which are exacerbated by climate change and compounded with sea-level rise, especially at high tide (Cox et al., 2025). Other services that can benefit from CoCliCo at this stage are the risks to coastal ecosystems – whereby flood maps can be simply crossed with existing and planned ecosystems or other thematic areas of adaptation shown in Figure 1 such as health, the cultural heritage, crops, etc. In this area there is a large potential for future services which involves not only CoCliCo but also other domains.

Several examples of existing services falling in this category and developed within CoCliCo and other projects of the Adaptation Mission can be mentioned: (1) the delivery of sea-level scenarios consistent with the national adaptation plan in France (Le Cozannet et al., 2025); (2) the assessment of the role of vertical ground motions in relative sea-level changes (Thiéblemont et al., 2024a); (3) the determination of times of emergence of chronic flooding events (Thiéblemont et al., 2023); (4) the broad scale assessment of the exposure of the French Conservation Agency to sea-level rise, informing its acquisition strategy to ensure it can achieve its strategic aim to own 30% of the coast despite sea-level rise (Thiéblemont et al., 2024b). These examples illustrate the diversity of potential downstream services falling within this category.

5.3 Planning

The planning phase of adaptation begins with identifying locally relevant adaptation measures or strategies. This is followed by an assessment of their feasibility, effectiveness, co-benefits, trade-offs, and limitations. The most suitable measures are then selected and organized into sequenced adaptation pathways (McGahey and Sayers, 2008, Haasnoot et al., 2013; IPCC, 2022; Muccione et al., 2024).

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Climate services on flood risks can support this step by evaluating the effectiveness and some aspects of the feasibility and limits of various adaptation strategies. For example, the economic benefits of raising coastal defences can be quantified using a core service such as CoCliCo, with the caution that raising coastal defences may be made at the expenses of ecosystem losses and lock-ins, ultimately resulting in higher costs on the long term (Vousdoukas et al., 2020). Hence, relying only on a narrow risk-based view of coastal adaptation can overlook critical dimensions of adaptations such as the thematic areas of poverty and livelihood, food and agriculture and biodiversity and ecosystems shown in Figure 1. This calls for downstream services expanding the consideration of adaptation at least to the thematic areas shown in Figure 1.

Several examples of services from CoCliCo and other projects from the Adaptation mission can be mentioned: (1) a large adaptation project in the Fence estuary, which is described in the subsection below; (2) The prioritization of coastal erosion prevention investments in the Maldives depending on the magnitude of the risks as well as communities preferences and governmental priorities (Hinkel et al., 2023); (3) the assessment of the impacts of adaptation strategies involving depolderisarion and ecosystem restoration on flood risks (Louisor et al., 2022). Importantly, high resolution adds a lot of value in order to avoid errors in the evaluation of adaptation options.

In addition, it must be recognized that other dimensions of the climate services supporting the planning phase of coastal adaptation to sea-level rise are not based on flood risk assessment, but rather start with the identification of adaptation measures (Baills et al., 2020a). This calls for future downstream services that also includes tools such as catalogues of relevant coastal adaptation options and generic assessment of their feasibility, effectiveness and co-benefits (Baills et al., 2020b; Pasquier et al., 2024; Raji et al., 2025).

5.4 A collaborative exploration of future coastal adaptation in the Fens, England.

The Fens, the UK’s largest coastal lowland, face a pressing climate challenge. Strategically crucial for national food production and home to a growing population and economy, this region is particularly vulnerable to climate risks like sea-level rise (SLR), coastal and fluvial flooding, drought, and heat stress (Figure 5). Over the centuries, the Fens have transformed into an engineered landscape, reliant on drainage channels, flood defences, and tidal barriers to manage water. But with large areas of the region below sea level and sea levels projected to rise by up to one metre by the end of the century, the risks are mounting.

In collaboration with the Environment Agency-funded Fens Climate Change Risk Assessment Project, CoCliCo partners (Sayers and Partners and UEA) have developed an in-depth climate risk assessment for the Fens and explored alternative

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high-level adaptation future storylines using the Future Flood Explorer and building upon the CoCliCo framework. The case study highlights the interconnectedness of climate risks, illustrating how rising seas, drought, and biodiversity loss intertwine to challenge the future of this vital region. The myriad of risks that could impact the Fens as global mean surface temperature increases, based on the climate risk modelling presented in this report. The arrows highlight when risks may be faced based on warming levels of 2°C, 3°C and 4°C are reached, reported by the Carbon Brief (2020) and IPCC (2023) and assuming a high emission future. Even if current pledges of international government action are considered and assumed to be delivered, temperatures rise beyond 2°C and potentially 3°C by the end of the century, with continued increases after that date (Climate Action Tracker, 2023).

