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INSPIRE

Innovative Solutions for Plastic Free European Rivers

Deliverable 4.1
Report on feedback loop including impact pathways generated by measures for prevention
Version 2.1

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[1] Dissemination level: **PU:** Public, **SEN:** Sensitive, **CL:** EU Classified, information as referred to in European Commission Decision 2015/844

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Executive Summary

Deliverable D4.1 – Report on feedback loop including impact Pathways Generated by Measures for Prevention, is part of the Horizon EU Mission Ocean project INSPIRE, and aims to provide detailed insights into the performance of various technologies by assessing them under real environmental conditions. This deliverable focuses on identifying areas where improvement and optimization are needed to enhance the overall efficiency of the technologies. Specifically, D4.1 establishes a framework for evaluating INSPIRE's detection, retention, collection, and elimination technologies through real-time data collection, which is essential for understanding their real performance and impact.

Real-time data gathered during the operation of these technologies will initially be stored on the INSPIRE dashboard as part of T4.4 – Impact Evaluation Dashboard. This dashboard will serve as a central hub for visualizing and analysing the performance data. Following this initial phase, the data will be integrated into the broader INSPIRE repository, where it will be further processed and used for subsequent assessments and comparisons across technologies. This subsequent assessment will also provide the feedback loop of information based on field testing data.

D4.1 is structured into several sections, each focused on evaluating different aspects of INSPIRE technologies. These technologies are designed to detect and eliminate various types of riverine litter, such as macro plastics and microplastics. By analysing key performance indicators in real-world environments, the deliverable aims to provide a comprehensive evaluation of each technology's effectiveness in mitigating plastic pollution.

The main outputs of D4.1 include several critical findings and frameworks for improving the performance of the technologies:

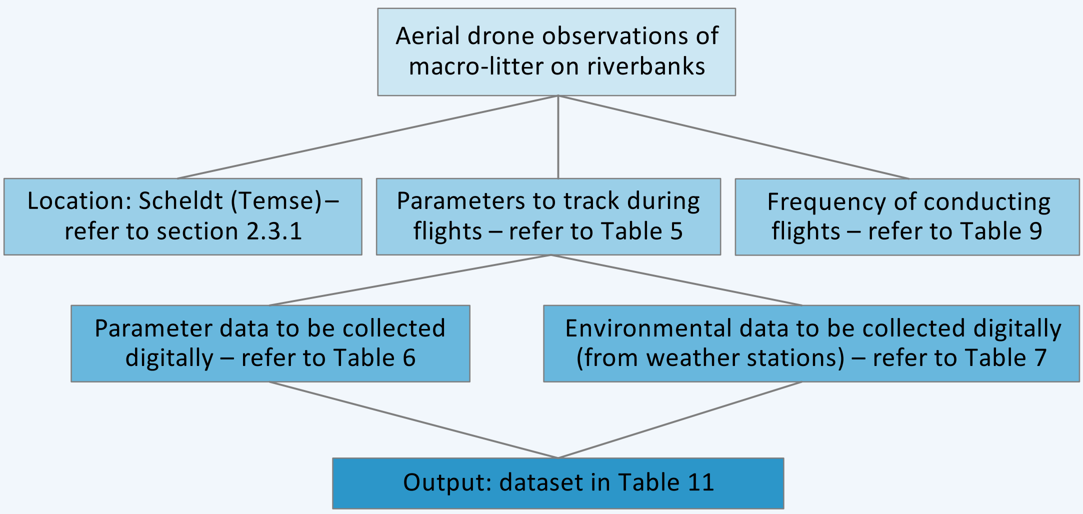
1. Optimization of aerial drone flight altitudes to enhance the quality of images used for detecting litter along riverbanks;
2. A framework for comparing the performance and accuracy of two different bridge-mounted AI cameras designed for detecting macro-litter in water bodies;
3. Development of a General Algebraic Mathematical System (GAMS) model to optimize the energy self-sufficiency of floating riverine litter retention technologies that utilize renewable energy sources, such as solar power;
4. In alignment with the EU Mission Restore Our Ocean and Waters by 2030, D4.1 aims to contribute to the goal of reducing macro plastic pollution in the environment by at least 50% by investigating the sources of plastic pollution and linking them to the responsible societal sectors, aiding in the development of targeted interventions;
5. In alignment with the EU Mission Restore Our Ocean and Waters by 2030, D4.1 aims to contribute to the goal of reduce microplastic pollution by at least 30 %, by evaluating the use of various microplastic retention and elimination technologies at different sources, resulting in a cross-validated methodology to estimate the abundance of nanoparticles and thus retention of these particles by INSPIRE technologies, using a size distribution model.

Overall, D4.1 contributes significantly to the goal of reducing plastic pollution in aquatic ecosystems by providing data-driven insights and frameworks for technological optimization. The use of the methodological frameworks in this document allows for detailed data collection by technology operators at respective demo sites, enabling them to collect data on the operating parameters of the technology, environmental information, as well as litter classification data. The methodology can be

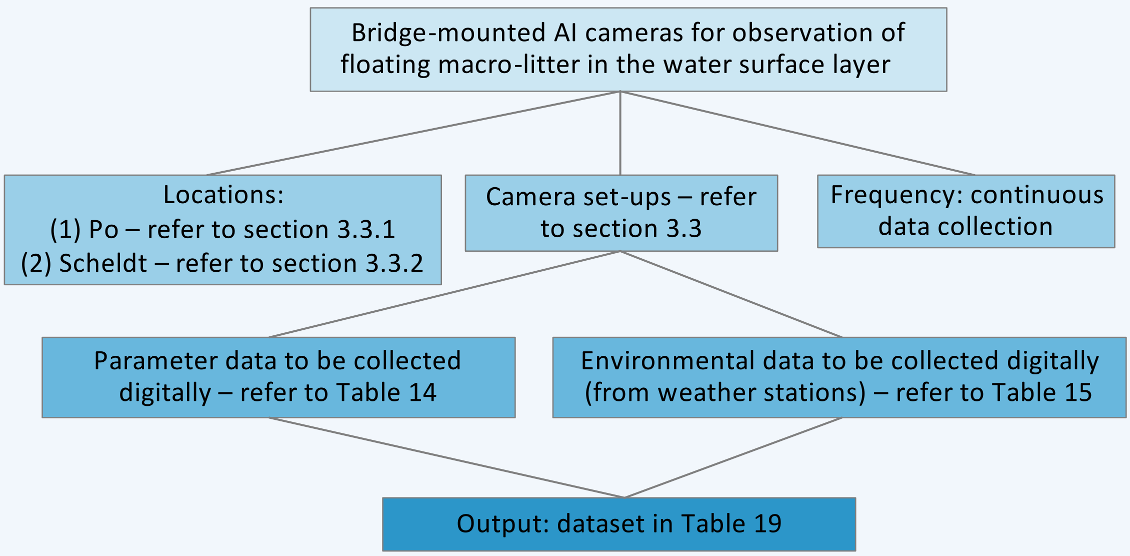
replicated to any implementation of the same technologies on rivers. The use of the evaluation frameworks presented in this document will be highly beneficial to validating the effectiveness of INSPIRE technologies on the field and will enable the quantification of results, with future assessments providing information on the contribution of INSPIRE to the EU Mission goal of reducing macroplastic pollution by 50% and reducing microplastic pollution by 30% by 2030.

The following section of the Executive Summary presents a brief visualized summary on how to use each chapter of the deliverable to serve as a guide for demo site operators performing technology evaluations.

