Ref. Ares(2023)7107319 - 19/10/2023

ReNEW

D1.6 - Mitigating degradation of ecological services on waterways v1

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Document Info

Document

Title	Resilience-centric Smart, Green, Networked EU Inland Waterways
Acronym	ReNEW
Call	HORIZON-CL5-2021-D6-01
Type of Action	HORIZON-IA
Grant Number	101069682
Start date	1 September 2022
Duration	36 months
Document identifier	D1.6 - Mitigating degradation of ecological services on waterways v1
Due Date of Delivery to EC	00-00-2023
Actual Date of Delivery to EC	00-00-2023
Dissemination level	PU - Public
Work package	WP1 - Methodology for EU Resilient and Sustainable IWT Infrastructure System
Lead Beneficiary	SINTEF Energi AS

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History Sheet			
Version	Date	Editor	Summary of Modifications
0.1	25/07/2023	Mauro Carolli	First draft
0.2	11/09/2023	Mauro Carolli	First review by ISL
0.3	09/10/2023	Mauro Carolli	Integration of reviewers comments
0.4	11/10/2023	Mauro Carolli	Integration of ISL comments

Acronyms and Abbreviations	Meaning
AA	Appropriate assesment
AI	Artificial Intelligence
BAT	Best Available Technique
DWD	Drinking Water Directive
EEA	European Environment Agency
EIA	Environmental Impact Assessment
END	Environmental Noise Directive
ES	Ecosystem services
EU	European Union
IED	Industrial Emissions Directive
IT	Information Technology
IWT	Inland Waterway Transport
KPI(s)	Key Performance Indicator(s)
LL	Living Lab
MAES	Working Group on Mapping and Assessment of Ecosystems and their Services
MSFD	Marine Strategy Framework Directive
PM	Particulate Matter
QGIS	Quantum Geographic Information System
RBMP	River Basin Management Plans
ReNEW	Resilience-centric Smart, Green, Networked EU Inland Waterways
SEA	Strategic Environmental Assessment
UWWTD	Urban Wastewater Treatment Directive
WFD	Water Framework Directive
WSP	Wate Safety Plan

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Executive Summary

ReNEW is the acronym for the project "Resilience-centric Smart, Green, Networked EU Inland Waterways". This project is funded by the European Commission under the topic “HORIZON-CL5-2021-D6-01-09 “Climate resilient and environmentally sustainable transport infrastructure, with a focus on inland waterways”.

This deliverable summarizes the impacts of common IWT infrastructures on the environment in the light of EU Directives by linking IWT measures and actions and their potential impact on waterbodies according to the “Guidance on IWT and Natura 2000 Sustainable inland waterway development and management. The deliverable sets a baseline for the evaluation of all actions and interventions proposed within the ReNEW project in the light of the EU environmental directives, with a specific but not exclusive focus on (i) Water Framework, (ii) Floods, (iii) Habitats, (iv) Birds, (v) Ambient Air Quality and (vi) Environmental Noise Directives. Moreover, we propose a set of ecosystem services to link with physical, chemical, and ecological processes to connect with IWT measures, and finally, we suggest a set of indicators that can be used in the following steps of the project to quantify the effects on ecosystem services.

1 Introduction

1.1 Mapping the ReNEW Output

The following table (Table 1) maps the ReNEW's Grant Agreement (GA) commitments, both within the formal Deliverable and Task description, against the project's respective outputs and work to perform.

Table 1: Adherence to ReNEW's GA Deliverable & Tasks Descriptions

Deliverable D1.6 Mitigating degradation of ecological services on waterways
Measures Catalogue, and Design tool specification.

Task T1.3 Mitigating degradation of ecological services on waterways
Develop of Decision Support facilities to support environmental impacts analyses in the definition of ReNEW strategies and interventions.

ReNEW GA Element Title	ReNEW GA Element Outline	Respective document Chapter (s) and Description
ST1.3.1 Impacts of common IWT infrastructures on the environment in the light of EU directives	Produce a catalogue of measures, IWT actions and their potential impact on waterbodies according to the Guidance on IWT and Natura 2000 Sustainable inland waterway development and management.	Chapter 4 describes ITW measures, which processes might be involved and the EU environmental Directives should be considered when implementing measures
ST1.3.1 Impacts of common IWT infrastructures on the environment in the light of EU directives	Set a baseline for the evaluation of all actions and interventions proposed within the ReNEW project, following their expected environmental impacts from context-specific to regional conditions, using collected information about cargo and passenger ports, floating and steady platforms, navigation locks, groynes as they have been reported in various national and EU projects. From national and EU Environmental Agencies integrate guidelines for infrastructural changes on waterways, as these according EU environmental Directives apply on (i) Water Framework, (ii) Floods, (iii) Habitats, (iv) Birds, (v) Environmental Impact Assessment and (vi) Strategic Environmental Assessment.	Chapters 2 describes the ecosystem processes likely impacted by IWT activities, Chapter 3 describes the relation between IWT and the EU environmental Directives.

ST1.3.2 Provide supplementary tool to address environmental services affected by innovative actions of ReNEW and integrate it to the Decision support system developed in WP1	Implement a Decision Support Tool for environmental impacts analysis, using Bayesian networks, setup and configure Living Labs strategies, evaluate, assess and report aiming to minimise their environmental impact. Using Data collected in the Knowledge Graph, also linking where appropriate data from the ReNEW data space, apply machine learning techniques to combine different networks and find the best performing setups on selected waterway sections. Baseline Assets: (a) The applied technique has been developed for similar purpose in FIThydro project (nr: 727830) aiming environmental goals on hydropower regulated water recourses.	

1.2 Background

In this deliverable, we define how to relate the EU environmental Directives, the IWT measures, with a special focus on the Living Labs measures, and the ecosystem services. The final aim is to assist in identifying which Directives and ecosystem services are involved when specific measures are planned or realized.

A popular concept for the evaluation of ecosystem services highlights how they depend on the ecosystem processes and functions. This concept is the cascade model, proposed by Haines-Young and Potschin (2010). The model, summarized in Figure 1, describes the relationship between processes, functions, ecosystem services, and their benefits to human well-being.

The model consists of four main components. The first component is ecosystem structure and processes, which represents the physical and biological elements of an ecosystem, such as soil, water, plants and animals. It also includes the ecological processes that occur within the ecosystem, such as nutrient cycling, pollination, and water purification. The second component is the ecosystem functions and refers to the processes and interactions that occur within an ecosystem. The wider research literature is not clear about how to distinguish between the ecosystem functions by which services are generated (a mechanism that generates the services) and the services themselves (Haines-Young and Potschin, 2010), but it might be also redundant with processes definition in some cases. The function can be defined as the capability of an ecosystem to provide services by the interaction between basic processes and the ecosystem elements. The third component is the ecosystem services. Ecosystem services are the benefits that people derive from ecosystems. They can be categorized into four types: provisioning services (e.g., food, water, timber), regulating services (e.g., climate regulation, water purification), supporting services (e.g., nutrient cycling, soil formation), and cultural services (e.g., recreational opportunities, cultural heritage). Regulating services involve the regulation of environmental conditions, such as climate regulation or water purification. Provisioning services involve the production of goods, such as food, water, and raw materials. Supporting services refer to the underlying processes that enable other ecosystem services to occur,

such as soil formation or nutrient cycling. Cultural services are non-material benefits, including aesthetic, spiritual, and recreational values The last component is the human well-being, and it represents the various dimensions of human well-being that are influenced by ecosystem services. These dimensions include material well-being (e.g., access to food and clean water), health, security, social relations, freedom of choice, and cultural identity.

We choose the cascade model because it describes the interconnectedness and interdependencies between these components. It emphasizes that changes in ecosystem structure and processes can affect the supply of ecosystem functions, which, in turn, can impact the provision of ecosystem services. The availability and quality of ecosystem services then influence different aspects of human well-being.

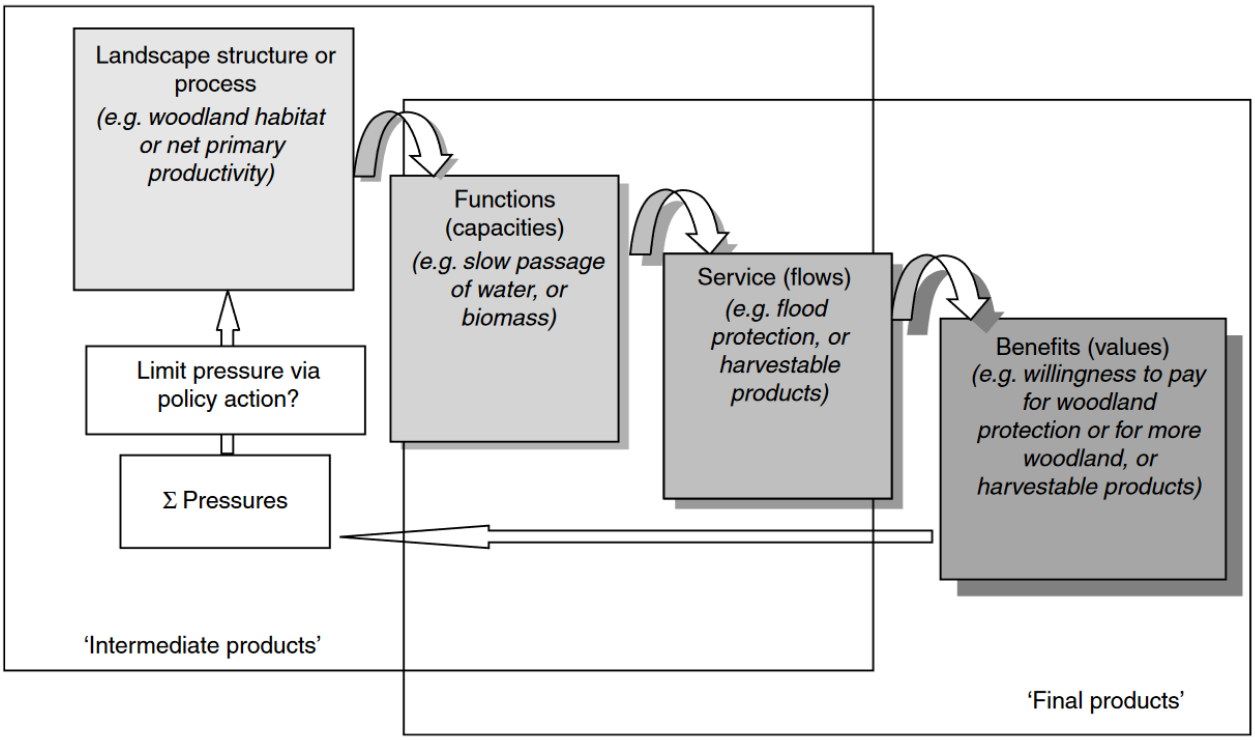


Figure 1: The cascade model showing how ecosystem services depend on processes and functions.

In this deliverable, we plan to use the cascade model not only to connect the ecosystem processes with the ecosystem services, but also to connect them with the EU environmental Directives. Moreover, the ReNEW measures can be considered as applying pressure on the processes and therefore connect with the Directives and the ecosystem services. We decided to work at the processes level and not the functions level as it is briefly explained in Chapter 2.

Processes and functions are described in Chapter 2 that can be related to the Directives (Chapter 3), and that support ecosystem services (Chapter 4).

2 Ecosystem processes

2.1 ReNEW relevant processes

Several definitions of processes and functions have been published by different authors (see de Groot et al., 2002; MEA 2005, Garcia de Jalon et al., 2013). One definition of processes as "the abiotic and biotic dynamics that shape the physical component of the ecosystem". For our purposes, we underline that we are interested in processes that can be directly managed to deliver services for IWT and the society, and therefore can be influenced by IWT measures (adapted from Wallace, 2007). Processes on which the effect of measures cannot be directly accounted for or managed (e.g., several biotic processes) are not described here. For the river ecosystem, previous projects categorized the hydromorphological processes (Garcia de Jalon et al., 2013, Carolli et al., 2019), the most important being: water flow dynamics, sediment dynamics, morphodynamics, vegetation dynamics, large wood dynamics, aquifer dynamics. The last three processes are of minor interest for the ReNEW project, thus they will be considered only partially. On the other hand, other processes not directly related to rivers and river management are important for the Living Labs and their activities. Water quality dynamics is partially connected with hydromorphological processes, but it requires a specific assessment. Air quality dynamics are connected with barge operations and goods transport, as well as the environmental noise.

The description of the following processes is readapted from Carolli et al. (2019).

Water flow dynamics is the combination of rainfall events, snow and ice melting, catchment morphology and geology, soil and vegetation cover which together determine the rate at which water is conveyed from the catchment to the stream system. It is characterized by several parameters such as average flow, fluctuations, and frequency of high and low flow events (Richter and Baumgartner, 1996). Basic descriptors of the flow regime are the seasonal variations of flow, and the frequency of unpredictable flow peaks within various seasons. Complex interactions between water discharge, orography and land use determine the spatial distribution of flow velocity and water depth, which controls the sediment transport capacity of river channels and ultimately the river morphology. The typical temporal pattern of water discharge fluctuations of a river represents one of the fundamental drivers of hydromorphological processes. The river discharge remains in the river channel up to bank full discharge, and inundation of the floodplain occurs when the bank full capacity is exceeded. The most effective discharge in terms of sediment transport is the bank full discharge (Knighton, 1998).