A key takeaway from the Fens case study is the need to view the region's climate risks through a systems lens. The Fens' challenges are deeply interconnected. Sea-level rise, flooding, water scarcity, and agricultural impacts all affect one another, meaning that the solutions must be similarly integrated. By considering the various climate and socio-economic factors, CoCliCo has provided an adaptable framework for adaptation that can guide future actions.

Through high-resolution modelling and data from climate projections (including UK Met Office UKCP18 data), the study not only analyses the risks of flooding and drought but also considers their cascading effects on agriculture, biodiversity, and community health. The study's integration of the pan-European CoCliCo framework offers a scalable tool for stakeholders to build adaptive strategies that are both local and collaborative. **This offers a significant opportunity for future services by incorporating tools such as the Future Flood Explorer into the climate service to provide support to adaptation choices.**

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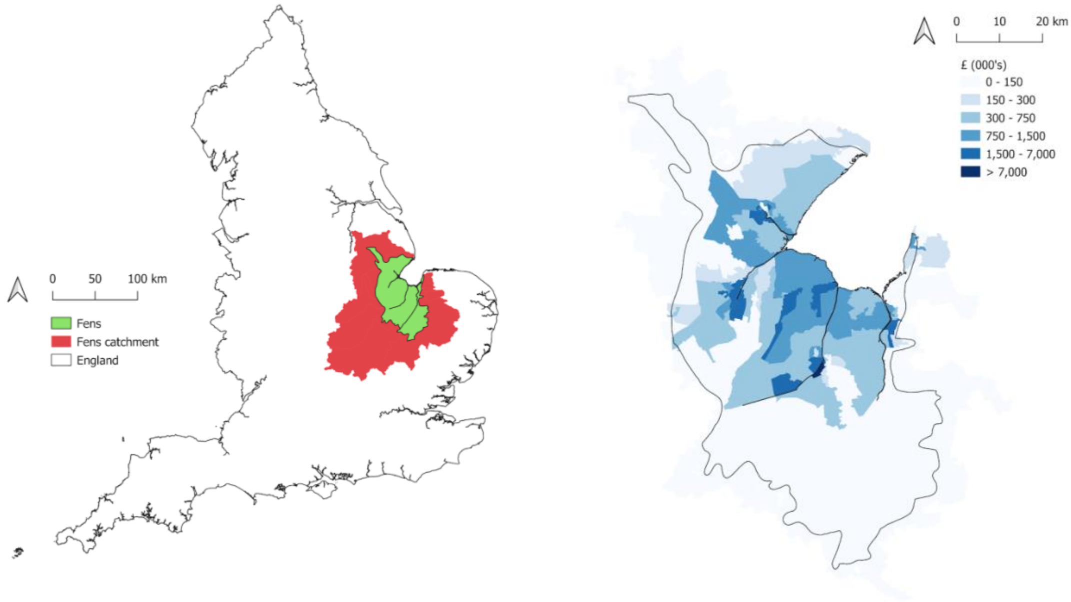

Figure 5: Fens Exploration of future services – Adaptation and high resolution risks; Left: The Fens Coastal Floodplain, and right the Present Day Expected Annual Damages assessed using the Future Flood Explorer, highlights the potential to provide high resolution risks in support of adaptation choices.

The lessons from the Fens extend beyond this region and offer valuable insights for coastal lowlands worldwide. As the impacts of climate change become more pronounced, the need for integrated adaptation strategies becomes ever clearer. This case study provides a model for other regions facing similar challenges, offering a comprehensive framework for assessing risks, identifying opportunities, and making decisions that balance environmental, social, and economic needs.

The pilot shows that the use high-resolution, localised climate data also side adaptation exploratory tools is crucial. The CoCliCo framework enables downscaled analyses that offer actionable insights, ensuring that local needs are met within a broader climate adaptation strategy.