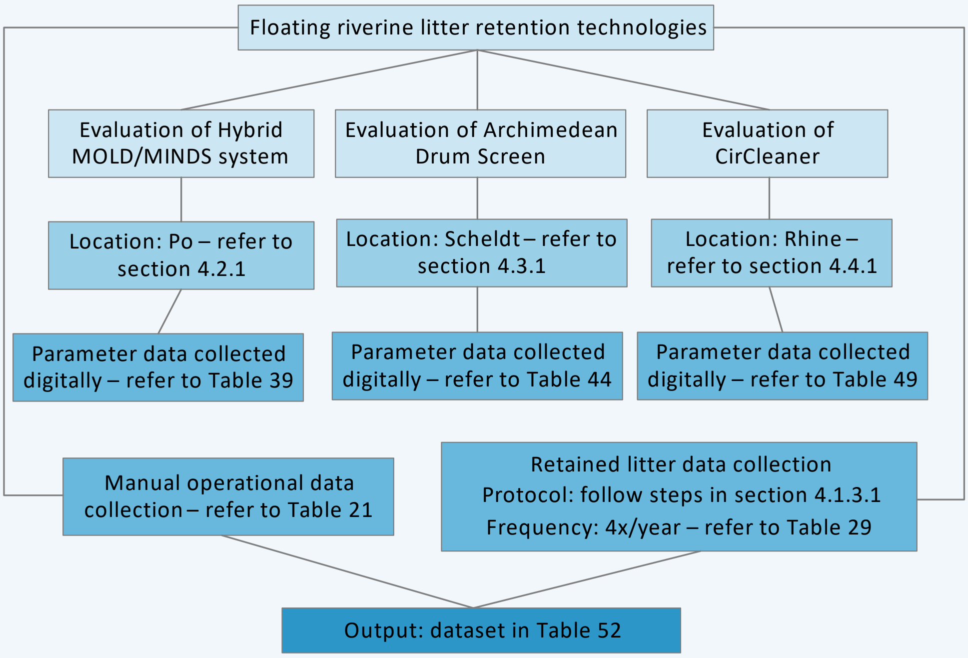
Demo site operators of the aerial drones used for observation of macro-litter on riverbanks should refer to the procedure in the flowsheet below.



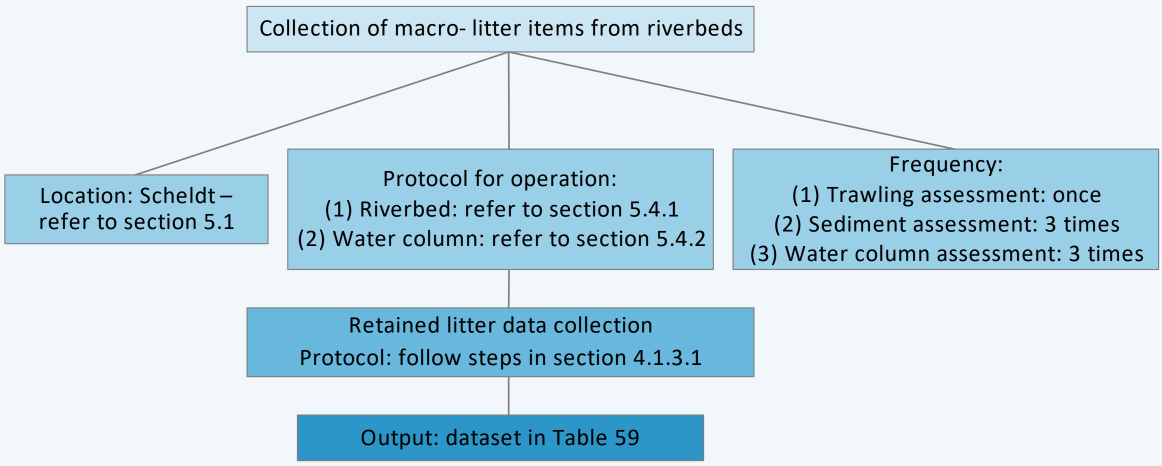
Demo site operators of the bridge-mounted AI cameras for observation of floating macro-litter in the water surface layer should refer to the procedure in the flowsheet below.



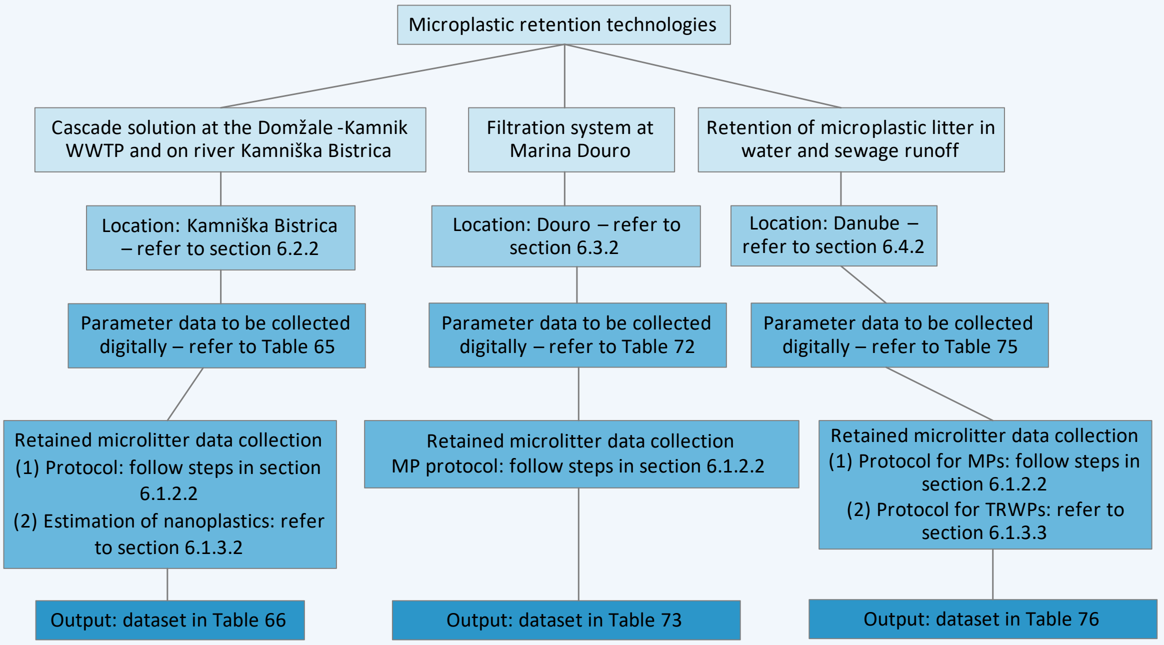
Demo site operators of the floating riverine litter technologies should refer to the procedure in the flowsheet below.



Demo site operators of the technologies for collection of macro-litter items from riverbeds should refer to the procedure in the flowsheet below.



Demo site operators of the floating riverine litter technologies should refer to the procedure in the flowsheet below.



Acronyms

Acronym	Description
ACAS X_u	Unmanned aerial collision avoidance system
AI	Artificial Intelligence
AIT	Asian Institute of Technology
ATM	Air traffic management
BOD	Biochemical oxygen demand
CDI	Capacitive deionization
CPU	Central Processing Unit
CNR	Consiglio Nazionale Delle Ricerche
DJI	Da-Jiang Innovations
DEM	Digital Elevation Model
EASA	Easy Access Rules for Unmanned Aircraft Systems
EEA	European Environment Agency
EPSG	EPSG Geodetic Parameter Dataset (also EPSG registry)
FF	Fishflow Innovations
FOV	Field of View
FTIR	Fourier transform infrared
μFTIR	micro-Fourier transform infrared
GAMS	General Algebraic Modelling System
GCP	Ground Control Points
GPS	Global Positioning System
GSD	Ground Sampling Distance
ILO	International Labour Organization
IMU	Inertial Measurement Unit
INFOR	Infordata
ISO	International Organization for Standardization
JRC	Joint Research Centre
LIDAR	Light detection and ranging
MINDS	MINDS Technologies and Environmental Sciences PC
MP	Microplastic
MSFD	Marine Strategy Framework Directive
MSFD TG ML	Marine Strategy Framework Directive Technical Group on Marine Litter
NIR	Near Infrared
NOR	Noria
NP	Nanoplastic
NPV	Negative Predictive Value
PFAS	Per- and polyfluoroalkyl substances
PV	Photovoltaics
PVGIS	Photovoltaic Geographical Information System
PVV	Positive Predictive Value
PoE	Power over Ethernet
RCU	River Clean Up
RIC	Resin Identification Code
UCA	University of Cadiz
TBT	Tributyltin
TOC	Total organic content
TRWP	Tyre and Road Wear Particles

VITO	Vlaamse Instelling voor Technologisch Onderzoek
VLIZ	Vlaams Instituut Voor De Zee
WWTP	Wastewater treatment plant

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1. Introduction

One of the main objectives of the INSPIRE project, funded by the European Commission under the EU Mission Restore our Ocean and Waters by 2023, is to test different technological solutions for efficient detection, collection, and prevention of plastics litter in European rivers. The project consists of 7 Work Packages, with Work Package 4 - Sustainability assessment and optimisation of implemented measures - looking at the assessment of upstream and downstream impacts, with the aim of quantifying the impact of implemented measures by assessing the pollution after the solutions has been implemented. This will be carried out in T4.1, which will oversee additional monitoring activities conducted at the demo sites before and after measures have been taken, considering various parameters to measure their efficiency in real environments.