With **sediment dynamics,** we refer to the physical processes of sediment production, transport, and deposition in river catchments. In mountain areas, sediment production is supply controlled by the geomorphic activity of hillslopes (e.g., land sliding, gullying, debris flows), which is a function of the geology, relief, climate and land-use. Beside the source of the exogenous sediment (e.g., sediment sources outside the active channel, like hillslopes, floodplains, and terraces), another source of sediment is the endogenous sediment supply (coming from in-channel alluvial storage, like gravel

bars), which is more common in lowland areas. Once sediments are in the stream network, they move downstream with the flowing water during floods, as suspended load (for silts and clays), and as bedload (for sands, gravels, cobbles, and boulders). The suspended load is generally rapidly flushed from the catchment, except during flow discharges above the bank full capacity, which generate overbank deposition of fines in the floodplain. In some circumstances, fine sediments may accumulate in active channels and induce clogging (or colmation), a process which is known to reduce the porosity of gravels by the deposition of inorganic or organic fine sediments in the interstitial spaces of coarse sediment. Colmation can be reversed by mobilization of sediments during high discharge, which results in the resuspension of fine sediments, and thus in the decolmation of coarse sediments. The magnitude of bedload transport during flow events is a function of the transport capacity of the flow and the sediment supply. The downstream transfer of bedload along the river network is known to be an intermittent and slow process, with a resulting strong imprint on channel morphology.

Morphodynamics include all the processes that shape the river morphology. Lateral shifting of river channels is associated with bank erosion and/or bank accretion. The major processes of bank erosion are bank failures induced by instability and gravitation as well as fluvial erosion (induced by the shear stresses of the flow), which erodes coarser or finer sediment particles or aggregates from the riverbank surface or removes failed material which accumulated along the bank toe. Both bank failure and fluvial erosion, deliver bed and/or suspension to the sediment load into river. Bank erosion is often accompanied by aggradation, causing the bank accretion at the opposite bank or the emergence or enlargement of channel bars. Scour and fill processes result from deposition and erosion of sediment, causing changes in the elevation of the riverbed or floodplain. The tendency of sediment to deposit or erode is determined by changes in the hydraulic load (due to increased or decreased bed shear stresses and turbulence), which is exerted to the riverbed, as well as by the quantity and quality (grain size) of the supplied sediment. The development of bedforms (ripples, dunes, antidunes) occurs depending on the grain size and the hydraulic load. Bar formation is characteristic for braided rivers as well as for the alternating bar-type and transitional rivers between the state of braiding and meandering (wandering rivers).

Vegetation dynamics highlights as the vegetation interacts with water and sediments, and both affects and is affected by morphodynamic processes of rivers (Gurnell 2014).

Aquifer dynamics refers to the interaction between the river and its floodplain and the groundwater. Aquifer recharge or infiltration is the flow of water from the river or its floodplain into the aquifer. The water can flow from the riverbed, banks and riparian areas through the hyporheic zone to the groundwater or can infiltrate vertically during floods. Aquifer discharge or exfiltration is the flow from groundwater to a surface water or to the land surface. The water can flow directly into the riverbed or emerge in springs.

Water quality includes all the processes that contribute to meeting the standards for which the water is used (e.g., drinking water, irrigation). Processes might be for example hydrological processes,

interaction with the morphology, bank filtration, interaction with vegetation. Also, some processes and activities like wastewater spillage or nutrient pollution can contribute to decreasing water quality in relation to the desired standards. Nutrient cycling is crucial for maintaining water quality standards. Nutrients, including nitrogen and phosphorus, are naturally cycled through the system, supporting the growth of aquatic plants and phytoplankton, which form the base of the food chain. Proper nutrient cycling helps sustain a healthy ecosystem and maintain water quality.

Similarly to water quality, **air quality** refers to the condition of the air in terms of the presence of pollutants and its overall suitability for human health and the environment. It is determined by measuring the concentrations of various pollutants and assessing their potential impact on air quality standards and guidelines. The processes that affect air quality can be categorized into natural and human-induced factors. In particular, human-induced processes can be: industrial release of pollutants such as sulphur dioxide (SO2), nitrogen oxides (NOx), particulate matter (PM), and volatile organic compounds (VOCs); vehicle emissions: including nitrogen oxides, carbon monoxide, and particulate matter; agricultural activities like burning crop residues and using fertilizers; improper waste management including open burning and landfill emissions. These processes can lead to the accumulation of pollutants in the air, which can have adverse effects on human health, ecosystems, and climate.

Environmental noise refers to the presence of unwanted or excessive sounds in the environment that can disrupt or disturb normal human activities. It is typically generated by various sources and can have negative impacts on human health, well-being, and the ecosystem. Causes of environmental noise can be

- Transportation Noise generated by road traffic, trains, airplanes, and ships.
- Vehicles' engines, tires, and exhaust systems produce noise. Industrial activities such as factories, power plants, construction sites, and mining operations produce significant noise.
- Machinery, equipment, generators, and manufacturing processes can contribute to high noise levels.
- Construction activities involving excavation, demolition, drilling and building can generate substantial noise.
- Heavy machinery, pneumatic tools, and construction vehicles contribute to the overall noise levels.

The detrimental effects of environmental noise include hearing impairment, sleep disturbances, stress, annoyance, impaired cognitive performance, and increased risk of cardiovascular diseases. Efforts to mitigate environmental noise include implementing noise regulations, using noise barriers, promoting noise reduction technologies, and designing urban areas with noise reduction in mind.

The processes considered in ReNEW are summarized in the following table.

Table 2: Land structure and processes

Land structure and process
Water flow dynamics
Sediment dynamics
Morphodynamics
Aquifer dynamics
Vegetation dynamics
Water quality
Air quality
Environmental noise

2.2 The concept of Functions and Related issues

According to the cascade model, all the processes described above influence a set of functions whose variation affects positively or negatively the ecosystem services. Some examples of these functions are flow regime, physical habitat and connectivity. For the scope of this deliverable, we decided to link Directives and measures with the ecosystem processes and physic-chemical-biological properties. As previously mentioned, the definition of function is often ambiguous and not objective and might lead to confusion. The term 'function' can have different meanings in ecology, environmental sciences and in general (Jax, 2005). It is often used to refer to processes that operate within an ecosystem (like water purification, biological community interactions such as predation). It has also been suggested by some authors to drop it from ecosystem services conceptual modes, as the cascade modell (Wallace, 2007).

3 IWT and the EU environmental framework

3.1 EU Directives

Inland Waterway Transport is considered in general more sustainable and environmentally friendly than other modes of transport. However, like all the river uses, inland waterway development and management have to comply with the EU environmental laws, such as the Environmental Noise Directive and the Ambient Air Quality Directive, specific laws for river protection and management as the Water Framework Directive and the Floods Directive, and laws dedicated to the environmental protection as the Habitats and Birds Directives. The EU Restoration Law is currently under discussion at the EU parliament, and it is not yet in place.

Table 3: EU environmental Directives

Directive	Year of publication
Birds	1979 (Amended in 2009)
Habitats	1992
Water Framework	2000
Environmental Noise	2002
Floods	2007
Ambient Air Quality	2008
Strategic Environmental Assessment	2009
Environmental Impact Assessment	2011

Other Directives for example the Environmental Impact Assessment Directive must be considered only upon the decision of the Member States. The Directives are discussed below.

3.2 IWT and the Birds and Habitat Directives

The Birds and Habitat Directives, officially known as the Birds Directive (Directive 2009/147/EC) and the Habitats Directive (Directive 92/43/EEC), are two key pieces of European Union legislation aimed at conserving biodiversity and protecting important habitats and species within the EU. The Birds Directive was adopted in 1979 and focuses on the conservation of wild bird species. It establishes a network of Special Protection Areas (SPAs) for birds across the EU member states. The Directive aims to protect all wild bird species naturally occurring in the European territory of the member states, including migratory species, their nests, and habitats. It prohibits the deliberate killing, capture, or disturbance of birds listed in its annexes, as well as the destruction of their nests and eggs. The Directive also promotes the conservation and management of bird habitats and ensures the maintenance or restoration of favourable conservation status for bird populations. The Habitats

Directive, adopted in 1992, aims to protect and conserve natural habitats and species of European importance. It establishes the Natura 2000 network, which consists of Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). The Directive requires EU member states to identify and designate these areas to safeguard the habitats of certain plant and animal species listed in its annexes, including endangered or vulnerable species. The Habitats Directive also requires the development and implementation of conservation measures and management plans to maintain or restore the favourable conservation status of these habitats and species. Both Directives work in tandem to protect and conserve biodiversity across the European Union. They promote the sustainable management of habitats and species, ensure the protection of important areas for birds and other wildlife, and contribute to the overall preservation of Europe's natural heritage. These Directives are crucial for maintaining ecological balance, protecting endangered species, and fostering the conservation of Europe's natural environment.

The two Directives require „Site designation and management measures “, aimed at conserving core areas for species in the Directives Annexes, and „Species protection provision “, aimed at protecting wild birds and other endangered species included in the Annexes. The two Directives required the Member States to designate Natura 2000 sites, which should be managed to maintain or restore species and habitat types in a good conservation condition. The management of these sites is tackled in the Article 6 of the Habitats Directive. For the purposes of ReNEW and Living Lab activities, the most relevant Articles are Articles 6(3) and 6(4) which describe the procedure to follow when planning new projects that might impact Natura 2000 sites. When performing new projects, the EU legislation and authorities suggest applying an integrated approach to project planning, to minimize conflicts at a later stage of the project. For more details, see Chapter 4 in the document „ Guidance document on sustainable inland waterway development and management in the context of the EU Birds and Habitats Directives” (EU Commission, 2018).

EU nature legislation allows development activities in and around Natura 2000 sites. However, it requires that any project that might have a significant negative effect on Natura 2000 sites performs an appropriate assessment (AA). It is important to avoid confusion over the environmental impact assessments required by the EIA and SEA Directives and the AA required by the Article 6(3) of the Habitats Directive. In relation to new projects and developments, the Directives also prohibit in case of strict species protection: the deliberate disturbance during breeding, rearing, hibernation and migration; the deterioration or destruction of breeding and rearing sites; the deliberate destruction of nests or eggs, or the uprooting or destruction of protected plants.

3.3 IWT and the Environmental Assessment Directives

The Strategic Environmental Assessment (SEA) Directive is an EU Directive that requires the assessment of the environmental effects of certain plans and programs before their adoption. It aims to integrate environmental considerations into decision-making processes and promote sustainable development by ensuring that potential environmental impacts are taken into account at an early stage. The Strategic Environmental Assessment Directive includes:

- Scope: The Directive applies to plans and programs that are prepared for sectors such as agriculture, energy, transport, waste management, and water management. These plans and programs can include regional development plans, urban development plans, and sectoral policies.

- Environmental Assessment: The Directive requires the assessment of the likely significant effects on the environment of the proposed plans and programs. This assessment considers various environmental factors, such as air quality, water resources, biodiversity, climate change, and cultural heritage.

- Decision-Making Process: The SEA Directive aims to ensure that environmental considerations are fully integrated into the decision-making process. The environmental assessment information is provided to decision-makers, enabling them to make informed choices and consider environmental concerns.

- Public Participation: The Directive emphasizes the importance of public participation in the SEA process. It requires that the public be given early and effective opportunities to express their opinions and contribute to the decision-making process.

- Monitoring and Review: The SEA Directive also promotes the monitoring and review of the environmental effects of implemented plans and programs. This helps to ensure that their environmental impacts are assessed over time and necessary adjustments can be made.

IWT projects often require an environmental impact assessment (EIA) to evaluate their potential effects on the environment. The EIA assesses various environmental aspects, including air and water quality, noise, biodiversity, and socio-economic factors. IWT projects typically require permits and authorizations from relevant authorities. These permits may consider the findings of the EIA and ensure compliance with environmental regulations and standards. When significant adverse environmental impacts are identified through the EIA process, mitigation measures are implemented to minimize or offset these impacts. These measures can include pollution control measures, habitat restoration, noise reduction measures and biodiversity conservation. IWT projects often involve engagement with various stakeholders, including local communities, environmental organizations, and relevant authorities. Consultations and public hearings may be conducted to gather input and address concerns related to the project's environmental impacts.

When IWT projects are part of larger plans or programs subject to strategic environmental assessment, the SEA Directive's requirements would apply to the relevant plans or programs that encompass IWT projects, ensuring that their potential environmental effects are assessed and addressed in a comprehensive and sustainable manner.

The Environmental Impact Assessment (EIA) Directive is an EU Directive that establishes a framework for assessing and managing the potential environmental impacts of certain public and private projects. Its objective is to ensure that projects likely to have significant effects on the environment are subject to a comprehensive assessment before they are approved or authorized.

Key points regarding the Environmental Impact Assessment Directive include:

- Scope of Application: The Directive applies to a wide range of public and private projects, including infrastructure developments, industrial facilities, energy projects, and transportation projects.

- Assessment Process: The EIA process involves the preparation of an Environmental Impact Assessment report, which assesses the likely significant environmental effects of the project. The report covers various aspects such as air quality, noise, water resources, biodiversity, landscape, and cultural heritage.

- Public Participation: The Directive emphasizes the importance of public participation in the EIA process. It requires the public to be informed and provided with opportunities to express their opinions and concerns about the project's potential environmental impacts.

- Decision-Making: The EIA process provides the competent authority with the necessary information to make an informed decision on the project's approval or authorization. The decision takes into account the environmental impacts identified in the assessment report and any mitigation measures proposed.

In the context of IWT projects, the EIA Directive plays a significant role in ensuring that potential environmental impacts are adequately assessed and addressed. It provides a systematic framework for evaluating the potential effects on the environment, facilitating informed decision-making, and promoting sustainable development.