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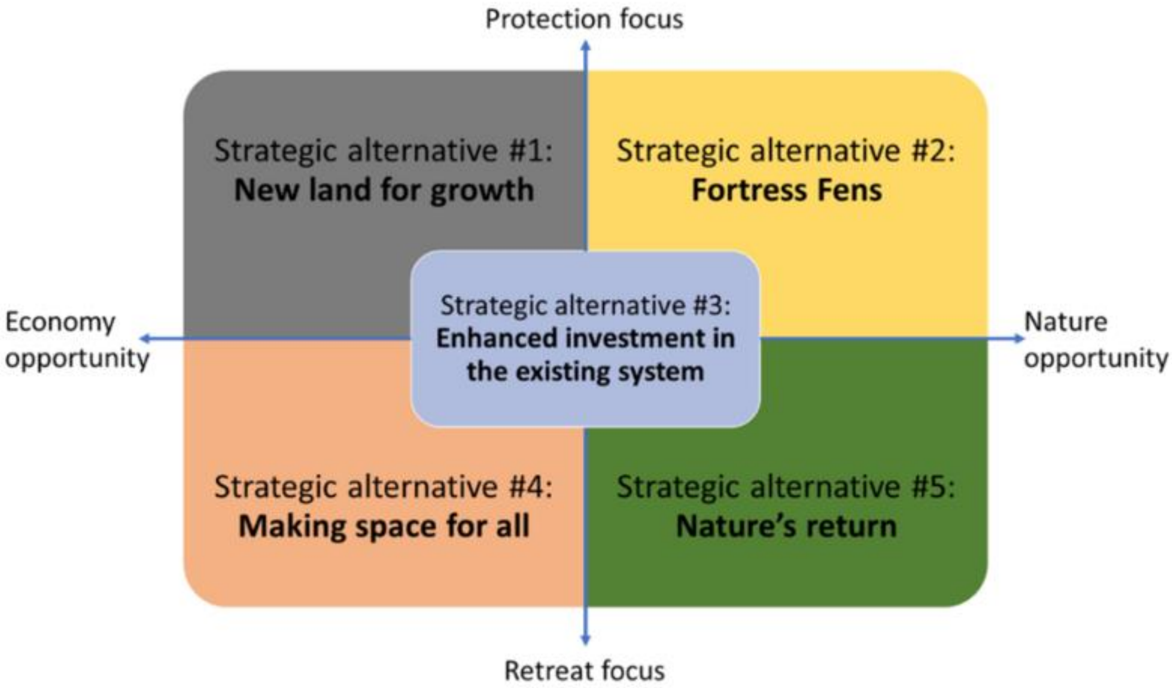

Figure 6: Decision-making matrix for the Fens, by Sayers and Partners and UEA

Throughout the team collaborated with organisations like Anglian Water, Lincolnshire County Council, and Cambridgeshire & Peterborough Combined Authority and these partners are now exploring how to use the exploratory findings to shape future flood resilience strategies. The future of the Fens will depend on the collective action of its stakeholders and this exploration of future services highlights that tools like CoCliCo when linked with the Future Flood Explorer (or similar tools) can provide valuable insights to help navigate the complex challenge of adapting to sea level rise.

5.5 Implementation

Services supporting the implementation of adaptation typically covers activities such as project management assistance. Here we anticipate only a minimal utility of climate services such as CoCliCo.

5.6 Monitoring, evaluation and learning

Monitoring, evaluating and learning from coastal adaptation implementation first requires observations of the socio-ecosystem at risk. Climate services such as CoCliCo and their downstream services would rather be positioned as recipients of information from this step. For example, ex-post analysis of damages delivered by the insurance industry can be used to better estimate damage costs from coastal disasters and how.

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Climate services on flood risks can also provide support, for example contextualizing observations. For example, an adaptation project may be considered unsuccessful due to a large flood disaster or an unfavorable sequence of storms, which may actually be an extremely specific event much larger than expected. Conversely, climate services can also contextualize observations that are difficult to interpret, e.g. when climate variability masks the acceleration of sea-level rise in specific regions as in the Netherlands over the past decade (Keizer et al., 2023). Many other services, not necessarily building on flood risks assessment such as CoCliCo, can be developed, for example to assess to what extent the adaptation implemented has contributed to adaptation or may result in increased risks (maladaptation) (Magnan et al., 2016, 2023), or has the potential to become transformative, more efficient (Termeer et al., 2017).This stage is also an opportunity to come back to the framework presented in Figure 6, evaluate which thematic areas and enabling conditions have insufficiently been covered or mobilized, so that these gaps can be corrected in the next iteration of the adaptation process.

This stage of adaptation is also closely connected to another aspect of climate policies, that of losses and damages. In this area, a clear challenge will be to identify to what extent specific damages can be attributed to climate change, in order to inform the debate on the responsibility of these losses and damage and eventually engage in litigation procedures (Callahan and Mankin, 2025). To respond to this need adequately, coastal impacts models will need to reach challenging levels of precision and accuracy, which today, in our view, can only be reached using the highest resolution data available such as Lidar.

6. Conclusions

This report presents the potential for future services to emerge from the CoCliCo core service, if sustained over time. Building upon the finding in this report, several recommendations can be made in order to support the emergence of downstream services that effectively support adaptation:

- Instead of opposing high-resolution and broad scale climate services, acknowledge that both provide useful information and have limitations, and that if properly used and interlinked, they can support coastal adaptation.
- Maintain and develop the core service, as recommended in the policy brief of CoCliCo, in order to offer the infrastructure required for the development of services
- Expand the scope of current services to make sure that they cover all relevant dimensions of adaptation, starting with those fo the UAE Framework for Global Climate Resilience

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- Pursue the well established objectives of climate services development such as education and training, sustained financing, certification of climate services
- Create a governance and policy environment that allow climate services to operate effectively.

7. Acknowledgement

We used artificial intelligence to correct grammatical errors and enhance the overall use of English in this document.

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