Deliverable D4.1 functions as a support tool for both technology providers and demo site leaders. It offers a thorough field assessment of the technologies involved and establishes a framework for the future validation and optimization of INSPIRE's technological solutions. The document is organized into six sections, each corresponding to a specific type of technology under evaluation:

- Section 2 assesses artificial intelligence (AI)-enabled aerial drones for detecting macro-litter along riverbanks;
- Section 3 focuses on bridge-mounted AI cameras for detecting macro-litter in the water surface layer;
- Section 4 examines floating riverine litter retention technologies;
- Section 5 evaluates collection technologies for macro-litter removal from riverbeds;
- Section 6 investigates microplastic retention technologies across different environments.

Sections 2 and 3 cover two automated litter detection technologies developed as part of Work Package 1 – Monitoring Riverine Litter (WP1). In this context, deliverable D4.1 will serve as a data collection point during the operation of these technologies, enabling performance evaluation, offering recommendations for optimizing detection and classification accuracy, and laying the groundwork for subsequent AI algorithm assessment and benchmarking. This further evaluation will be conducted in T4.4 – Impact Evaluation Dashboard.

Section 4 delves into the evaluation of floating litter retention technologies, which are part of Work Package 2 – Prevention, retention, collection and elimination of plastic litter (WP2). Here D4.1 will provide the groundwork for the evaluation of litter retention and technologies from their operational point of view under real environmental conditions, with the following overarching objectives: (i) to determine the ratio between the amount of process water with the amount of litter and its qualitative type descriptions that the technologies are able to retain, (ii) to relate these retained litter to their corresponding societal sectors, and (iii) to perform optimisation models for the energy self-sufficiency of technologies that use renewable sources of electricity.

Section 5 lays the foundation for evaluating collection technologies used to remove litter accumulated on riverbeds. The assessment includes an evaluation of bottom trawling technology and its ability for removing this accumulated litter, while simultaneously also examining its impact on the riverbed ecosystem.

Lastly, Section 6 outlines an evaluation framework for INSPIRE microplastic retention technologies. technologies. It presents a detailed plan for data collection during the implementation of these solutions and offers a methodology for the quantitative assessment of their performance under real environmental conditions, at various use cases including wastewater treatment plants, marinas, and road runoff water.

As D4.1 establishes the framework for evaluating detection, collection, and prevention technologies under real environmental conditions, various data will be collected. This data, either automatically gathered in real time via sensors or manually inputted and streamed to the INSPIRE repository in line with the dataset collection activities outlined in T4.4, and the data storage requirements defined in T7.3 – Data Management. T4.4 aims to develop a web-based impact evaluation dashboard with an intuitive user interface for visualizing the outcomes of project activities. Additionally, the results will be displayed using an effective UX design, incorporating generated datasets and technology benchmarks.

2. Aerial drone observations of macro-litter on riverbanks

Litter is distributed across various river compartments, one of which also includes riverbanks, as it accumulates along river margins due to natural factors, such as currents and wind (González & and Oosterbaan, 2016; Madricardo et al., 2019), or as a result of human activities, whether intentional or accidental (Ledieu et al., 2022).

Traditionally, determining the amount of litter on riverbanks has relied on visual observations conducted by trained operators. However, this method is labour-intensive, time-consuming, and has spatial limitations (Gonçalves et al., 2022). Moreover, some riverbank areas are difficult to access or dangerous, and the observation results are susceptible to human error. To address these challenges, automated approaches have been increasingly adopted. One such approach is the use of unmanned aircraft systems (UAS) or aerial drones, which are capable of collecting high-resolution temporal and spatial data (Escobar-Sánchez et al., 2021). Despite their limited battery capacity, drones offer a non-invasive method of data collection, and their flexibility and small size allow them to capture images at lower altitudes and in narrower areas (Escobar-Sánchez et al., 2021).

The effectiveness of aerial drones in environmental monitoring studies has been demonstrated by a number of applications, including assessment of water quality (De Keukelaere et al., 2023) and mapping of vegetation (Bertacchi et al., 2019). More recently, drones have increasingly been evaluated for observations of plastic pollution (Andriolo et al., 2023; Geraeds et al., 2019; Topouzelis et al., 2019). They have been extensively utilized for observation of litter across a wide range of environments, including beaches (Taddia et al., 2021), continental shores (Martin et al., 2021), coastal waters (Garcia-Garin et al., 2021), and riverbanks (Cortesi et al., 2023).

The efficacy of litter mapping activities is closely linked to the technical and operational specifications of the drone and camera employed. D4.1 aims to identify the optimal operating conditions for the generation of highest quality results and will provide insight into the impact of drone flight altitude on spatial resolution and the performance of AI algorithms used to detect macro plastic litter. Flight altitude will be the key parameter for optimization, as the remaining drone operating parameters will be fixed.

This section is divided into the following subsections. In Subsection 2.1, the employed methodology is discussed, outlining the drone platforms and sensors utilized within INSPIRE for macro plastic detection. It focuses on drone regulations, key parameters, and flight planning. Subsection 2.2 provides a detailed account of the INSPIRE drone observation areas and outlines the planned drone activities. Subsection 2.3 provides a description of the demo site location. Subsection 2.4 discusses the optimization process for drone planning and data acquisition, defining a method to analyze the performance of AI-based image analysis results.

The impact pathway specified by this case study relates to the relation between the technology, the use case, the activities of flight parameter optimization and AI performance analysis, and the expected outputs. Figure 1 shows a brief overview of the defined impact pathway, which is the purpose of this section in D4.1.

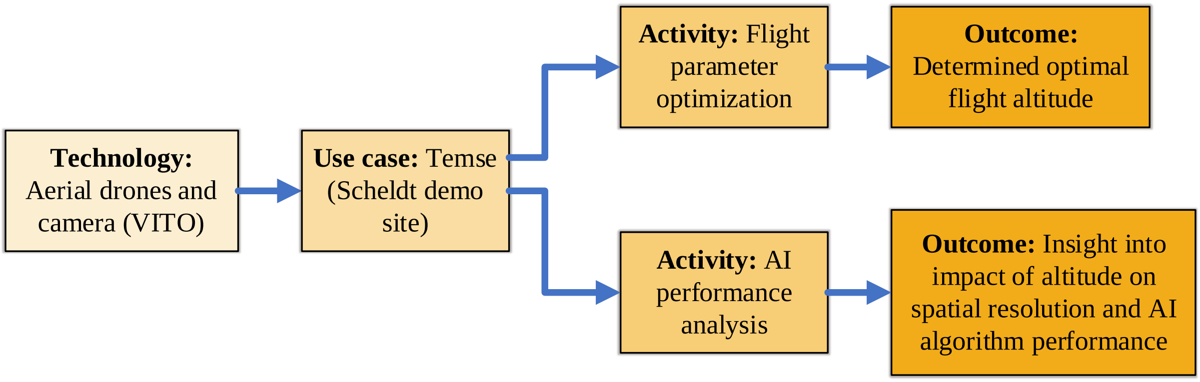


Figure 1: Impact pathway for the case of aerial drones.

2.1. Methodology

This section outlines the methodology that will be applied to assess the impact of drone flight altitude on the AI's ability to detect macro-litter items. Firstly, three key parameter groups associated with drone technology are presented. Next, a brief overview of EU regulation pertaining to unmanned aircraft systems is provided, accompanied by a description of associated technical challenges. Finally, a description of key influencing parameters is provided, listing the targeted values adhered to during INSPIRE activities.