There are many similarities between the procedures for SEA and EIA, and the appropriate assessments described under the Birds and Habitat Directives chapter, but there are some important differences. Therefore, an SEA and EIA cannot replace, or be a substitute for, an AA as neither procedure overrides the other. These assessments are very often performed together, but each assessment has a different purpose and assesses different impacts on the environment. The difference between these assessments is crucial: the authorities should take into consideration the SEA and EIA assessments, while the AA is legally binding. In case the AA identifies negative impacts in the site, the authorities may ask to redesign the project, introduce mitigation measures, or explore alternative solutions. Details are described in the “Guidance on Inland waterway transport and Natura 2000”, chapter 6.4 and specifically 6.4.3.

3.4 IWT, Water Framework Directive and Groundwater Directive

The Water Framework Directive (WFD) is an important piece of European Union legislation aimed at protecting and improving the quality of Europe's water resources. Here is a summarized overview of the key points of the Directive:

1. The WFD's primary objective is to achieve and maintain a good status for all water bodies (including rivers, lakes, coastal waters and groundwater) within the European Union. It emphasizes the need for integrated water resource management and sets out specific environmental objectives to ensure the sustainable use and protection of water resources. In the case of heavily modified water bodies (HMWB), the objective is to reach the good ecological potential.

2. River Basin Approach: The WFD adopts a river basin management approach, considering water management at the scale of river basins rather than individual water bodies. It promotes coordination and cooperation among Member States sharing the same river basin, as well as the involvement of stakeholders, to develop and implement river basin management plans.

3. Environmental Objectives: The Directive sets out environmental objectives to be achieved by Member States for their water bodies. These objectives include achieving good ecological status or potential and good chemical status, preserving protected areas and preventing further deterioration of water bodies.

4. Programs of Measures: Member States are required to develop and implement programs of measures to achieve the environmental objectives set by the WFD. These measures can include pollution control, water conservation, restoration of habitats, implementation of water pricing mechanisms, and public participation.

5. Monitoring and Reporting: The WFD establishes a monitoring and reporting framework to assess the status of water bodies. Member States are required to monitor water quality, ecological status, and other relevant parameters, and report this information to the European Commission.

Overall, the Water Framework Directive provides a comprehensive framework for the protection and sustainable use of Europe's water resources. It aims to achieve good ecological and chemical status for water bodies through integrated management, stakeholder involvement and the implementation of measures to address pollution and promote sustainable water use.

Some impacts of the IWT on the WFD goals are described below. For example, IWT can potentially lead to water pollution through accidental spills or leaks of hazardous substances. These pollutants can negatively impact the water quality and ecological status of the water bodies, thereby going against the objectives of the WFD. Construction and maintenance activities associated with IWT can lead to habitat disturbance and fragmentation, affecting aquatic ecosystems and biodiversity. This can hinder the achievement of good ecological status as outlined in the WFD. IWT can facilitate the

introduction and spread of invasive species, both through ballast water and vessel hulls. Invasive species can disrupt native ecosystems and biodiversity, thereby impacting the ecological status of water bodies.

3.5 IWT and the Floods Directive

The Floods Directive is a European Union Directive that focuses on assessing and managing flood risks to reduce the potential impacts of floods on human health, the environment, infrastructure, and socioeconomic activities. The primary objective of the Floods Directive is to establish a framework for the assessment and management of flood risks to reduce the adverse consequences of floods. It aims to enhance coordination and cooperation among Member States to achieve a higher level of protection for humans, the environment, cultural heritage, and economic activities. Member States are required to conduct preliminary flood risk assessments and detailed flood hazard and risk maps. These assessments and maps help identify areas at risk, including potential consequences and vulnerabilities, taking into account climate change projections. Member States develop and implement flood risk management plans based on the flood risk assessments. These plans outline the objectives, measures, and actions to reduce flood risks. They also address preparedness, response, and recovery measures, as well as public information and awareness. Like the Water Framework Directive, the Floods Directive adopts a river basin management approach. It promotes coordination and cooperation among Member States sharing the same river basins to address transboundary flood risks and develop joint flood risk management plans where necessary. The Floods Directive recognizes the need to consider climate change in flood risk management. It requires Member States to consider potential climate change impacts on flood risks and integrate adaptation measures into their flood risk management plans. Overall, the Floods Directive provides a framework for assessing and managing flood risks in Europe. It aims to enhance preparedness, reduce the impacts of floods and promote cooperation among Member States to improve overall flood risk management and resilience.

The interaction between IWT and the Floods Directive lies in their shared objective of managing and reducing flood risks. While the Floods Directive primarily focuses on assessing and managing flood risks, IWT can both be influenced by and have an impact on flood management efforts. Here are some key interactions between the two. The Flood risk assessment can help identify areas where IWT may be at risk and inform measures to mitigate those risks. It may involve measures such as improving flood forecasting and warning systems for IWT operators and developing emergency response plans to ensure the safety of vessels and cargo during flood events. IWT infrastructure, including locks, dams and riverbanks, can contribute to flood risk management efforts. Proper design, maintenance, and upgrading of these infrastructure components can enhance their resilience against flooding, allowing them to continue functioning effectively even during high water levels. This can help maintain continuity in IWT operations and reduce disruptions caused by floods. IWT operators may need to adapt their operations and infrastructure to address potential changes in flood patterns due to climate change. This could involve adjusting navigation routes, improving vessel designs to

withstand higher water levels and incorporating climate change projections into long-term planning for the sector.

3.6 IWT and other water-related Directives

IWT and most of the other water-related Directives interact for water quality concerns and issues. Below we provide a brief description of the Directives and their possible relation with IWT.

The **Urban Wastewater Treatment Directive (UWWTD)** is a European Union (EU) Directive that aims to protect the environment and public health by regulating the collection, treatment and discharge of urban wastewater. It sets standards and requirements for wastewater treatment and promotes the sustainable management of water resources. The Directive applies to wastewater generated from urban areas, which includes residential, industrial, and commercial sources. The UWWTD establishes minimum treatment standards for urban wastewater before it is discharged into the environment. The level of treatment required depends on the size of the urban area and the sensitivity of the receiving water bodies. The Directive sets different treatment levels, ranging from primary treatment (removal of solids and organic matter) to more advanced secondary or tertiary treatment (additional removal of nutrients and pollutants). While the UWWTD and IWT are distinct regulatory frameworks, there may be some intersections between them. For example, the treatment of wastewater from inland waterway vessels is subject to the UWWTD requirements. Additionally, the management of water quality in inland waterways, influenced by both urban wastewater discharges and IWT activities, is crucial for maintaining ecological balance and supporting sustainable transport operations.

The **Industrial Emissions Directive (IED)** is an EU Directive that aims to minimize the environmental impact of industrial activities by setting common standards for the prevention and control of industrial emissions. It applies to a wide range of industrial sectors, including energy production, manufacturing, waste management, and chemical production. The IED adopts an integrated approach to environmental permitting, combining various environmental aspects such as air pollution, water pollution, waste management, and energy efficiency into a single permitting system. The Directive requires industrial installations to use Best Available Techniques (BAT) to prevent or reduce emissions and their impact on the environment. BAT is defined as the most effective and advanced techniques for achieving a high level of environmental protection. The IED establishes a permitting system for industrial installations, ensuring they meet specific emission limit values and comply with environmental standards. It also mandates monitoring and reporting of emissions and requires regular assessments of compliance. IED and IWT may interact in some cases. For instance, industrial activities located near waterways may be subject to both the IED emission standards and specific requirements related to the protection of inland water quality. Additionally, industrial emissions from manufacturing processes or energy production can have indirect implications for air and water quality, which can affect the environmental conditions of inland waterways.

The **Drinking Water Directive (DWD)** is an EU Directive that establishes quality standards and requirements for the production and supply of drinking water. It aims to ensure the provision of clean

and safe drinking water to protect public health. The Directive sets specific quality standards for drinking water, including parameters related to microbiological, chemical, and radiological aspects. It defines maximum allowable concentrations of certain substances and establishes guidelines for monitoring and control. The DWD requires member states to conduct risk assessments to identify and evaluate potential risks to drinking water sources and supply systems. Based on these assessments, appropriate risk management measures must be implemented to safeguard water quality. The DWD promotes the implementation of Water Safety Plans (WSPs) for water supply systems. WSPs are comprehensive risk management frameworks that encompass the entire drinking water supply chain, from source protection to consumer tap. They involve identifying hazards, assessing risks, and implementing control measures to ensure the safety of drinking water. Activities related to IWT, such as vessel maintenance or fuel handling, may have implications for water quality in the vicinity of waterways and potentially affect the quality of water sources used for drinking water supply.

The **Marine Strategy Framework Directive (MSFD)** is an EU Directive aimed at achieving and maintaining good environmental status of marine waters. It establishes a framework for the protection and sustainable use of marine ecosystems and resources. The Directive sets environmental objectives for marine waters, focusing on specific descriptors such as biodiversity, fish populations, marine litter, underwater noise, and eutrophication. Member states are required to develop strategies to achieve and maintain these objectives. The MSFD promotes an integrated and ecosystem-based approach to marine management. It emphasizes the need for coordination and cooperation among various stakeholders and sectors to address cumulative impacts and achieve sustainable use of marine resources. IWT can have implications for water quality in marine environments if they involve the discharge of pollutants or the release of harmful substances. In such cases, the MSFD's objectives related to water quality and ecosystem health may be relevant in assessing the impacts of IWT on marine waters.

Water Reuse Regulation pertains to the guidelines and standards governing the use of reclaimed water or recycled water for various purposes, such as irrigation, industrial processes, and urban non-potable uses. The specific regulations related to water reuse vary across different regions and jurisdictions, but they generally focus on ensuring the safety and quality of recycled water. Water reuse regulations typically set specific quality standards for recycled water, including parameters related to microbiological, chemical and physical aspects. These standards aim to protect public health and the environment and may vary depending on the intended use of the recycled water. The regulations often outline treatment requirements for reclaimed water to ensure the removal of contaminants and pathogens. They may also specify monitoring and reporting obligations to verify compliance with the quality standards and assess the effectiveness of treatment processes. Water reuse projects usually require permits or approvals from regulatory authorities. These processes involve assessing the proposed reuse scheme, reviewing the treatment processes, and evaluating the potential risks associated with the recycled water use.

A possible interaction with IWT is if IWT operations require significant water resources, recycled water from water reuse projects could potentially be used to meet the water needs of vessels, such as for cooling purposes. In such cases, the regulations and guidelines related to water quality, treatment processes, and the safe use of reclaimed water may be relevant for ensuring compliance.

3.7 IWT and other Environmental Directives

The **Ambient Air Quality Directive** is an EU Directive that establishes standards and objectives for the assessment and management of ambient air quality. It aims to protect human health and the environment by setting limits for certain pollutants in the air and establishing measures to improve air quality. The Directive sets limit values and target values for various pollutants, including particulate matter (PM), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), lead (Pb), benzene (C_6H_6), carbon monoxide (CO), and ozone (O_3). These standards are designed to ensure air quality meets specific health and environmental objectives. Member States are required to establish air quality monitoring networks to assess pollutant concentrations in the ambient air. They must regularly report the monitoring results to the European Commission, enabling the evaluation of compliance with the air quality standards. When air quality limits are exceeded, Member States are obligated to develop and implement air quality plans to improve air quality. These plans include measures such as emission controls, traffic management, land-use planning, and public awareness campaigns. The Directive establishes zones for assessing and managing air quality. These zones include agglomerations (urban areas), industrial areas, and rural areas. Different requirements and measures may apply to each zone type. IWT activities can contribute to air pollution through emissions from vessels, particularly in terms of nitrogen oxide (NOx) and particulate matter (PM) emissions. Consequently, the air quality objectives set by the Ambient Air Quality Directive may be relevant in assessing and managing the air pollution impacts associated with IWT.

The **Environmental Noise Directive (END)** is an EU Directive that aims to assess and manage environmental noise to protect human health and well-being. It establishes a framework for the assessment and management of noise in the environment, including sources such as transportation, industrial activities and recreational activities. The Directive requires member states to develop strategic noise maps for major urban areas, major roads, railways and major airports. These noise maps provide an overview of noise levels and help identify areas where noise exposure exceeds established thresholds. Member States are required to develop action plans based on the results of noise mapping. These plans include measures to prevent and reduce environmental noise, such as noise barriers, traffic management strategies, land-use planning, and insulation measures for buildings. The END establishes noise limits and quality objectives for different noise sources, including transportation. These limits aim to ensure acceptable noise levels for the population and protect sensitive areas such as residential areas, hospitals, and schools. The Directive emphasizes the importance of public information and participation in noise management. Member States are required to provide the public with access to noise maps, action plans, and relevant information. IWT activities can contribute to noise pollution, particularly through vessel engines and navigation-related

activities. Therefore, the requirements and objectives set by the Environmental Noise Directive, such as noise limits and action plans, may be relevant in managing and mitigating noise impacts associated with IWT.

3.8 The EU Restoration Law

The EU Restoration Law requires a separated mention, because the law is not adopted yet by the EU, and it is currently under discussion. As this deliverable is prepared (June 2023), the EU Restoration Law is as follows:

The proposal combines an overarching restoration objective for the long-term recovery of nature in the EU's land and sea areas with binding restoration targets for specific habitats and species. These measures should cover at least 20% of the EU's land and sea areas by 2030, and ultimately all ecosystems in need of restoration by 2050.