Optimisation of drones will be conducted through the evaluation of parameters, which have been categorized into three groups:

1. **Technical parameters** include the technical specifications of the drone, as well as sensors that will be mounted on the drone to acquire aerial images.
2. **Operational parameters** include:
    a. Operational parameters of the drone, such as the drone flight altitude and drone flight speed (aligned with T1.3);
    b. Operational parameters of the AI algorithm, such as the energy consumption of AI model and image resolution.
3. **Environmental parameters** include environmental conditions that prevail during the drone observation period. Key environmental parameters, such as solar irradiation, wind speed and direction, as well as precipitation information, will be gathered from nearby weather stations.

Within INSPIRE, we collaborate with local drone pilots who possess the requisite permissions, are familiar with local regulations and can fulfil the technical requirements, including the use of the appropriate drone platform and/or camera sensor.

2.1.1. European Union's regulation on Unmanned aircraft systems

Unmanned aircraft systems are, in accordance with Regulation (EU) 2018/1139, defined as “any aircraft operating or designed to operate autonomously or to be piloted remotely without a pilot on board” (European Union, 2018). The European Union Aviation Safety Agency (EASA) has, in Easy Access Rules for Unmanned Aircraft System (Regulations (EU) 2019/947 and 2019/945 (EASA, 2021), established a framework for defining airworthiness of UAS and their operational requirements, divided into 3 categories:

1. **Open category** encompasses UAS with a maximum take-off mass (MTOM) of less than 25 kg. It is the responsibility of the drone operator to ensure that the drone is kept at a safe distance from people and that it remains in the drone operator's visual line of sight, with a maximum above-ground flight level of 120 m.
2. **Specific category** includes UAS with a MTOM greater than 25 kg. Such aircraft are permitted to operate beyond the visual line of sight of the pilot and have a maximum above-ground flight level of 120 m. They are authorised to operate at specific airspaces. In the case of the specific category, a risk assessment must be conducted.
3. **Certified category** encompasses the operation of UAS over an assembly of people and during the transportation of hazardous materials and/or passengers.

A designated airspace for UAS operations is referred to as U-space, which can be either segregated or integrated. Segregated U-space permits only unmanned aviation, while integrated U-space allows UAS to coexist with manned aviation. Currently, UAS typically operate in discrete airspace, with ongoing operational, technical, and regulatory measures required to ensure safe integration of these systems (Steer, 2023). The challenges of integrating UAS into shared airspace are outlined in Table 1. In the absence of a definitive standard for UAS and the ongoing debate surrounding their operation in airspace, the compilation of a list of challenges represents an initial step towards the establishment of a comprehensive framework.

Table 1: Overview of the challenges of integrating UAS into shared airspace, from (Steer, 2023).

Technical challenges	- Outdated communication, navigation, and surveillance systems require modernization to manage increased UAS traffic and resolve altitude issues. - Automating 'see and avoid' with 'detect and avoid' systems ensures safe interaction with manned aircraft relying on visual separation; - Integrating U-space with Air Traffic Management (ATM) requires UAS compliance with instrument flight rules and standards for safe de-confliction with manned aircraft; - In controlled airspace, drones must operate like other users, requiring a voice link with controllers; future ATM modernization will reduce voice communication reliance through datalink and automation, reserving controllers for complex or emergency situations.
Safety challenges	- A strong safety culture and standardized reporting for UAS are essential, but regulations require updates to include UAS-specific incidents and tackle underreporting; - Rising UAS traffic increases collision risks, requiring procedural measures, 'detect and avoid' technology, and advancements like unmanned aerial collision avoidance system (ACAS X_u) and Light detection and ranging (LIDAR) for safety; - Adverse weather present challenges to the operation of UAS, with higher power demands, reduced battery life, signal loss, and malfunction risks. This

	emphasizes the need for clear regulations and personal weather minima to ensure safety of UAS operations.
Security challenges	- Cybersecurity risks for UAS include potential hostile takeovers, weaponization, privacy breaches, and espionage, with current international conventions inadequately addressing these evolving threats; - UAS pose risks such as contraband smuggling, weaponization for terrorism, and disruption of public services, necessitating advanced detection systems and updated regulations to counter these security threats.
Regulatory challenges	- UAS liability is complicated and inconsistent, with differing national laws and insurance requirements, underscoring the need for a unified framework and improved mechanisms for compensating victims of uninsured operators; - Concerns about cost-sharing between UAS and manned aviation, with ongoing debates on fair financing and potential variable user fees for airspace services.

Furthermore, additional geographical zones, as defined by each Member State, may impose further flying restrictions regarding UAS. Within the INSPIRE project, preference is given to Matrice 350 RTK aerial drones or comparable models. These multicopters are safe, widely used, and require only a vertical take-off and landing spot, making them highly flexible in their use. Given that their weight is below the 25 kg threshold, these devices can be operated under the ‘Open’ category.

2.1.1.1. Open Category regulations for UAS

The open category regulations for UAS are further subdivided into four classes, each characterized by a distinct maximum take-off mass and pilot qualification requirements, as outlined in Table 2. In all categories, operations must prioritize safety, ensuring drone stability and manoeuvrability to minimize potential risks and injuries to people.

Table 2: Overview of open category classes.

Class	MTOM	Remote pilot	Max hight
C0	< 250 g	No training required	120 m above ground level
C1	< 900 g	Completing online training for Open category	120 m above ground level
C2	< 4 kg	Remote pilot certificate of competency for open subcategory	120 m above ground level
C3	< 25 kg	Completing the online training A1/A3 open	120 m above ground level
C4	< 25 kg	Completing the online training A1/A3 open	120 m above ground level

Under INSPIRE, the Matrice 350 RTK or comparable drones, used for aerial drone imaging of riverbanks, are included within the C3 class of the Open Category.

2.1.2. Key parameters influencing aerial drone imaging

The quality of aerial drone images depends on various technical and operational parameters, including:

1. Spatial resolution or Ground Sampling Distance (GSD), depending on the flying altitude (Andriolo et al., 2023) and the camera specifications (focal length); In order to accurately detect macro-plastic litter (>2.5 cm), defining a good GSD is essential.
2. Potential blurring, depending on camera settings (shutter speed) and the drone velocity;
3. Accuracy of georeferencing:
    a. Direct georeferencing (over water): depends on the accuracies of the Global Positioning System (GPS), the Inertial Measurement Unit (IMU), the angle of the camera mount, the camera calibration, and the used Digital Elevation Model (DEM).
    b. Photogrammetry (over land): the percentage of overlap (min. 80 % front and side) and camera calibration are important and georeferencing can be improved using Ground Control Points (GCP's) in the field.
4. Occurrence of saturation when bright objects are in proximity to darker objects, influenced by the camera's ISO settings, shutter speed and aperture. These parameters can be adjusted based on payload options, such as auto-exposure or manual settings. To prevent information loss, it's crucial to avoid saturation especially when the post-processing relies on spectral signatures (e.g. processing multispectral images). However, if object detection relies primarily on shape, saturation becomes less problematic. Clear sky conditions can also exacerbate saturation.

In the INSPIRE project, AI techniques (object detection and segmentation) will be applied for the purpose of detecting macro-litter items (> 2.5 cm) on riverbanks. The effectiveness of these algorithms is heavily influenced by the spatial resolution of the images, which is determined by the camera specification and drone flight altitude. Flying at higher altitudes permits greater area coverage but results in lower spatial resolution compared to low-altitude flights. Conversely, lower-altitude flights provide a higher GSD, which may be necessary for the detection of smaller macro-litter items (2.5 cm).

Under INSPIRE project, drone imaging adheres to the flight altitude guidelines, as defined by EASA (EASA, 2021) for C3 drones, which is 120 m above ground level. While EASA does not specify a minimum flight altitude for C3 drones, these drones are unable to operate effectively at very low altitudes due to the presence of obstacles such as houses, poles, and trees. Therefore, a minimum altitude of at least 10 m is advisable for drone safety (Andriolo et al., 2021). Table 3 showcases the maximal and minimal altitudes for aerial drone flight in the context of INSPIRE drone imaging. It should be noted that local deviations are possible due to changes in local regulations.