The proposal contains the following specific targets:

- targets based on existing legislation (for wetlands, forests, grasslands, rivers and lakes, heath & scrub, rocky habitats, and dunes) - improving and re-establishing biodiverse habitats on a large scale and bringing back species populations by improving and enlarging their habitats.
- pollinating insects – reversing the decline of pollinator populations by 2030, and achieving an increasing trend for pollinator populations, with a methodology for regular monitoring of pollinators.
- forest ecosystems – achieving an increasing trend for standing and lying deadwood, uneven aged forests, forest connectivity, abundance of common forest birds and stock of organic carbon.
- urban ecosystems – no net loss of green urban space by 2030, and an increase in the total area covered by green urban space by 2040 and 2050.
- agricultural ecosystems – increasing grassland butterflies and farmland birds, the stock of organic carbon in cropland mineral soils, and the share of agricultural land with high-diversity landscape features; restoring drained peatlands under agricultural use.
- marine ecosystems – restoring marine habitats such as seagrass beds or sediment bottoms that deliver significant benefits, including climate change mitigation, and restoring the habitats of iconic marine species such as dolphins and porpoises, sharks, and seabirds.
- river connectivity – identifying and removing barriers that prevent the connectivity of surface waters, so that at least 25 000 km of rivers are restored to a free-flowing state by 2030.

On 20th June 2023, the EU council reached an agreement about the Restoration Law. From the press release (https://www.consilium.europa.eu/en/press/press-releases/2023/06/20/council-reaches-agreement-on-the-nature-restoration-law/): "The Council agreed that member states would put in place restoration measures that bring at least 30% of habitats in terrestrial, coastal, freshwater and marine ecosystems that are not in good condition, into good condition by 2030. This would apply to

at least 30% of the total area of the habitat types that are deemed not in good condition, as opposed to the area for each habitat group, as initially proposed by the Commission. Member states would however set restoration measures on at least 60% by 2040 and on at least 90 % by 2050 of the area of each habitat group that is not in good condition." For more details, see the link above.

On June 12th 2023 the EU Parliament passed the Nature Restoration Law. We expect that guidelines and deliverables from the EU Commission will be published in the next months and we will keep the ReNEW consortium updated.

3.9 Directives and processes

In this section, based on the experience of the authors of the deliverable, we linked the directives with the processes described in chapter 2.

Table 4: Relation between Directives and ecosystem processes

	Water flow dynamics	Sediment dynamics	Morphodynamics	Vegetation dynamics	Water quality	Air Quality	Environmental noise
Birds	+	+	+	+	+	+	+
Habitat	+	+	+	+	+	+	+
Strategic Environmental Assessment	+	+	+	+	+	+	+
Environmental Impact Assessment	+	+	+	+	+	+	+
Water Framework	+	+	+	+	+		
Floods	+	+	+	+	+		
Urban Wastewater Treatment					+		
Industrial Emissions					+		
Drinking Water					+		
Marine Strategy Framework					+		
Water Reuse Regulation					+		
Ambient Air Quality						+	+
Environmental Noise						+	+

4 IWT infrastructures and key elements

Inland waterway infrastructure refers to the physical structures and facilities that support the transportation of goods and passengers on inland waterways, such as rivers, canals, and lakes. This infrastructure includes various components and facilities that enable safe and efficient navigation and the transfer of cargo and passengers. Here are some key elements of inland waterway:

1. Navigational Channels: Navigational channels are the primary routes along which vessels travel on inland waterways. These channels are designed and maintained to provide sufficient depth and width for vessels to navigate. They are typically marked with navigational aids, such as buoys and beacons, to guide vessels and ensure safe navigation.
2. Locks and Dams: Locks and dams are structures constructed on inland waterways to manage water levels and facilitate navigation. Locks are chambers that raise or lower vessels between different water levels, allowing them to pass through changes in elevation, such as changes in river gradient or water flow direction. Dams, on the other hand, regulate water flow, provide flood control, and maintain consistent water depths in navigation channels.
3. Terminals and Ports: Inland waterway terminals and ports serve as transfer points for loading, unloading, and transhipment of cargo, as well as passenger embarkation and disembarkation. These facilities include berths or quays where vessels can dock, storage yards, warehouses, and handling equipment for efficient cargo handling and storage. Intermodal terminals are developed to facilitate the transfer of cargo between inland waterway vessels and other modes of transport.
4. River Information Services (RIS): River Information Services involve the use of advanced information and communication technologies to enhance navigation, safety, and efficiency on inland waterways. RIS includes the provision of real-time traffic information, electronic navigation charts, vessel tracking systems, and communication networks to assist vessel operators in making informed decisions and ensuring safe navigation.
5. Maintenance and Dredging: Regular maintenance and dredging are crucial for keeping inland waterway infrastructure in good condition. Maintenance activities include routine inspections, repair of locks, dams, and other structures, and maintenance of navigational aids. Dredging involves removing sediment and debris from navigation channels to maintain sufficient water depth for vessel traffic.
6. Vessel types.. Vessel types for example are barges, flat-bottomed vessels primarily used for bulk cargo transportation on rivers and canals; ferries, vessels designed for transporting passengers, vehicles, or both across rivers or lakes; riverboats, generally smaller vessels used for recreational purposes, such as sightseeing or leisure cruises; tankers, specifically designed vessels for transporting liquid cargo, such as petroleum, chemicals, or liquefied natural gas (LNG),

Inland waterway infrastructure development also considers environmental considerations. Measures are implemented to minimize the impact on ecosystems, mitigate erosion, and protect biodiversity. Sustainable design principles, erosion control measures, and environmental impact assessments are often incorporated into infrastructure projects.

4.1 Processes and IWT

The measures planned in the Living Labs can be included in the groups described in the previous paragraphs. In the next chapter, we present some examples of how these groups might relate to the processes.

Navigational channels can affect **water flow dynamics** in several ways. Navigational channels are often constructed by modifying rivers or natural waterways to create a suitable path for vessels. When a channel is narrower or wider than the original watercourse, it may lead to changes in hydraulic variables such as water velocity, water depth, and shear stress. Navigational channels can alter the natural distribution of water flow. By diverting water into a narrower channel, the overall flow in the original watercourse may decrease. This redirection of flow can have implications for downstream areas, potentially causing changes in water levels, sediment deposition, and erosion patterns. A well-designed channel with smooth walls and gradual bends can minimize flow resistance and promote efficient water flow. Conversely, abrupt bends or irregular channel shapes can cause flow disturbances, eddies, and turbulence, resulting in energy losses and changes in flow dynamics. When a navigational channel connects two water bodies at different elevations, it can create backwater effects. This occurs when the flow in the channel is obstructed, causing water levels to rise upstream. Backwater effects can affect water flow dynamics in upstream areas, impacting flood levels, navigation conditions, and aquatic habitats.

Navigational channels can have a significant impact on **sediment dynamics**. The construction and maintenance of navigational channels can influence bank erosion processes. Altering the channel alignment, introducing structures like revetments or groins, or modifying the flow patterns can affect the erosive forces acting on the riverbanks. These changes can lead to increased or decreased rates of bank erosion, which, in turn, can contribute to changes in sediment dynamics within the waterway. Navigational channels can cause localized erosion and deposition due to increased change in hydraulic variables.

By impacting water flow and sediment dynamics, navigational channels can alter the **morphodynamics**. Navigational channels often involve the narrowing or widening of waterways to accommodate vessels, directly changing morphology and associated processes. As previously mentioned, alterations in flow velocities, water depths, and other variables can affect the balance between erosion and sediment deposition. These changes can impact the natural habitats, **vegetation** dynamics, and ecosystems in and around the water body.

The construction of navigational channels often requires clearing vegetation and altering the natural landscape. This can result in the direct loss of vegetation, and the loss of habitat for wildlife, birds, and aquatic organisms. Navigational channels can fragment natural habitats by creating barriers to plant dispersal and wildlife movement. Conversely, channels can serve as pathways for the introduction and spread of invasive plant species.

Locks and dams have a significant impact on **water flow dynamics** in rivers and other water bodies. They are structures built across rivers to mainly regulate water flow. By controlling the release of water, they can stabilize river flows and maintain constant water levels for navigation purposes. Locks and dams create changes in water levels and water velocity, particularly in the areas upstream and downstream of the structures. In natural rivers, locks and dams can alter the natural flow regime of rivers, affecting aquatic ecosystems. Changes in water levels, flow velocity, and sediment transport patterns can disrupt habitats, impact fish migration, and alter the distribution of aquatic plants and animals. Fish ladders or other fish passage structures are often installed to facilitate fish migration.

Locks and dams can have relevant impacts on **sediment dynamics**. In the reservoir, sediment particles settle and accumulate on the bed. Over time, this sedimentation can reduce the storage capacity of the reservoir. Sediment accumulation behind the dam also alter the natural flow of sediments downstream. The reduced sediment load downstream of the dam can have consequences for the downstream river reach, altering sediment deposition patterns and potentially causing erosion or sediment starvation.

These structures also can alter the natural channel **morphological processes**. Reduced sediment transport can lead to erosion or incision downstream of the dam, resulting in changes to the channel shape, bed elevation, and overall geomorphology of the river. High-flow releases during flood events can result in erosion and sediment scouring downstream, while low-flow releases can reduce sediment transport. Some structures are designed to release sediment periodically to manage reservoir sedimentation. These flushing releases aim to mimic natural sediment transport processes by mobilizing accumulated sediment and transporting it downstream. Flushing can help maintain downstream channel stability and restore morphological processes in the river system.

Locks and dams can fragment river systems, can disrupt the connectivity of riparian habitats, and affect the distribution and composition of **vegetation**. Plant species that rely on seed dispersal or the movement of water for their life cycle may be adversely affected. The presence of locks and dams can facilitate the spread of invasive plant species because they can provide stable habitats and corridors that allow invasive species to colonize new areas. Invasive plants can outcompete native vegetation, disrupt ecosystems, and reduce biodiversity.

Changes in water flow and reservoir conditions associated with locks and dams can also influence **water quality parameters** such as temperature, turbidity, dissolved oxygen, and nutrient concentrations. These alterations can affect the suitability of water for plant growth and impact the composition and health of vegetation communities.

Terminals and ports can have an impact on the **water flow dynamics,** through the construction and operations phase which will include dredging to adapt the water depth at their approach channels and facilitate the use of large vessels. These modifications will impact water velocity, and hydrodynamics resulting in an impact on the **sediment** deposition and erosion. At the same time, the action of dredging during the construction or maintenance will alter the sediment deposition and erosion dynamics, which might result in an increase of siltation and an impact on the benthic habitats and hinder the movement of aquatic organisms.

The navigational channels, terminals and ports will also impact the **morphology** of the waterway, by constraining the floodplains and the banks of the river and estuary. These constraints will also impact the meandering dynamics and inundation areas of the floodplains, impacting also aquatic and land ecosystems and vegetation dynamics. Vegetation can be impacted also by direct clearance for the construction and change in the land use.

The operation of terminals and ports can impact the **water quality** from pollution discharges from the vessels, terminal facilities, and port-related activities, with pollutants such as oil, chemicals, and heavy metals. The operation of ports and terminals can also generate emissions that will lead to air pollution and have an impact on **air quality** through activities such as the loading and unloading of vessels, storage, and movements. These operations can also produce **environmental noise**, which at high levels and constant over a period can produce disruptions to the organisms and the ecosystem.

River Information Services (RIS) do not have a direct impact on the environment, since they are systems designed to improve the safety and efficiency of inland waterways navigation. On the other hand, if environmental considerations are taken into account such as environmental noise or disturbance from increased traffic, the impact could be beneficial from a more efficient planning and traffic management, reducing waiting times and effectively choosing a route that could reduce environmental impacts that could accumulate from other factors such as increased water temperature and/or low water levels.

Maintenance and dredging, similar to the effects of the dredging from terminals and ports, will have an impact on the **water flow dynamics** by changing water levels, velocities, and circulation patterns that will also result in impacts on the **sediment transport** and the **morphology**. Habitats for aquatic organisms will be impacted and degraded, altering the substrate needed for different species at different life stages that can provide shelter or refugia. Changes in depths and morphology can impact the waterways bank and vegetation dynamics as riparian vegetation and also aquatic vegetation from the banks and the waterways channel. Benthic and aquatic organisms that utilize the substrate as habitats will be directly impacted by the removal of the sediments. The removal of sediments can release pollutants that were trapped within the sediment column impacting the water quality with the resuspension of heavy metals and organic matters.

Vessel types, the various types of vessels utilized in IWT will have different environmental impacts, according to Zigic (2008), an optimal ship is defined as:

- Modern and environmentally friendly
- With low exhaust emissions
- With low fuel consumption
- Economical in operation
- Highly compatible with the waterway
- Having the capability to align to the river
- Having minimal impacts on bank vegetation and fish fauna

Vessels can be also classified depending on their speed, high speed vessels can produce what is called wave wash, wave wake or simply wash which is different than the natural waves, having long periods and significant energy. The amplitude is not so high compared to natural waves produced by storms, but they have a relatively long wave period. When these waves get into shallow water, their height will increase rapidly, often causing erosion on the shores and banks.

Cox and Macfarlane (2019) differentiate between transverse waves, which are the longest waves a vessel can generate and the divergent waves, or bow waves, which are either the same length or shorter than the transverse waves and are formed in packets. Several divergent systems are generated by vessels and can be superimposed in the far field. These divergent waves are the principal concern, but transverse waves can be problematic in narrow waterways.

The type of vessel and the speed can influence the magnitude of the wash waves. The period of transverse waves is a function only of vessel speed while the period of divergent waves is related to the vessel length.

The large waves generated by high-speed vessels are more pronounced in shallow waters. Impacts from wash waves will change the channel **morphology** due to the erosion, which will lead to destabilization of banks, the **sediment** eroded will also increase the sediment resuspension, increasing turbidity and changing the **water quality** that can impact aquatic organism. In addition, it will also have an impact on the **vegetation dynamics** since it might reduce the sunlight penetration and have an impact on the submerge aquatic vegetation and the species that use them as their habitat. Aquatic organisms and other species as birds might also be impacted by the displacement and disturbance of their habitats for breeding or nesting.