Table 3: Minimal and maximal drone flight altitudes. Local deviation can occur depending on local regulations.

	Value	Reference
Maximal drone height	120 m	(EASA, 2021)
Minimal drone height	10 m	(Andriolo et al., 2021)

A second key parameter to account for is the GSD, which refers to the distance between two consecutive pixel centres measured on the ground and is influenced by following factors (Andriolo et al., 2023), as depicted in Equation 1:

1. Drone flight altitude (H);
2. Width of sensor (w_s);

3. Size of the captured image in (img); and
4. Focal length of the camera (f).

$$GSD = \frac{H \cdot w_s}{f \cdot img} \qquad (1)$$

Based on the review conducted by (Andriolo et al., 2023), different GSD ranges have been proposed for litter observations in various environmental compartments, with the following identified median values of GSD:

- Beach: 0.54 cm/px
- Coastal dunes: 0.54 cm/px
- Riverbanks: 1 cm/px
- River waters: 0.6 cm/px
- Coastal waters: 0.7 cm/px

Within INSPIRE, a GSD of at least 0.25 cm/px will be targeted, enabling the classification of objects comprising more than 10 pixels, regardless of the environment. Should the relevant regulations, operational considerations, safety protocols and scheduling permit, flights with a higher GSD will also be planned. While all images can be downsampled to simulate lower spatial resolutions, additional flights will also be conducted at higher altitudes for comparison purposes.

2.2. Observations of macro-litter at riverbanks with aerial drones

The following section outlines the technical and operational aspects of aerial drone flights, namely the drone platform and sensor, as well as drone flight planning. This is an extension of the descriptions set out in D1.2 at the beginning of the project. The initial part of this section delineates the essential elements and technical specifications of the aerial drone utilized in INSPIRE. Additionally, a description of the attached cameras is provided. The observation protocol to be followed is described in detail, and the relevant numerical values for the different cameras are provided. Finally, a datasheet, which defines the values to be collected during the flights conducted in accordance with the established protocols, is defined.

Drone data will be collected in conjunction with manual clean-up activities, conducted by partner RCU, as outlined in T1.3. D4.1 focuses on identifying the optimal altitude of aerial drone imaging of macro-litter at riverbanks. To this end, a series of drone imaging flights at varying altitudes will be conducted prior to the commencement of manual clean-ups. The drone flights will be conducted by local accredited drone pilots, utilising certified drones and with all necessary permissions in place. The planning and execution of the flight operations will be undertaken in close collaboration with VITO.

2.2.1. Aerial drone equipment

The aerial drone equipment comprises the following elements:

1. Drone platform;
2. Camera sensor;
3. Auxiliary sensors: GPS and Inertial Measurement Unit (IMU).

Drone platform(s) used within INSPIRE: The commonly used Matrice 300 or Matrice 350 RTK drone platforms from DJI Enterprise are favoured. The Matrice 350 RTK drone from DJI Enterprise (as seen in

Figure 2) or a comparable model will be used to conduct riverbank observations. The technical specifications of the drone are displayed in Table 4.

Figure 2: Matrice 350 RTK drone platform (photograph by Mariana Miranda).

Table 4: Matrice 350 RTK drone technical specifications.

Unfolded size	810x670x430 mm
Weight	6.47 kg
Max flight height	7000 m
Max flight duration	55 minutes
Wind resistance	Up to 12 m/s

Camera(s) used within INSPIRE:

- Zenmuse P1 with 35 mm lens (default)
  The Zenmuse P1 camera will be the default choice for operational flights. It features a mechanical shutter and the advanced TimeSync 2.0 system, which synchronizes modules at the microsecond level. This allows the camera to capture centimetre-accurate data combined with real-time position and orientation compensation technology.

- Phase One iXM-100 camera with 80 mm lens (demo)
  During a selected specific test campaign, the very high-resolution Phase One iXM-100 camera with an 80mm lens will be used alongside the Zenmuse P1. The Phase One iXM cameras have been designed for the most demanding mapping, inspection, space, and security applications.

Both cameras are depicted in Figure 3.

Figure 3: Image of Zenmuse P1 (left) and Phase One iXM-100 (right) camera (Phase One, 2024).

2.2.2. Observation protocol for aerial drone imaging

The INSPIRE observation protocol for drone imaging will be implemented based on the description in D1.2, which specifies the requisite flight altitude and coverage for drone flight operations.

The drone flights will cover a maximum 250 m stretch from the pilot's location, maintaining a constant altitude above the ground. Images of the riverbank areas will be collected and later processed using MAPEO Water (De Keukelaere et al., 2023). This platform will perform quality checks on the images, as well as carry out necessary calibration and georeferencing. Subsequently, AI will be employed to detect litter across various terrain backgrounds, including grass, mud, stone, and pebbles. This will facilitate the identification of macro-litter on riverbanks. Subsequently, the results will be validated with those obtained from visual observations of riverbanks using the EEA Marine LitterWatch application.

T4.1 will further investigate the observation protocol for aerial drone imaging following the protocols of D1.2. This will entail drone flights at varying altitudes and at altitudes that simulate different elevations. The selected altitudes are based on required GSD and follow the height restrictions outlined in class C3 of the Open category of Easy Access Rules for Unmanned Aircraft Systems by EASA (EASA, 2021). Additionally, at the Temse demo site location, two camera sensors will be employed at various drone flight altitudes to capture images of differing resolutions.

Table 5 presents the GSD values identified and defined for the three consecutive drone flights. Based on flight altitude and technical specifications, the GSD values have been calculated using Equation 1.1.

Table 5: Defined GSD values and corresponding flight heights for the Zenmuse P1 35 mm lens and the Phase One 80 mm lens camera. The flight altitudes achieving a GSD of 0.25 cm are marked in grey.

Camera	Focal length (mm)	Aperture range	# pixel x	# pixels y	Altitude (m)	GSD (cm/px)
Zenmuse P1 35mm lens	35	f/2.8 – f/16	8192	5460	20	0.25
					50	0.63
					100	1.25
Phase One 80mm lens	80	f/2.8 – f/22	11664	8750	20	0.09
					50	0.24
					100	0.47

Figure 4 showcases examples of images captured during the first riverbank observations held in June 2024 in Temse, Belgium.

Figure 4: Drone image captured by Zenmuse P1 along the riverbank of the Scheldt River (left), zoom-in of plastic found along the riverbank (right) (photographs provided by VITO).

The GSD values outlined in Table 5 will be tested in real environments, where the parameters defined in T1.3 and specified in Table 6 will be collected.

Table 6: Datasets collected during drone operations.

Parameters	Description	Admitted values	Mandatory	Unit	Example
Sample_UID	Sample Unique Identifier	alphanumeric sequences + "/" (slash), "-" (hyphen) , "_" (underscore)	no	character	
Country_code	Two letter abbreviation of the country (ISO 3166-1 alpha-2)	https://vocab.nerc.ac.uk/collection/C32/current/	yes	character	BE
Rivername	Name of the river		yes	character	Scheldt
Riverbank_Section_ID	ID of the riverbank section		no	character	
Lat_Min	Latitude of the survey starting point (Degree.Decimal Degree of latitude) WGS84 reference system preferred	[-90.0, +90.0]	yes	decimal	
Lat_Max	Latitude of the survey ending point	[-90.0, +90.0]	yes	decimal	
Lon_Min	Longitude of the survey starting point (Degree.Decimal Degree of longitude) WGS84 reference system preferred	[-180.0, +180.0]	yes	decimal	
Lon_Max	Longitude of the survey ending point	[-180.0, +180.0]	yes	decimal	
Observation_Length	Length of the riverbank section observed in metres	Positive number	no	integer	200
Observation_Width	Width of the riverbank section observed in metres	Positive number	no	integer	20
EPSG_code	EPSG Geodetic Parameter Dataset is a spatial reference systems, Earth ellipsoids, coordinate transformations and related units of measurement		yes	character	WGW84
DateTimeStart	Start time of observation (Date format ISO 8601)	yyyy-mm-dd + hh:mm	yes	Date time	2024-08-22 12:00

Table 6: Datasets collected during drone operations (continued).