Vessels depending on the propulsion system could be classified as diesel-powered, hybrid, or electric. Those that will be powered by diesel (fuel) will have an impact on **air quality** from the emissions of particulate matter (PM), NOx, SOx, and CO_2. Some vessels can be powered by liquefied natural gas (LNG) as an alternative to traditional diesel or gasoline fuels, producing lower emissions of NOx and SOx than conventional fuel powered vessels.

It is important to consider that:

- CO_2 depends directly on the amount of fuel consumption
- NOx does not depend on consumption, but on the design and state of the engine

- PM is mainly carbon particles (soot), and depends on maintenance and fuel type
- SOx depends on the type of diesel fuel (sulphur content of the fuel)

Hybrid vessels will combine diesel powered engine with electric or other alternative sources, making a more efficient and optimized use of the fuel and reducing emissions by the usage of the electric motor. Vessels can be also fully electric, they have been increasing in the recent years, especially for passenger ferries and small vessels. They produce zero emissions; therefore, they will have no impact on the air quality.

In terms of noise pollution, the vessel's propulsion type can influence the noise pollution that is generated both in the air and underwater, affecting also underwater species. While the conventional diesel (fuel) engine vessels will generate more noise during the combustion process and during movement of mechanical component of the engines, the hybrid and electrical vessels will produce less noise, especially engines powered by batteries. In addition, the technology used in terms of propeller type and machinery can have different underwater noise impacts. Smith and Rigby (2022), reviewed a wide range of technologies, covering cavitation, propeller and flow noise, and machinery noise, are reviewed with differing levels of maturity finding that already exists several technologies that could be readily applied to many vessels and others that are more on an earlier stage that could provide substantial benefits to reduce underwater noise.

Table 5: Relation between processes and measures

	Water flow dynamics	Sediment dynamics	Morphodynamics	Vegetation dynamics	Water quality	Air Quality	Environmental noise
Navigational channels	+	+	+	+			
Locks and dams	+	+	+		+		
Terminal and ports	+	+	+	+	+	+	+
River information services	+				+	+	+
Maintenance and dredging	+	+	+	+	+	+	+
Vessel types	+	+			+	+	+

4.2 Linking IWT measures and Directives

The processes are useful to link Directives and the IWT measures, as shown in

. This represents a suggestion of the Directives that should be considered when performing an intervention or planning for a measure. However, as explained in Chapter 3, what is required by the EU legal framework is to perform an appropriate assessment according to Birds and Habitat Directives, and specific assessments in case is required by the Member State according to the SEA and the EIA Directives.

Table 6: Links between directives and measures. The symbol "(+)" indicates that the Directive is not directly involved in some cases.

	Navigational channels	Locks and dams	Terminal and ports	River information services	Maintenance and dredging	Vessel types
Birds	+	+	+	+	+	+
Habitat	+	+	+	+	+	+
Strategic Environmental Assessment	+	+	+	+	+	+
Environmental Impact Assessment	+	+	+	+	+	+
Water Framework	+	+	+	+	+	+
Floods	+	+	+	+	+	+
Urban Wastewater Treatment		+	+	+	+	+
Industrial Emissions		+	+	+	+	+
Drinking Water		+	+	+	+	+
Marine Strategy Framework		+	+	(+)	(+)	+
Water Reuse Regulation		+	+	+	+	+
Ambient Air Quality			+	+	(+)	+
Environmental Noise			+	+	+	+

4.3 Preliminary selection of KPIs relevant for the ReNEW Living Labs

According to D1.1, there are some KPIs that are defined in the GA and must be taken into account for all LL.

- Improved navigability capacity: This refers to the ability to move around a particular area more easily and efficiently. For example, a Living Lab might focus on improving the navigability of a city's streets by implementing smarter traffic management systems, better public transportation options, or more effective pedestrian and bike lanes.
- Enhanced land/sea/infrastructure resilience: This refers to the ability of an area's physical infrastructure to withstand and recover from natural or man-made disasters, such as floods, earthquakes, or cyberattacks. A Living Lab might focus on improving infrastructure resilience by implementing more robust building materials, better emergency response systems, or more secure information technology systems.
- Increase in modal shift: This refers to a change in the way goods are transported or people travel, such as moving from driving alone to carpooling or taking public transportation. Against the background of ReNEW a Living Lab might focus on increasing modal shift by implementing more efficient transportation options or promoting forms of transportation with alternative propulsion systems.
- Smooth functioning of passenger mobility: This refers to the ability of people to move around a particular area without experiencing significant delays or disruptions. A Living Lab might focus on improving passenger mobility by implementing smarter traffic management systems, better public transportation options, or more effective pedestrian and bike lanes.
- Reduce environmental impact [CO2e]: This refers to the amount of greenhouse gas emissions produced by a particular area or activity, which contribute to climate change. A Living Lab might focus on reducing environmental impact by promoting sustainable transportation options, implementing energy-efficient buildings and infrastructure, or promoting behaviour changes like reducing waste and conserving resources.
- Minimize the impacts of erosion linked to operation and maintenance:
- Minimize noise (air and underwater) from the operation and maintenance of infrastructures and vessels.

Living Lab #1 - Ghent's Multifunctional Synchromodality City Logistics Hub

According to the GA and the described use cases for LL1 some potential KPIs for evaluating the impact of climate disasters on the infrastructure resilience, and readiness in setting up emergency plans might be of relevance. These KPIs should help to assess the ability of the city's infrastructure to withstand and recover from natural disasters, and the effectiveness of emergency plans in protecting the population and minimizing damage to critical infrastructure. Additionally, these KPIs should enable the city to identify areas for improvement and make informed decisions about

allocating resources to enhance resilience and preparedness. For each type of risk (natural, technological, health, and safety risks), specific KPIs may need to be developed to evaluate the impact of disasters on infrastructure resilience and emergency response.

Living Lab #2 – Smart Douro Inland Waterway management – DIW2024

For LL 2 the focus of relevant KPIs might be on the overall performance of the Douro River transportation system in terms of safety, security, environmental protection, and navigation efficiency. They should also enable the identification of areas for improvement and the implementation of targeted measures to enhance the sustainability and effectiveness of the system.

Living Lab #3 - Planning mitigation demonstrator app for climate resilient and environmentally sustainable transport infrastructure, and in addition to boost modal shift

For LL3, which focuses on planning a mitigation demonstrator app for climate resilient and environmentally sustainable transport infrastructure, and to boost modal shift, the potential key performance indicators that could be relevant should help to evaluate the success of LL3 in promoting climate resilience and environmental sustainability in transport infrastructure and boosting modal shift towards sustainable transport options. They would also enable the identification of areas for improvement and the implementation of targeted measures to enhance the effectiveness and impact of the mitigation demonstrator app.

Living Lab #4 –Resilience promoting Autonomous zero-emissions barges

For LL4, KPIs which would help to evaluate the success of LL4 in promoting resilience through autonomous, zero-emission barges are important. They would enable the identification of areas for improvement and the implementation of targeted measures to enhance the effectiveness and impact of the autonomous barges in reducing emissions, promoting resilience, and ensuring economic viability.

5 Ecosystem services

Ecosystem services are the benefits that people obtain from ecosystems (MA, 2005), and the direct and indirect contributions of ecosystems to human well-being (TEEB, 2010). The ecosystem services concept has been developed to highlight the key role that biodiversity and ecosystem functions and processes play to support multiple anthropic activities.

Several classifications and conceptual frameworks have been proposed to analyse ecosystem services, such as the Millennium Ecosystem Assessment (MA, 2005a), the Economics of Ecosystems and Biodiversity (TEEB, 2010), and the Common International Classification of Ecosystem Services (CICES, Haines-Young and Potschin, 2013). The Working Group on Mapping and Assessment of Ecosystems and their Services (MAES) has developed a framework to ensure that consistent approaches are used by the EU and its Member States (Maes et al. 2013). The MAES conceptual framework is based on the CICES and has been tested in several pilot studies. To be consistent with the assessments carried out in the EU and other EU projects (MAES, MARS, HyMoCARES) we propose to follow MARS classification for water ecosystems, based on the CICES classification.

The list of proposed ecosystem services is in Table 7. In the ReNEW scheme, we added Navigation as a service supported by environmental abiotic conditions.

Table 7: Ecosystem services relevant for water systems (adapted from MARS 2018)

	Ecosystem services from MARS (for comparison)	Examples
Provisioning	Fisheries and aquaculture	Fish catch
	Water for drinking	Provision of water for domestic uses
	Raw biotic materials	Algae as fertilisers, vegetal compounds for cosmetics
	Water for non-drinking purposes	Provision of water for industrial or agricultural uses
	Raw materials for energy	Wood from riparian zones
Regulation & maintenance	Water purification	Excess nitrogen removal by microorganisms
	Air quality regulation	Deposition of oxides of nitrogen on vegetal leaves
	Erosion prevention	Vegetation controlling soil erosion on riverbanks
Regulation & maintenance	Flood protection	Vegetation or floodplains trapping and slowing down the water flow, coastal habitats protecting from inundation
	Maintaining population and habitats	Key habitats use as reproductive grounds, nursery, shelter for a variety of species
	Pest and disease control	Diseases and parasites are better controlled in the wild (by natural predation on weakened individuals)

	Soil formation and composition	Rich soil formation in floodplains or in wetlands borders
	Carbon sequestration	Carbon accumulation in vegetation or sediments
	Local climate regulation	Maintenance of humidity and precipitation patterns by wetlands or lakes, shading effect
Cultural	Recreation	Swimming, recreational fishing, sightseeing, boating
	Intellectual and aesthetic appreciation	Subject matter for research, artistic representations of nature
	Spiritual and symbolic appreciation	Existence of emblematic species or sacred places
Extra abiotic and environmental services	Raw abiotic materials	Extraction of sand & gravel from riverbed or river banks
	Abiotic energy sources	Hydropower generation

Extra abiotic and environmental services added in ReNEW	Navigation	Navigation	Passengers, trading goods

The ReNEW activities do not influence all the services. Based on previous literature in Section 3 we highlight which services are most important for IWT. In the following paragraphs, we link the services with the processes and consequently with the Living Labs based activities, and we propose some indicators to quantify ecosystem services on the basis of previous projects.

5.1 Processes, ecosystem services and LL activities

As described in the cascade model (Chapters 1 and 2), ecosystem services depend on processes and functions. In this paragraph, we firstly link the ecosystem services with the processes, and secondly, we linked the processes with the LL activities. The aim is to identify which activities are likely to influence the ecosystem services. The connections are presented as tables.

5.1.1 Water flow dynamics and ES

Table 8: Water flow dynamics and ES

Ecosystem service	Description
Fisheries and aquaculture	The water flow dynamics influence the biotic communities (Poff et al, 1997) with effects on this service.
Water for drinking	The water flow dynamics and the flow regime regulate the water quantity and the timing of the water available.
Raw biotic materials	The water flow dynamics influences the river primary productivity.

Ecosystem service	Description
Water for non-drinking purposes	The water flow dynamics and the flow regime regulate the water quantity and the timing of the water available
Raw materials for energy	-
Water purification	Empirical studies demonstrated the interaction between pollutants and floods. Physical process-based models are also applied to describe these interactions. For more details, see Patil et al., 2022. The flow patterns may affect the residence time of water and pollutants. Longer residence times can enhance natural purification processes, allowing more time for physical, chemical, and biological transformations of contaminants (Mulholland & DeAngelis, 2000).
Air quality regulation	-
Erosion prevention	The water flow dynamics and erosion are strictly connected.
Flood protection	The regulation of water flow is pivotal for flood prevention and protection. Moreover, the management of flow dynamics as reducing flood timing, reducing flow velocity contribute to flood protection (see van Zelst et al., 2021);
Maintaining population and habitats	The water flow dynamics is one of the key drivers for maintaining habitat and related populations (Poff et al., 1997).
Pest and disease control	It has been demonstrated as manipulation and regulation of the water flow contributes to the control of the diffusion of pest species (Bunn & Arthington, 2002) and how the flow regime influences the establishment of invasive species (Mathers et al., 2020).
Soil formation and composition	-
Carbon sequestration	This service is only partially related with water flow dynamics.
Local climate regulation	The water flow dynamics directly influence the temperature and the cooling capacity of the river.
Recreation	The water flow dynamics directly influence specific water related activities such as boating and rafting (see Carolli et al., 2017).
Intellectual and aesthetic appreciation	The stream flow and its dynamics have an important role on the aesthetical appreciation of the river landscape. One of the most relevant components is the frequency of occurrence of exceptionally low flows (temporary rivers or gravel bed rivers with limited extension of channels with flowing water may be less attractive for the general public). For further details, see Pflüger et al., 2010.
Spiritual and symbolic appreciation	Rivers and the associated water flow dynamics yield high cultural and symbolic value for many populations worldwide. For a review, see Anderson et al, 2019.
Abiotic energy sources	Rivers are exploited to produce hydropower production.
Navigation	Water flow dynamics and flow regime support navigation, and rivers are often regulated to improve navigability for different purposes.