DateTimeStop	End time of observation (Date format ISO 8601)	yyyy-mm-dd + hh:mm	yes	Date time	2024-08-22 13:00
FrameRate	Number of images/time unit (#/minute)	Positive number	no	integer	
Drone_Speed	Speed of the drone (m/s)	Positive number	no	km/h	
%_FrontalOverlap		Positive number	no	integer	
%_SideOverlap		Positive number	no	integer	
GSD	Dimensions of a single pixel in an image, unit is cm/px	0.01 cm/px < GSD < 2.50cm/px	yes	decimal	2.36
Min_Obs_Height	Min relative height difference between the drone and riverbank in meters	Positive number greater then 10 m	no	integer	
Max_Obs_Height	Max relative hight difference between the drone and riverbank in meters	Positive number less than 120 m	no	integer	
Drone_Platform	Description of the drone used		no	character	
Camera Sensor	Description of the camera sensor used		no	character	
%_Plastic_Coverage		Positive number	no	decimal	
No_Items(2.5-5cm)		Positive number	no	integer	
No_Items(5-10cm)		Positive number	no	integer	
No_Items(10-20cm)		Positive number	no	integer	
No_Items(20-30cm)		Positive number	no	integer	
No_Items(30-50cm)		Positive number	no	integer	
No_Items(>50cm)		Positive number	no	integer	

The data collection table will also serve to record the number of litter items, categorized according to the 180-item classification from the Joint List of Litter Categories for Marine Macro Litter Monitoring (J-List), developed by Joint Research Centre (JRC) (Fleet et al., 2021). Furthermore, additional environmental parameters will be obtained from nearby weather stations, as detailed in Table 7.

Table 7: Environmental parameters obtained from weather stations.

Parameter	Description	Admitted values	Mandatory	Unit	Example
Wind speed	The speed of wind obtained from nearby weather station	Positive number	yes	km/h	6
Wind direction	Prevailing winds (from North)	N, NE, E, SE, S, SW, W, NW	yes	/	NE
Precipitation			no	mm	
Solar irradiance			no	W/m^2	

2.3. Drone deployment locations and observation frequencies

In the INSPIRE project, aerial drone observations are being carried out at three demonstration sites: the Scheldt, the Rhine, and the Po. Aerial drone observations will be conducted at all three locations. The particular effects of drone flight altitude and the utilization of different cameras on litter mapping will be investigated at the Scheldt demonstration site. This site was chosen due to the unique observational challenges posed by its dense riverbank vegetation.

2.3.1. Temse (The Scheldt river)

The Scheldt river has a length of 435 km, flowing through northern France, western Belgium, and the south-western Netherlands before finally flowing into the North Sea. As part of the INSPIRE project, observation activities are being conducted in the town of Temse in East Flanders, Belgium. Riverbank observations will be performed along the riverbanks of the Scheldt, in the areas highlighted in the satellite image shown in Figure 5.

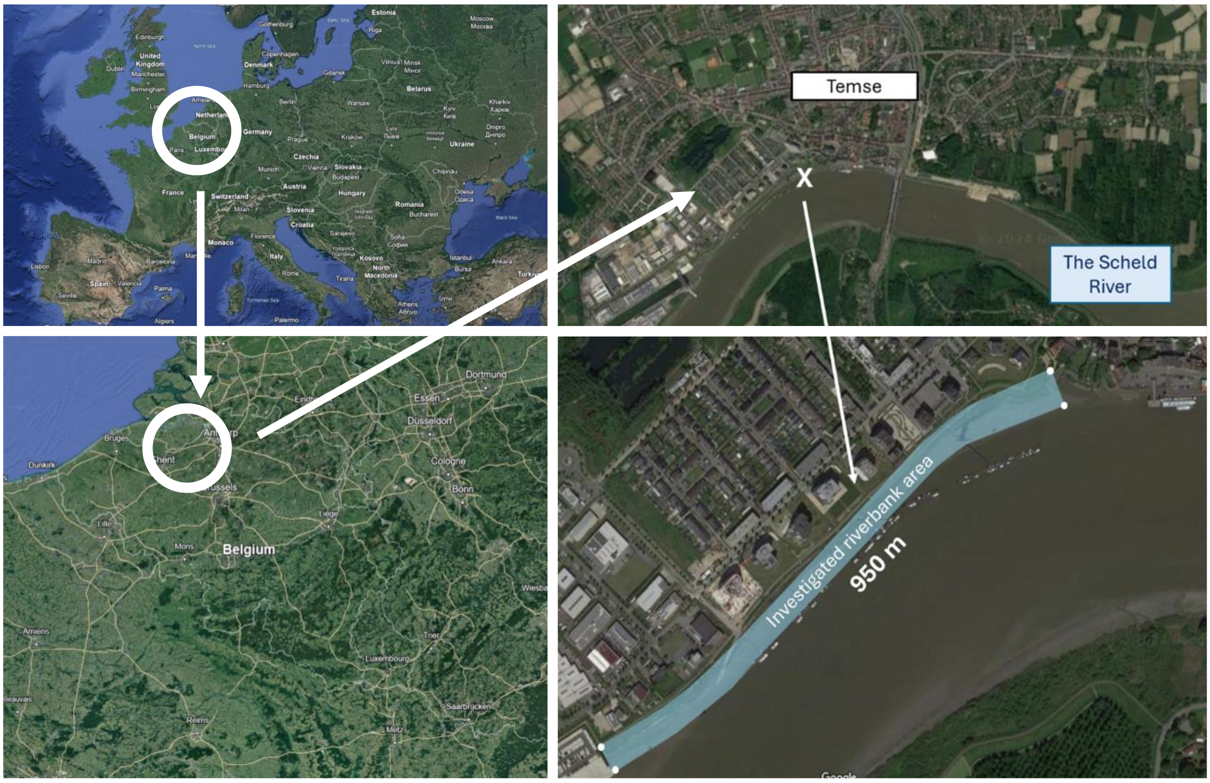


Figure 5: Location of the Temse riverbank (top left: map of the EU, bottom left: map of Belgium, top right: Temse municipality within Belgium, bottom right: detailed satellite image of the riverbank).

The selected location on the riverbank is relatively flat and overgrown with grass, although smaller rocks are also common in some areas near the waterline. Some parts are overgrown with large and lush vegetation, which can cover large parts of riverbank. Figure 6 shows the riverbank conditions in two different sections of the investigated area.

Figure 6: The Scheldt riverbank in Temse (photograph by Mariana Miranda).

No additional geographical limitations are defined for this location (Geocortex, 2024), thus drone flights comply with the basic operating limitations, as defined in Easy Access Rules for Unmanned Aircraft Systems by EASA (EASA, 2021).

The environmental parameters will be obtained from nearby weather (red) and hydro stations (blue), as illustrated in Figure 7.

Figure 7: Location of weather (red circle) and hydro (blue circle) stations for Temse demo site (marked with blue).

Additional information regarding specific names, coordinates, and websites of each station is presented in Table 8.

Table 8: Weather and hydro station information for the Temse demo site.

Station type	Station name	Coordinates	Website
Weather station	ITEMSE26	51.1270, 4.1969	https://www.wunderground.com
Hydro station	Temse tij/Zeeschelde	51.1227, 4.2184	https://waterinfo.vlaanderen.be

2.3.2. Frequency of drone flight for drone optimisation

Given that drone observations are conducted along riverbanks that are significantly affected by the tidal cycle, tidal information for the corresponding rivers is essential. The width of the riverbank is directly influenced by the tidal cycle. The requisite tidal information for the rivers will be obtained from the nearby hydrological stations delineated in Table 8. It is imperative that drone flights are conducted only under clear weather conditions, in the absence of precipitation or winds exceeding 10 m/s.