5.1.2 Sediment Dynamics and ES

Table 9: Sediment Dynamics and ES

Ecosystem service	Description
Fisheries and aquaculture	Fish populations are directly influenced by fine suspended sediments via affecting food availability and foraging efficiency, physiology and behaviour (Kemp et al., 2011). If the river channel is eroding rapidly, it can scour out the bottom of ponds or cages, making it difficult to maintain a stable environment for the farmed organisms. On the other hand, if a river channel is depositing sediment too quickly, it can smother ponds or cages, making it difficult for the farmed organisms to survive. Other effects of sediments are more related to the habitat and are described below.
Water for drinking	Usually, sediments are detrimental to drinking water. Water needs to be cleaned and filtered in case is contaminated by sediments.
Raw biotic materials	Sediment dynamics might influence primary productivity (Parkhill et al., 2002).
Water for non-drinking purposes	Sedimentation can prevent water abstraction and therefore impact this service.
Raw materials for energy	Riparian vegetation actively interacts with sediment dynamics, especially during floods, by retaining part of the sediments (Vigiak et al., 2016)
Water purification	Sediment dynamics do not contribute to water purification. However, it can impact water quality by transporting pollutants through the network (Vigiak et al., 2016).
Air quality regulation	Organic matter decomposing in the sediment can release greenhouse gases like carbon dioxide and methane, which can indirectly impact air quality and contribute to climate change. Sediments carrying various pollutants, including heavy metals and organic contaminants, can become resuspended in the water column, and eventually be transported by water turbulence or wind action.
Erosion prevention	Sediment dynamics have a direct impact on this service, with land use being the main driver that alter sediment dynamics and erosion patterns (Noe et al., 2020).
Flood protection	Together with geomorphological alterations, with which sediment dynamics are entangled, sediments can impact flood frequency and, more in general, should be considered in flood risk management (Nones, 2019). Sediment transport patterns, and sediment deposition can lead to aggradation, raising the riverbed elevation. Excessive aggradation may reduce the channel's conveyance capacity and increase flood risk (Graf, 2006).

Ecosystem service	Description
Maintaining population and habitats	The sediment dynamics and sediment regime are key drivers of the habitat creation and conservation.
Pest and disease control	The link is not clear, however, in some cases flush flooding of sediments might help to partially restore the sediment regime and prevent the establishment of invasive species (e.g., Rovira & Ibanez, 2007)
Soil formation and composition	-
Carbon sequestration	-
Local climate regulation	-
Recreation	Recreational activities might be affected by pollutants and contaminants related to sediment dynamics. Therefore, sediment quality should be considered also for recreational activities (Chavez-Diaz et al., 2020)
Intellectual and aesthetic appreciation	Increase turbidity results in lower aesthetic appreciation and value (Pflüger et al., 2010).
Spiritual and symbolic appreciation	There is not a direct connection, the link is mainly via morphology.
Abiotic energy sources	Sediments need to be managed to maintain the hydropower production. Sediments can for example reduce available water volume in reservoirs, affect the turbines, impact penstocks and pipelines.
Navigation	Sediment dynamics (erosion and deposition) can affect navigation by changing bed elevation and reshape cross section. Accumulation of sediments in the riverbed can create shallow areas that hinder navigation. Dredging is often employed to maintain navigable depths in certain areas. High sediment levels can lead to increased siltation in river channels, resulting in shallower water depths and narrower navigation passages. This requires more frequent dredging operations to maintain sufficient depth for vessels.

5.1.3 Morphodynamics and ES

Table 10: Morphodynamics and ES

Ecosystem service	Description
Fisheries and aquaculture	The effect is mainly through erosion-deposition. Channel instability might affect aquaculture structures.
Water for drinking	Morphodynamic processes contribute to the availability of drinking water by e.g., bank filtration. Shifts in the location and extent of riverbank filtration zones may require adjustments in

Ecosystem service	Description
	water intake locations and infrastructure for drinking water treatment facilities
Raw biotic materials	Morphodynamic processes can function as natural disturbances that reset ecological succession. Disturbances can open new areas for colonization and might lead to shifts in plant community composition, affecting primary productivity patterns.
Water for non-drinking purposes	Morphodynamic processes can impact the connectivity between river channels, floodplains, and other water bodies. Changes in connectivity can alter water availability and flow dynamics in the river system (Poff & Zimmermann, 2010)
Raw materials for energy	Morphodynamic processes may cause the river channel to migrate laterally. As the channel shifts trees may be lost due to bank erosion, and new vegetation may establish in areas where aggradation occurs.
Water purification	Morphological changes in river channels can create diverse habitat types, which support various ecological processes and contribute to water purification (Palmer et al., 2010). Morphodynamic changes can influence the flow patterns in rivers, affecting the residence time of water and pollutants. Longer residence times can enhance natural purification processes, allowing more time for physical, chemical, and biological transformations of contaminants (Mulholland & DeAngelis, 2000). The morphological complexity of river channels can influence nutrient cycling dynamics. Certain morphological features, like wetlands or floodplains, may function as nutrient sinks or sources, affecting the overall nutrient balance in the river and its water quality.
Air quality regulation	-
Erosion prevention	Morphodynamic studies aid in identifying areas where bank erosion is likely to occur. By understanding morphodynamic processes, appropriate bank stabilization measures can be implemented to prevent erosion and protect riverbanks (Garcia, 2008). Understanding morphodynamics can help identify locations where natural bars may form. These bars can function as sediment sinks, reducing the sediment supply downstream and minimizing erosion in those areas.
Flood protection	Morphological changes, such as channel widening or narrowing, can alter the river's capacity to convey water during flood events. Meander migration and bank erosion can impact floodplain connectivity and alter the channel's alignment. This can affect flood routing and the extent of inundation during high flows. Morphodynamics influence the connectivity and storage capacity of floodplains, which can significantly impact flood attenuation. Properly functioning floodplains can absorb and store excess

Ecosystem service	Description
	water during floods, reducing downstream flood peaks (Serra-Llobet et al., et al., 2022).
Maintaining population and habitats	Morphodynamics can influence the physical structure of river channels, creating different habitats for aquatic plants. The presence of diverse habitats can support a variety of plant species, contributing to overall primary productivity in the river ecosystem (Petts and Amoros, 1996).
Pest and disease control	While it may not directly focus on pest and disease control, morphological changes could impact river ecosystems and the species interactions within them. For example, potential effects may include changes in habitat availability, especially in riparian areas.
Soil formation and composition	
Carbon sequestration	The floodplain is an essential component of river ecosystems and can act as a vital site for carbon sequestration. Morphodynamic processes, such as flooding and sediment deposition on floodplains, contribute to the accumulation of organic carbon in these areas (Salerno et al., 2023).
Local climate regulation	Changes in river channel width and depth can alter the heat exchange between water and the atmosphere. A narrower and deeper channel might have less surface area exposed to sunlight, resulting in cooler water temperatures. On the other hand, a wider and shallower channel can lead to warmer water temperatures due to increased solar radiation absorption.
Recreation	For rivers popular for white-water sports like kayaking or rafting, morphological changes can influence the intensity and difficulty of specific stretches of the river, potentially affecting the overall experience for participants (e.g., Carolli et al., 2017). Changes in the river's channel and flow can affect access points for recreational activities.
Intellectual and aesthetic appreciation	The overall shape and size of a river can impact its aesthetic appeal. The presence of natural features such as waterfalls, rapids, riffles, and islands can enhance the aesthetic appeal of a river. These features add complexity and diversity to the landscape, making it more visually captivating. (Daniel et al., 2012).
Spiritual and symbolic appreciation	Although it is acknowledged that rivers and other natural features can hold significant spiritual and cultural value for various communities, we could not find any specific scientific studies on the effects of morphology on spiritual value in rivers.
Abiotic energy sources	River channel morphology plays a crucial role in determining the hydropower potential of a river. The presence of natural obstacles, such as waterfalls or rapids, can create favourable conditions for hydropower development, while the overall flow

Ecosystem service	Description
	characteristics and sediment transport might impact the efficiency and performance of hydropower installations.
Navigation	Channel geometry can influence navigation. Wider and deeper channels generally provide more space for vessels to navigate. River bends can create navigation challenges, particularly in larger vessels. The centripetal force experienced while navigating bends can make steering difficult and may require additional manoeuvring techniques to maintain control and avoid an accident.

5.1.4 Vegetation Dynamics and ES

Table 11: Vegetation Dynamics and ES

Ecosystem service	Description
Fisheries and aquaculture	Aquatic plants play a role in biological filtration, removing suspended particles and organic matter from the water. Plants help break down and assimilate the organic material, possibly reducing the risk of water pollution and maintaining a healthier environment for fish. Photosynthesizing aquatic plants release oxygen into the water during daylight hours. In densely vegetated aquaculture ponds or rivers, this can increase dissolved oxygen levels, which are crucial for fish respiration and growth. Adequate oxygen levels prevent hypoxia and related fish stress or mortality.
Water for drinking	Vegetation plays a crucial role in enhancing water quality by acting as a natural filter. It helps in reducing sedimentation, nutrient loads, and pollutants entering the water. The roots of plants can also absorb and store excess nutrients, such as nitrogen and phosphorus, preventing their release into the water. As a result, the water quality is improved, making it safer for drinking purposes (Dosskey et al., 2010)
Raw biotic materials	Vegetation provides shade, which can help regulate water temperature in rivers. Higher water temperatures can lead to reduced oxygen levels and promote the growth of harmful algae. By providing shade, vegetation helps maintain water temperatures, which is beneficial for the survival of aquatic life and the overall ecological health of the river (Caissie, 2006).
Water for non-drinking purposes	Vegetation can influence water flow and help regulate the quantity of water in rivers. During periods of heavy rainfall, vegetated areas can absorb and store water, reducing the risk of flooding. Conversely, during dry periods, vegetated areas can release stored water slowly, maintaining a more constant flow in the river.

Ecosystem service	Description
Raw materials for energy	Riparian plants provide wood as biomass for energy production.
Water purification	Aquatic vegetation can act as a natural water purifier. It helps to filter out excess nutrients like nitrogen and phosphorus from the water. This process can improve water quality, making it more suitable for fish and other aquatic organisms. (Barko & Smart, 1986).
Air quality regulation	Aquatic vegetation, such as submerged aquatic plants and algae, contributes significantly to oxygen production through photosynthesis. This process helps maintain dissolved oxygen levels in the water, which is essential for aquatic life and helps prevent the formation of anaerobic conditions that can lead to the release of harmful gases like methane and hydrogen sulphide into the atmosphere (Downing et al., 1999). Riparian vegetation can act as a natural filter, capturing and removing various air pollutants from the atmosphere. The leaves of trees and plants can trap particulate matter, nitrogen oxides, sulphur dioxide, and other harmful substances, thereby reducing their dispersion into the air (Nowak & Greenfield, 2013). Vegetation can absorb and control emissions of volatile organic compounds, such as benzene, toluene, and formaldehyde, which are common air pollutants with adverse health effects (Karl et al., 2010).
Erosion prevention	Vegetation stabilizes riverbanks, enhances cohesion, and reduces the erosive impact of flowing water (Gregory et al., 1991). Healthy vegetation, such as trees, grasses, and shrubs, helps to intercept and slow down rainfall, reducing the amount of surface runoff that enters the river. This slows the flow of water and allows it to infiltrate into the soil, reducing erosion and the amount of sediment carried into the river during heavy rainfall events.
Flood protection	Plants in and around rivers influence the shape and morphology of the river channel, creating natural barriers and meandering patterns that dissipate energy during floods, reducing the potential for channel erosion and downstream flooding. In areas where vegetation has been intentionally preserved or restored as buffer zones along rivers, it acts as a natural flood barrier, reducing the risk of floodwaters inundating nearby communities and infrastructure. Vegetation on floodplains can increase the storage capacity for floodwater during high water events (Ferreira et al., 2021). Trees and wetland vegetation can help to trap and hold water, slowing its progress downstream and reducing peak flow rates during floods (Mitsch & Gosselink, 2015).

Ecosystem service	Description
	Healthy vegetation, such as trees, grasses, and shrubs, helps to intercept and slow down rainfall, reducing the amount of surface runoff that enters the river. This slows the flow of water and allows it to infiltrate into the soil. While some vegetation can help reduce sediment transport and control erosion, excessive vegetation in the river channel can increase flood risk by obstructing the natural flow paths during high water events (Hupp & Osterkamp, 1996).
Maintaining population and habitats	Vegetation provides an essential habitat and shelter for fish, especially during their early life stages. The presence of vegetation can offer protection from predators and serve as breeding grounds for fish species (Looby et al., 2021). Riparian wood provides critical habitat for a wide range of aquatic and terrestrial species, including fish, amphibians, birds, and mammals. The diverse vegetation structure and food sources offered by riparian wood contribute to enhanced biodiversity along rivers (Naiman et al., 2005)
Pest and disease control	Some aquatic plants have natural pest-repellent properties, helping to reduce the prevalence of certain aquatic pests and diseases. For example, integrating appropriate plant species into aquaculture systems can act as a biocontrol measure, minimizing the need for chemical interventions (Kim et al., 2022).
Soil formation and composition	
Carbon sequestration	Riparian vegetation, including trees and wetland plants, can sequester carbon dioxide from the atmosphere through photosynthesis and store it as organic matter. This process helps mitigate the impacts of greenhouse gas emissions and climate change (Mitsch & Gosselink, 2007).
Local climate regulation	The presence and health of riparian vegetation along riverbanks can significantly impact the local climate. Vegetation provides shade, which can lower water temperatures, and it also influences the moisture content in the air through transpiration. Riparian vegetation provides shade and reduces the "urban heat island" effect, where urban areas experience higher temperatures than surrounding rural areas. By moderating local temperatures, vegetation helps prevent the formation of ground-level ozone, a harmful air pollutant (Livesley et al., 2016).
Recreation	Vegetation along riverbanks can enhance the visual appeal of recreational areas, providing a natural and serene environment for activities such as fishing, picnicking, and birdwatching (Chalker-Scott, 2010).

Ecosystem service	Description
	Riparian vegetation helps regulate water temperature, which is essential for recreational activities such as swimming and boating. Naiman & Decamps, 1997). Vegetation along riverbanks provides shade, creating comfortable spaces for relaxation and recreation. Riparian vegetation can enhance fishing opportunities as it provides a habitat for aquatic insects, small fish, and other organisms that attract game fish. While vegetation can provide benefits, the presence of invasive plant species in rivers can negatively impact recreational activities. Invasive plants can impede boating, fishing, and swimming, and may require management efforts to maintain recreational access (Keller & Lodge, 2007).
Intellectual and aesthetic appreciation	The presence of vegetation along the riverbanks (riparian zone) can positively influence the aesthetics of the river environment. Dense and diverse vegetation can provide a sense of naturalness and contribute to the overall beauty of the river landscape.
Spiritual and symbolic appreciation	In various cultures, rivers and the vegetation surrounding them can hold significant spiritual value. They may be associated with specific deities or considered sacred sites where rituals and ceremonies are performed. The presence of certain plants along the riverbank might also hold symbolic meanings related to spiritual beliefs.
Abiotic energy sources	Vegetation along riverbanks and in the riparian zone can act as natural filters, reducing the amount of sediment flowing into the river. This helps in maintaining reservoir capacity and prolonging the life of hydropower infrastructure (Wohl, 2017). Dense vegetation can obstruct the flow of water, leading to reduced flow velocity. Excessive vegetation growth in and around hydropower infrastructure can increase maintenance costs, as regular removal and management of vegetation become necessary to ensure optimal performance.
Navigation	Dense vegetation can slow down the flow of water and reduce water depth in certain areas of the river, making navigation more challenging. Overgrowth of vegetation can create blockages and obstacles in the river channel, impeding the movement of boats and posing safety hazards. Vegetation can alter the flow patterns within the river, leading to the formation of eddies and crosscurrents, which may make navigation more unpredictable and challenging (Nepf, 2012).

5.1.5 Water quality and ES

Table 12: Water quality and ES

Ecosystem service	Description
Fisheries and aquaculture	Poor water quality, such as low dissolved oxygen levels, high ammonia, nitrite, and nitrate concentrations, can lead to stress and increased susceptibility to diseases in fish (Boyd & Tucker, 1998). Adequate water quality is essential for optimal growth and efficient feed conversion in fish. Water quality can significantly influence the reproductive success of aquaculture species. Fish exhibit altered behaviour in response to poor water quality, such as reduced swimming activity and increased surface gulping. These behaviours are often associated with stress (Iwama et al., 1997).
Water for drinking	Water quality in rivers directly affects the safety and suitability of drinking water sources. Various contaminants can pose health risks to humans when present in drinking water. Poor water quality in rivers can result from the discharge of untreated sewage, agricultural runoff, or other sources of microbial contaminants. Pathogenic microorganisms like bacteria, viruses, and protozoa can contaminate the water, leading to waterborne diseases. Common pathogens include Escherichia coli (E. coli), Cryptosporidium, and Giardia (Hrudey & Hrudey, 2004). Industrial discharges, agricultural runoff, and urban pollution can introduce various chemical contaminants into rivers. These contaminants may include heavy metals (e.g., lead, mercury), pesticides, herbicides, and organic pollutants. Long-term exposure to such substances through drinking water can have adverse health effects (WHO, 2017). Poor water quality in rivers can increase water treatment costs for various purposes, such as drinking water supply. A study by Vörösmarty et al. (2010) highlighted how water quality degradation increased treatment costs for municipalities along the Danube River.
Raw biotic materials	Water quality plays a significant role in the growth and proliferation of algae in rivers. Different factors related to water quality can influence algal populations, and their interactions can be complex (e.g., Dodds et al., 2009; Smith & Schindler, 2009; Reynolds, 2006).
Water for non-drinking purposes	Pollution can decrease by decreasing water availability. However, we could not find any reference
Raw materials for energy	Water quality impacts the health and growth of riparian vegetation, which, in turn, influences the overall stability and function of the riparian ecosystem.

Ecosystem service	Description
Water purification	The effects of water quality on water purification in rivers are significant as the natural purification processes can be affected by various factors, partially included in the former processes.
Air quality regulation	Water quality plays a critical role in the complex interactions between water and air environments. Pollution and degradation of water bodies can have far-reaching consequences on air quality and contribute to various environmental and public health issues. For example, water quality directly impacts the dissolved oxygen levels in rivers. When water is polluted with organic matter or nutrients, it can lead to excessive algal growth, a process known as eutrophication. During the night, these algae consume oxygen for respiration, leading to lower dissolved oxygen levels during those hours. Consequently, when the water mixes with the air, it releases less oxygen into the atmosphere, potentially affecting the overall air quality (Smith & Schindler, 2009)
Erosion prevention	-
Flood protection	-
Maintaining population and habitats	Water quality directly affects the diversity and abundance of aquatic organisms. Higher water quality, characterized by lower levels of pollutants and contaminants, supports a more diverse range of species (Vannote et al., 1980). Särkkä et al. (1978) found that water contaminants negatively impacted bird populations in Finland.
Pest and disease control	Poor water quality, particularly high levels of organic pollutants and nutrients, can lead to the proliferation of certain pests, such as aquatic insects and snails that serve as intermediate hosts for disease-causing parasites (Allan & Castillo, 2007). Poor water quality can disrupt the natural biological control mechanisms that help keep pest populations in check. For example, pesticides and pollutants can harm beneficial organisms, such as predatory insects and fish, which would otherwise help control pest populations (Relyea and Diecks, 2008).
Soil formation and composition	
Carbon sequestration	Water quality influences methane emissions from rivers. Organic matter in the water, such as decaying vegetation and waste, undergoes anaerobic decomposition, producing methane gas. The methane can then escape into the atmosphere from the water's surface. High levels of organic pollutants can lead to increased methane emissions from rivers, contributing to greenhouse gas concentrations in the atmosphere (Bastviken et al., 2004)
Local climate regulation	Clean water can help regulate the temperature of rivers. Higher water quality with less pollution allows for better heat exchange

Ecosystem service	Description
	with the atmosphere, preventing extreme temperature fluctuations in the river ecosystem (Palmer et al., 2010).
Recreation	Poor water quality can lead to high levels of microbial contamination, including bacteria and pathogens, which can cause recreational water illnesses (RWIs). These illnesses can result in gastrointestinal, respiratory, and skin-related issues for swimmers and individuals engaged in water contact activities (Yoder et al., 2008). Poor water quality, particularly high levels of pollutants and contaminants, can negatively impact fish populations and aquatic ecosystems. This can result in reduced fish stocks, impaired fish health, and ultimately affect the overall fishing experience for recreational anglers. Water quality issues such as excessive algal blooms and accumulation of floating debris can hinder boating and water sports activities. Algal blooms can produce harmful toxins that are dangerous to human health and can lead to the closure of water bodies for recreational use (Backer et al., 2015). Water quality affects the overall experience of canoeing and kayaking. Poor water quality with visible pollution or unpleasant odours can discourage individuals from participating in these activities.
Intellectual and aesthetic appreciation	High levels of pollution can diminish the aesthetic value of rivers and negatively impact the overall experience. People might be less likely to engage in recreational activities in rivers that appear dirty or polluted. Water quality can affect the emotional and aesthetic experience of being near or interacting with a river. Clear and unpolluted waters are more likely to evoke positive emotions, contributing to their spiritual value (Kaplan, 1995)
Spiritual and symbolic appreciation	Higher water quality is often associated with a greater perception of sacredness or spiritual significance in rivers. Clean and pristine waters may be seen as more sacred, inviting, and closer to a natural state, enhancing their spiritual value.
Abiotic energy sources	Water with high acidity or aggressive chemical properties can cause corrosion of turbine materials, leading to structural damage and reduced turbine performance.
Navigation	Water quality parameters like acidity (pH) and dissolved oxygen levels can affect the corrosiveness of water, potentially leading to accelerated corrosion of vessels' hulls and river infrastructure (e.g., piers, docks, bridges). Corrosion can increase maintenance costs and reduce the lifespan of navigation-related structures.

5.1.6 Air quality and ES

Table 13: Air quality and ES

Ecosystem service	Description
Fisheries and aquaculture	Air pollution can introduce various pollutants and particulate matter into the air, which can settle on the water surface and decrease the exchange of gases between the atmosphere and the water. This can lead to reduced dissolved oxygen levels in the water, which is critical for the survival of aquatic organisms, including fish. Air pollution from industrial emissions and vehicular exhausts can lead to the formation of acidic compounds in the atmosphere, which, when dissolved in rainwater, can result in acid rain. Acid rain can lower the pH of river water, making it more acidic, and negatively impacting fish and other aquatic species (Driscoll, C. T., & Schecher, 1990).
Water for drinking	Airborne pollutants, such as sulphur dioxide (SO_2) and nitrogen oxides (NOx), can form acid rain, which can acidify rivers and lakes, leading to lower pH levels in the water. Acidification of water bodies can affect the suitability of water for drinking purposes (Driscoll, C. T., & Schecher, 1990). Airborne particles, such as dust, soot, and other particulate matter, can settle on the surface of rivers and lakes, contributing to sedimentation, reducing water clarity, and degrading water quality.
Raw biotic materials	Primary production in rivers is primarily influenced by water quality parameters such as nutrient levels (nitrogen and phosphorus), temperature, light availability, and flow conditions. However, it is worth noting that air quality can indirectly impact populations in rivers through atmospheric deposition and other related factors.
Water for non-drinking purposes	-
Raw materials for energy	Airborne nitrogen deposition can have significant from various human impacts on riparian vegetation. Elevated nitrogen levels in the atmosphere can lead to nitrogen enrichment in rivers and adjacent riparian zones, stimulating the growth of certain plant species, leading to alterations in the riparian biomass composition (e.g., increased dominance of nitrophilous species) (Bobbink et al., 2010).
Water purification	Several factors related to air quality can influence the condition of water bodies, affecting the purification processes and overall ecological health. Some of these factors are acid rain (Driscoll et al., 2003).
Air quality regulation	The link is straightforward and regulated by law.
Erosion prevention	Air quality can affect the health and stability of vegetation along riverbanks. Healthy vegetation, such as trees and grasses, can help stabilize soil and prevent erosion by binding the soil with its

Ecosystem service	Description
	roots. Pollutants in the air, such as nitrogen oxides and sulphur dioxide, can damage vegetation and reduce its ability to anchor soil, leading to increased erosion. Airborne pollutants, such as sulphur dioxide and nitrogen oxides, can contribute to acid rain formation. Acid rain can have detrimental effects on soil quality, weakening its structure and reducing its ability to resist erosion.
Flood protection	Air pollutants like ozone and nitrogen oxides can negatively impact plant health. In riparian zones (areas along the riverbanks), healthy vegetation plays a crucial role in flood management, as it can stabilize soil, reduce erosion, and absorb excess water during floods.
Maintaining population and habitats	Acid rain can then fall onto the land and water bodies, including rivers, leading to water acidification. Acidification negatively impacts aquatic life, alters pH levels, and disrupts the ecological balance in river habitats. Some air pollutants can be transported to rivers through deposition or runoff, accumulate in the food chain, and ultimately affect the overall health and viability of river ecosystems (e.g., U.S. EPA, 2018).
Pest and disease control	Air quality can have indirect effects on pest and disease control in rivers, as it impacts the overall health and well-being of the ecosystem, especially by impacting vegetation.
Soil formation and composition	
Carbon sequestration	Air quality has a direct impact on carbon sequestration due to the different effects on the vegetation. However, this is not specific to the river ecosystems.
Local climate regulation	Air pollution, particularly from greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4), can contribute to global warming, which in turn affects local temperatures around rivers. Warmer air temperatures can influence water temperatures, leading to altered thermal regimes in rivers.
Recreation	Air quality has a direct impact on recreational activities. However, this is not specific to the river ecosystems. As previously explained, air pollution can decrease water quality, thus affecting recreational activities
Intellectual and aesthetic appreciation	We could not find any scientific work demonstrating the connection.
Spiritual and symbolic appreciation	We could not find any scientific work demonstrating the connection
Abiotic energy sources	-
Navigation	

5.1.7 Environmental noise and ES

Table 14: Environmental noise and ES

Ecosystem service	Description
Fisheries and aquaculture	Noise has a negative effect on life cycle of fish (Wysocki et al., 2007)
Water for drinking	-
Raw biotic materials	-
Water for non-drinking purposes	-
Raw materials for energy	-
Water purification	-
Air quality regulation	-
Erosion prevention	-
Flood protection	-
Maintaining population and habitats	Noise pollution can indirectly affect the health of the river ecosystem. For instance, it might disturb aquatic species, alter their reproductive behaviour, and potentially contribute to habitat degradation (Francis & Barber, 2013).
Pest and disease control	-
Soil formation and composition	-
Carbon sequestration	-
Local climate regulation	-
Recreation	Noise pollution can decrease the overall enjoyment of recreational activities such as fishing, boating, and hiking along riverbanks.
Intellectual and aesthetic appreciation	Loud and persistent noise can disrupt the visual perception of a river's environment (Benfield et al., 2018)
Spiritual and symbolic appreciation	Exposure to environmental noise, especially persistent or high-intensity noise, can lead to increased stress and annoyance levels in individuals living or visiting those areas. Chronic stress and annoyance can negatively impact a person's ability to find tranquillity and engage in spiritual practices (WHO, 2018). Noise pollution can disrupt the natural soundscape of rivers, making it challenging for individuals to experience potential spiritual experiences associated with natural environments (Pijanowski et al., 2011).
Abiotic energy sources	-
Navigation	-

5.2 Ecosystem services indicators

In the literature, several indicators are available for the assessment of ecosystem services. Defining new indicators goes beyond the scope of this project, therefore we refer to the indicators from the

literature review described and suggested by Grizzetti et al. (2015) in the MARS project. The following table is adapted from the Annexes of Grizzetti et al. (2015), and we follow the authors' suggestion for which is considered the best indicator (highlighted in red).