The assessment of aerial drone flight altitude will follow the deployment plan of riverbank drone observations, as defined in T1.3. Drone flights will be conducted before and after manual clean-up activities, or prior to observation activities with smartphones on the selected riverbank. In order to assess the optimal altitude for drone flights, only those conducted prior to the manual monitoring activities utilising the EEA Marine LitterWatch or JRC Floating Litter Monitoring application will be considered. Four drone flights will be conducted over the course of one year, commencing in June 2024, with one flight scheduled for each season:

1. Winter (December – February);
2. Spring (March – May);
3. Summer (June – August);
4. Autum (September – November).

Exact dates for the drone flight observations will be determined by VITO and VLIZ, the local demo case leaders, and by RCU, the partner responsible for conducting manual clean-up and observation activities. Table 9 provides an overview of the drone flight schedule for the Temse demo site.

Table 9: Overview of drone observation of riverbanks.

	Temse (The Scheldt)
Country	Belgium
Demo site leader	VITO, VLIZ
Drone flight frequency	Four times once every season starting in June 2024. 1. Summer 2024 (06.06.2024); Flights conducted with Zenmuse P1 at 12 m, 20 m and 50 m.
Drone flights	VITO (in collaboration with local drone operators)

2.4. Benchmarking and performance optimisation

This section outlines the data that will be collected during aerial drone observations, which will be used for optimizing the performance of aerial drone operations and the AI algorithm for litter detection. The collected parameters are shown in Table 10. To optimize the operation of aerial drones, the optimal flight altitude will be determined based on the results of the AI litter detection algorithm. This analysis will utilize all aerial images captured during aerial drone observations at various altitudes and camera specifications along the Temse riverbank locations.

Table 10: Parameters considered during drone optimisation.

Parameter	Unit
Flight altitude	m
% overlap	%
Battery usage	%
Speed	m/s
Operation time	hh:mm
Length of mission	m
Image interval	s
Area covered in one flight	m^2
Total number of images	number
Number of flights to cover the total area	number
Total size of raw uploaded pictures	Mb

To determine optimal aerial drone flight altitude and camera characteristics, parameters listed in Table 10 should be considered in conjunction with results obtained from the AI litter detection algorithm. Additionally, environmental considerations which will be incorporated in the assessment are:

a. Cloudy and rain conditions, which could result in images of reduced quality (Kaur et al., 2023);
b. Windy conditions, which could lead to increased power consumption during drone flights (Beigi et al., 2022).

The AI image litter identification technology, developed by VITO, will be assessed in a closed loop with T4.4, where a digital tool will be developed to benchmark its performance in terms of accuracy, sensitivity, specificity, Positive Predictive Value (PPV) and Negative Predictive Value (NPV) (Shakya, 2020). Additionally, the assessment will consider the robustness of the technology, defined as the ability of an AI system to maintain its performance when faced with a variety of inputs, including those it has not seen before, and under different conditions, such as noise.

It is important to note that AI technology image processing is a highly energy-consuming process. Therefore, it is essential to optimise its routines to reduce the energy demand for computation activities. The following parameters of AI technology will be observed with the assistance of the digital tool developed by T4.4 for AI assessment:

1. **Performance parameters:**
    a. Accuracy;
    b. Sensitivity;
    c. Specificity;
    d. Positive Predictive Value (PPV);
    e. Negative Predictive Value (NPV);
    f. Energy Consumption.
2. **Robustness**

The AI performance of the applied algorithms for litter detection of both camera sensors (Zenmuse P1 and Phase One) will be analysed and benchmarked.

2.5. Data collection sheet

Data from the Temse demo site for aerial drone observations will be collected by partners in the following datasheets, based on methodologies and procedures presented in the preceding sections and shown in Table 11. Data will be collected for each drone flight separately. This datasheet will be digitized, allowing demo site data to be streamed to the INSPIRE repository in accordance with activities of dataset collection from demo sites in T4.4, and with data storage requirements in T7.3.

Table 11: Data collection sheet for aerial drone observations for macro-litter on riverbanks.

	Parameter	Unit
Location information	Country code	/
	Rivername	/
	Minimal latitude of the survey point	degree
	Maximal latitude of the survey point	degree
	Minimal longitude of the survey point	degree

	Minimal longitude of the survey point	degree
	Wind speed	km/h
	Wind direction	/
	Solar irradiance	W/m^2
	EPSG code	/
Drone observations	Start of observation	YYYY-MM-DD + HH:MM
	End of observation	YYYY-MM-DD + HH:MM
	GSD	cm/px
	Flight altitude	m
	% overlap	%
	Battery usage	%
	Speed	m/s
	Length of mission	m
	Image interval	s
	Area covered in one flight	m^2
	Total number of images	/
	Number of flights to cover the total area	/
	Total size of raw uploaded pictures	Mb
AI performance	Accuracy	%
	Sensitivity	%
	Specificity	%
	PPV	%
	NPV	%
	Energy consumption	W

2.6. Conclusion

Through the use of aerial drones, INSPIRE aims to demonstrate effective, scalable, and automated methods to assess the accumulation of macro-litter along riverbanks. This section provides a framework for extensive data collection to guide future observation efforts, with a primary focus on aerial drones for capturing high-resolution images of riverbanks.

The drone flights will be meticulously scheduled to align with optimal environmental conditions, such as low wind speeds and clear skies, to ensure that the drones can capture high-quality data. A range of operational parameters will be collected during each flight, including flight altitude, drone speed, and image overlap, which are essential for optimizing the data for later AI-based analysis. The environmental conditions will also be recorded, with data on solar irradiation, wind speed, and precipitation obtained from nearby weather and hydro stations. These parameters will be essential to adjust drone operations to local conditions, such as the tidal cycles of the Scheldt River in Belgium, which directly influence the width and accessibility of riverbanks during flights.

The timeline of these activities depends heavily on scheduled clean-up activities taking place at the demo sites, where drone flights and clean-up plans will be merged as part of T1.3, with riverbank cleanups planned to be organized 4 times over a period of 2 years. Data collected from the demo sites will provide valuable insights into the most effective strategies for detecting and quantifying plastic pollution, allowing for the refinement of drone technologies.

3. Bridge-mounted AI cameras for observation of floating macro-litter in the water surface layer

It is estimated that the upper pelagic layer of rivers is the primary compartment where litter tends to accumulate (Van Emmerik et al., 2019). Floating litter items are transported through the river system until eventually ending up in the sea. Research has demonstrated a strong correlation between floating plastic items transport and river discharge (van Emmerik, De Lange, et al., 2022). It is also important to consider that the majority of plastics that enters the environment do not ultimately reach the ocean. In this manner, riverine systems function as reservoirs for plastic materials (Van Emmerik, Mellink, et al., 2022).

The quantification of plastic movement within river systems is achieved through the utilisation of a range of techniques. One common approach is visual observation of litter on the water surface (González-Fernández & Hanke, 2017) or the collection of floating or submerged litter items using trawling nets (Kiessling et al., 2021). Although these conventional techniques offer insights at the local scale, they are labour-intensive, necessitate the use of specific sampling equipment, and are not suited to long-term, widespread implementation (van Lieshout et al., 2020).

An alternative to these traditional monitoring methods is the utilization of camera technology, which allows for continuous observations of floating litter items. Video cameras are particularly advantageous due to their relatively low cost and ease of installation (Armitage et al., 2022). Studies have shown that camera-based observation methods are more effective than traditional observer-based approaches in detecting marine macro-litter on ocean surface (Garcia-Garin et al., 2020). Although cameras have been extensively used for marine litter observations, their application for riverine litter is less prevalent. However, the effectiveness of photographic methods for observation and quantification of plastic pollution is significantly influenced by environmental factors such as wind speed and cloud coverage (Armitage et al., 2022). Aerial photography is challenging in river environments due to the need for high temporal resolution.

The transport of macro-litter can be successfully quantified by observing the river surface with digital cameras and applying image processing techniques to differentiate floating macro-litter items. Such AI algorithms can identify and potentially classify litter items with high accuracy (Anggraini et al., 2024). This process eliminates the need for time-consuming visual observation and classification of litter items.