Table 15: Ecosystem services indicators suggested in previous projects.

Ecosystem services	Natural capacity	Service flow	Social benefit
Fisheries and aquaculture	Status of fish population (species composition, age structure, biomass) Abundance of fish Relative fish abundance based on catch per unit effort (CPUE) Condition of fish stocks Number of wild species used for human food	Fish catch Aquaculture production Sea food productivity Wild vegetation used in gastronomy Fish production from sustainable sources (e.g., the proportion of fish stocks caught within safe biological limits, certified/viable fisheries…)	Number of anglers Employment in fishing, mariculture and related sectors Fish products as a percent of total animal protein in people's diet Value of fish and sea food landings, or value of aquaculture sales Marginal value of a change in fisheries management
Water for drinking	Surface water availability Total freshwater resources Nitrate-vulnerable zones River salinity Renewable water supply accessible to humans Water storage capacity	Water consumption for drinking Water abstracted Water exploitation index Consumptive water use by the end user	Proportion of the population using an improved drinking water source Proportion of cities obtaining water supplies from protected areas Water-stressed population
Raw (biotic) materials	Land cover (Wood) biomass production over stem diameter classes	Wild vegetation used in cosmetic or pharmaceutical uses Surface of exploited wet forests (e.g., poplars), coastal forests (e.g. mangroves) and reeds cutting Timber produced by riparian forest	Value of pharmaceutical products developed in natural systems or from marine organisms Investment in natural products prospecting Value of (wet or coastal) timber forest products Net value added of raw materials:

Ecosystem services	Natural capacity	Service flow	Social benefit
		Timber from sustainably managed forests Organisms from which drugs have been derived Number of species that have been the subject of major investment or have become a commercial product	seaweed, fishmeal, fish oil, ornamental
Water for non-drinking purposes	Surface water availability Ground water availability Total freshwater resources Salinity levels Renewable water supply accessible to humans Water storage capacity	Water use per sector Water abstracted Water exploitation index Area water-logged by irrigation Volume of water desalinated	Cost of water and water delivery Total water requirements Net value added: desalinated water supply
Raw materials for energy	(Wood) biomass production over stem diameter classes	Production of peat Surface of exploited wetlands for peat and biofuels Firewood produced by riparian or coastal forests	Net present value of clearance logging and fuelwood under different management scenarios
Water purification	Indicators on surface water quality (e.g., microbiological data, BOD, phosphate concentration, oxygen conditions, saprobiological status, suspended matter) Indicators on groundwater quality (e.g., NO3, pesticide, trace metals, emerging pollutants) Nutrient concentration	Nutrient loads Nutrient retention Nutrient uptake by organisms Removal of nutrients by wetlands Amount of waste processed by ecosystems Sedimentation and accumulation of organic matter	Access to safe water Value of ecosystem waste treatment and water purification Cost of effluent treatment or nutrient abatement

Ecosystem services	Natural capacity	Service flow	Social benefit
	Trophic status Ecological status Area occupied by riparian forests Presence of floodplains, wetlands, estuaries, or mangroves Presence/distribution of nitrophilous macroalgae or macrophytes Potential mineralization or decomposition		
Air quality regulation	Tree cover Pollutant concentration Atmospheric cleansing capacity	Deposition velocity Flux in atmospheric gases	
Erosion prevention	Ground water level evolution Soil erosion rate by land use type Geomorphology Vegetation distribution and properties (of riparian or coastal zones) Area affected by erosion Presence of seagrass meadows or kelp	Sediment accretion /soil retention Siltation	Willingness-to-pay of local residents Loss in property values from declining shoreline protection
Flood protection	Water holding capacity of soils Conservation status of riverbanks, lake banks and riparian zones Floodplain area Area of wetlands located in flood risk zones Ground water level evolution	Flood risk maps Record of annual floods Trends in the number of damaging natural disasters Probability of incident Wave attenuation or surge reduction	Percentage of the population living in water hazard prone areas Population in floodplain/coastal area Spending on disaster assistance for floods Construction and/or maintenance cost of sea defences

Ecosystem services	Natural capacity	Service flow	Social benefit
	Soil capacity to transfer groundwater Infiltration capacity of an ecosystem Floodplain water storage capacity Area of intact wetlands, floodplains, coral reefs, mangroves, sandbars, or barrier beaches Vegetation distribution and properties (of riparian or coastal zones)		Avoided damage per storm condition
Maintaining populations and habitats	Biodiversity value (species diversity or abundance, endemics or red list species, spawning areas) Ecological status Hydromorphological status Coverage, condition and structural complexity of nursery and feeding areas (e.g., coral, mangrove) Macrophyte species richness	Habitat suitability Species abundance and richness Habitat change Juvenile density Postlarvae production per hatchery	Community perception of the importance of habitat provision Economic value of the annual juvenile fish production based on the price of aquaculture growth
Pest and disease control	Alien species introduced in aquatic environments and riparian zones Disease vector predator populations	Pest density Control of aquatic disease bearing invertebrates and plants by fish Occurrence of problems limiting crop and livestock productivity Increase in disease vectors mosquitoes Estimated change in disease burden as a result of changing ecosystems	Population affected by water-related diseases Waterborne and water related disease incidence

Ecosystem services	Natural capacity	Service flow	Social benefit
Soil formation and composition	Presence of hydromorphic soils Surface of floodplains Potential mineralization or decomposition Decomposition of dissolved and particulate organic matter by bacteria and fungi in the sediments	Fluvisols surface Nutrients stored in the sediments	
Carbon sequestration	Organic carbon stored or carbon stock Above and below-ground biomass Carbon in soil or sediments Dissolved organic matter	Carbon sequestration or carbon change Carbon uptake Soil carbon accumulation	Quantity of carbon fixed combined with the marginal damage costs of carbon emissions Market value of carbon
Local climate regulation	Riparian zone Ground water level Temperature & Precipitation Evapotranspiration Cloud formation Canopy stomatal conductance	Drought frequency	
Recreation and tourism	National Parks and Natura 2000 sites Number of birds watching sites Number of beaches Fish and waterfowl abundance Condition of fish stocks Quality of fresh waters for fishing Accessibility Footpaths Size of marine leisure and recreation hotspots Cover and smell of decomposing algae	Number of visitors to natural places (e.g., to National Parks, lakes, rivers, protected wetlands) Number of visitors to attractions (e.g., thermal, mineral and mud springs and balnearies, speleology sites, species watching) Number of fishing licenses and fishing reserves Beach closure due to bacteria limit,	Tourism revenue Traffic census Amount or spending on nature tourism Beach visitors and travel cost Tourists' perception of a marine protected area

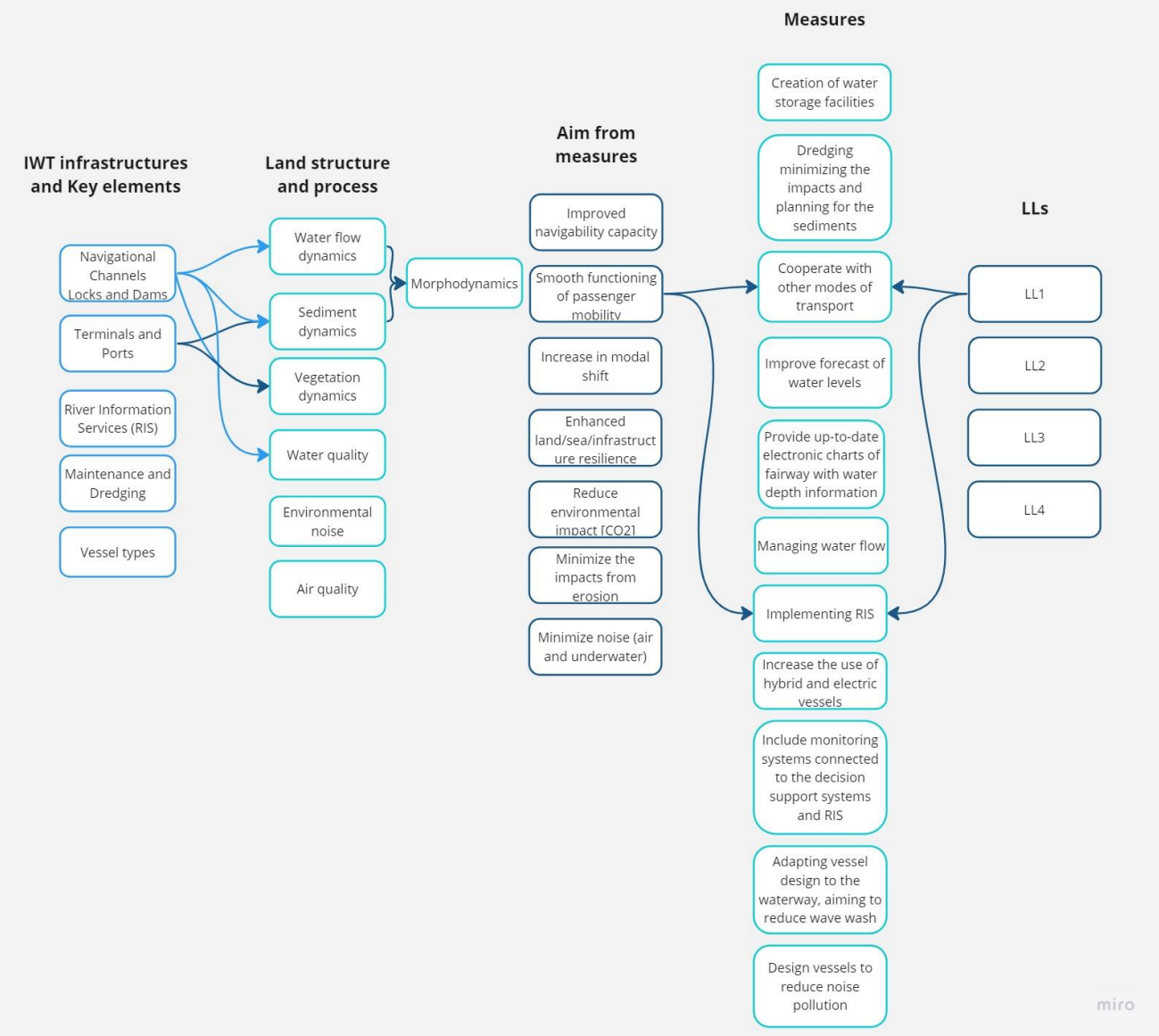
Ecosystem services	Natural capacity	Service flow	Social benefit
	Presence of a coralligenous community or cetacean population	discoloured or turbid water Number of bathing areas Number of waterfowl hunters, anglers and amateur fishermen	
Intellectual and aesthetic appreciation	National Parks and Natura 2000 sites Contrasting landscapes (e.g., lakes close to mountains) Proximity of scenic rivers or lakes to urban areas Monitoring sites by scientists Fish studies as a source of information Seabird populations	Cultural sites and number of annual cultural activities organised Classified sites (e.g., World Heritage, label European tourism) Number of visitors Number of scientific projects, articles, studies, patents Number of educational excursions at a site Number of TV programmes, studies, books, etc. featuring sites	Changes in the number of residents and real estate values Comparative value of real estate nearer to nature/ cleaner water bodies Price of a hotel room with sea views Willingness to pay for improvement in the environment/ improved water quality Taxes and subsidies that support maintaining open space Financial expenditure in research
Spiritual and symbolic appreciation	National species or habitat types Rare species Cultural landscape intactness	Sacred or religious sites (e.g., catastrophic events, religious places) Number of sites or species fundamental to the performance of rituals Number of visitors Number of (environmental) associations registered	Changes in the number of residents and real estate values Incentives to maintain traditional cultural landscapes

6 Conclusions

In this deliverable, we propose a scheme to link IWT measures with the EU environmental Directives. We connected IWT measures with all the potentially affected Directives via the effects of the measures on physical, chemical, and biological processes. Under the EU legal framework, an appropriate assessment involving the Birds and Habitat Directives is mandatory, while EIA and SEA are upon request of the Member States, but they are required in case of transnational projects. Although most of the Directives have been in place since the beginning of the 'nineties, thus the IWT industry is already complying with the requirements, during the project we will follow the development and the application of the Nature Restoration Law, and report if and how the IWT will be affected by the new regulation. Furthermore, we linked the processes and the activities with the ecosystem services and proposed some indicators for the quantification of the ecosystem services.

6.1 Next steps

In the next phase of the task, we will combine the information from this deliverable into networks, as shown in the figure below. These networks are the starting points for the definition of the Bayesian networks (ST 1.3.2).


Measures
IWT infrastructures and Key elements
Land structure and process
Aim from measures
LLs
Navigational Channels Locks and Dams
Terminals and Ports
River Information Services (RIS)
Maintenance and Dredging
Vessel types
Water flow dynamics
Sediment dynamics
Vegetation dynamics
Water quality
Environmental noise
Air quality
Morphodynamics
Improved navigability capacity
Smooth functioning of passenger mobility
Increase in modal shift
Enhanced land/sea/infrastructure resilience
Reduce environmental impact [CO2]
Minimize the impacts from erosion
Minimize noise (air and underwater)
Creation of water storage facilities
Dredging minimizing the impacts and planning for the sediments
Cooperate with other modes of transport
Improve forecast of water levels
Provide up-to-date electronic charts of fairway with water depth information
Managing water flow
Implementing RIS
Increase the use of hybrid and electric vessels
Include monitoring systems connected to the decision support systems and RIS
Adapting vessel design to the waterway, aiming to reduce wave wash
Design vessels to reduce noise pollution
LL1
LL2
LL3
LL4
miro

7 References

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