Under INSPIRE, two automated observation systems will be deployed. These systems involve different camera technologies mounted on bridges, the function of which is to monitor the presence of floating macro-litter on the water surface. The operation of these camera systems will be centrally managed and analysed through D4.1, which will serve as the primary data collection point. The data obtained from the camera system and AI algorithms will permit a comparative analysis of the plastic fluxes captured by each system, thus providing a basis for benchmarking their performance and establishing best practices for future observation efforts.

The structure of this chapter on bridge-mounted AI cameras is as follows: Section 3.1 outlines the methodology, which describes the type of parameters that would be gathered during the operation of the camera systems. Section 3.2 provides an overview of the used camera technologies. Section 3.3 provides information of the deployment locations. Lastly, section 3.4 provides an overview of the parameters that will be employed in the benchmarking of the camera system, thus establishing the foundation for the subsequent benchmarking of the AI algorithm.

The impact pathway specified by this case study relates to the relation between the technology, the use case, the activities of data collection from the monitoring and AI system, and the expected outputs. Figure 8 shows a brief overview of the defined impact pathway, which is the purpose of this section in D4.1.

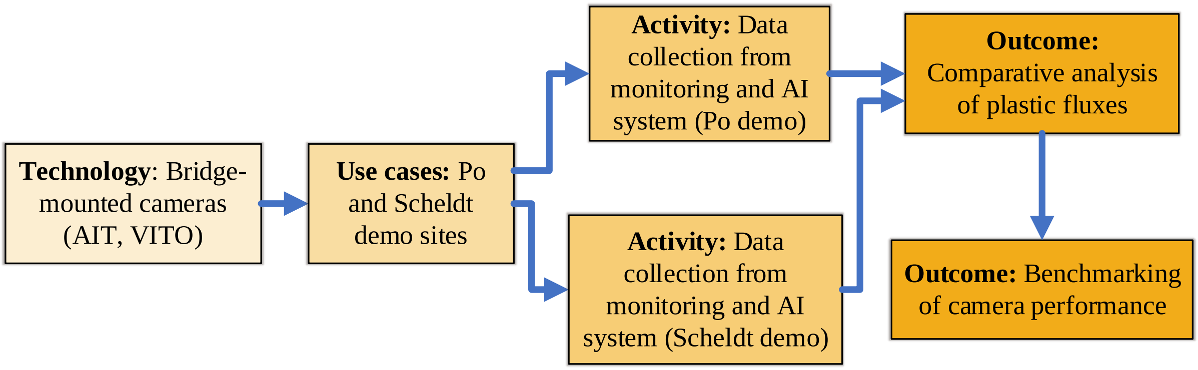


Figure 8: Impact pathway for the case of bridge-mounted AI cameras.

3.1. Methodology

This section describes the methodology that will be employed for the assessment of the bridge-mounted AI cameras. The following parameters, classified into three categories, will be considered:

1. **Technical parameters** include the technical specifications of the two RBG cameras;
2. **Operational parameters** include**:**
   a. Camera operational parameters such as mounting angles and frame rate (aligned with T1.3);
   b. AI algorithm operational parameters such as the energy consumption of the AI model and image resolution.
3. **Environmental parameters** include environmental conditions during the drone observations. Key environmental parameters, such as light radiation, wind speed and directions as well as precipitation information will be gathered from nearby weather stations.

In D4.1, data collected from bridge-mounted cameras will be employed to evaluate the performance of two camera systems and to establish a foundation for the benchmarking of AI classification algorithms, as outlined in T4.4.

3.2. Monitoring of floating macro-litter in the water surface layer

Under WP1, T1.3, the monitoring of floating macro-litter in the water surface layer will be conducted using a combination of automated and human-based visual observations. The former will be facilitated by the deployment of cameras, in conjunction with the JRC Floating Litter Monitoring App, provided by UCA. The automated monitoring system will initially be calibrated through catch-release experiments, described in detail in D2.1. The automatic system output will be the number of floating litter items or plastic flux in the observed area. This will be validated by comparing results with the plastic flux recorded during visual observations of floating macro-litter using the JRC Floating Litter Monitoring App on the same bridges.

The camera setup and visual monitoring activities will be conducted in accordance with the guidelines specified in D1.2. In D4.1, operational, environmental, and technical data will be collected during the deployment of the bridge-mounted AI camera system for the purpose of comparison and benchmarking.

This section includes the following components: Section 3.2.1 details the two bridge-mounted cameras system, while Section 3.2.2 outlines the parameters that will be collected during the operation of bridge-mounted camera systems.

3.2.1. Equipment

The detection and monitoring of floating macro-litter items in the water surface layer are part of T1.3 of WP1, which is led by VITO. As outlined in D1.2, the INSPIRE project utilizes two different operational camera setups:

1. A stand-alone set-up. All cameras work as individual stations, relying on batteries and solar panels for power. A 4G/LTE WiFi dongle is included for each camera unit to provide internet connection. The camera used in this set-up is the pLitterCCTV camera provided by AIT (see Figure 9). This stand-alone system is powered by a deep learning-based object detection model and enables the detection and monitoring of plastic flux in rivers and canals. The system can distinguish between six different classes of litter, four of which are specifically related to plastic categories: general plastic, polystyrene, plastic bottles, and rubbish bags. The remaining two categories are composed of non-plastic items: glass bottles and other types of litter.
2. A connected set-up. In this configuration, each camera is connected using an ethernet cable to a network PoE (Power over Ethernet) switch, which provides both power and network connection towards a network video recorder. The recordings are uploaded to the processing facility via an internet connection. The camera used is the RLC-1212a camera with a 4 mm lens (see Figure 9). The images are post-processed on VITO servers, where AI algorithms are applied to (i) detect plastics in individual images, and (ii) calculate the plastic flux by avoiding double counting of same objects identified in multiple images. The camera specifications are provided in Table 12.

Figure 9: Camera systems used within INSPIRE: RBG RLC-1212a 4 mm camera (left) and pLitterCCTV unit with housing mounted on a bridge (right).

Table 12: Technical specifications of the RLC-1212a 4 mm camera and the pLitter CCTV.

Parameter	RLC-1212a 4mm	pLitterCCTV
Field of View (deg)	93	5-60
Focal Length (mm)	4	5-50
Sensor size	8.43	10.16
# Pixels (width)	4512	3840
# Pixels (height)	2512	2160

Table 13 presents the GSD obtained and the total number of cameras required to cover the entire cross-section of a river of 100 m wide river, with the cameras positioned 10 m above the water level.

Table 13: Example illustrating the number of cameras needed to cover the full cross-section of a 100 m wide river, and the resulting GSD when the cameras are placed 10 m above water level.

Parameter	RLC-1212a 4mm	pLitterCCTV
Swath [deg]	21	19.5
GSD [cm/px]	4.7	5.1
# Cameras	5	6

3.2.2. Parameters retrieved during camera systems operation

During the operation of the two camera systems, the parameters listed in Table 14 will be collected, as specified in T1.3. The table provides a framework for data collection with a focus on observation parameters. It includes a unique sample identifier and the ISO 3166-1 alpha-2 country code to catalogue each survey accurately. The table records the river name and section ID, along with precise geographic coordinates (latitude and longitude) using the WGS84 reference system to pinpoint the survey's start and end points. Observational data include start and end times for flux rate calculations, imaging frequency in terms of number of images per minute, and water level measurements in meters. The table also captures the minimum relative height difference between the observer (whether a person, camera, or drone) and the water level or riverbank, which is crucial for accurate measurements.

The data collection table will also record the number of litter items, categorized according to the 180-item classification from the Joint List of Litter Categories for Marine Macro Litter Monitoring (J-List), developed by JRC (Fleet et al., 2021).

Table 14: Datasets collected during camera operations.

Parameter	Description	Admitted values	Mandatory	Unit	Example
Sample_UID	Sample Unique Identifier			character	
Country_code	ISO 3166-1 alpha-2	https://vocab.nerc.ac.uk/ collection/C32/current/	yes	character	BE
Rivername	Name of the river		yes	character	Scheldt
Riverbank_Section_ID	ID of the river section			character	
Lat_Min	Latitude of the survey starting point (Degree.Decimal Degree of latitude) WGS84 reference system preferred	[-90.0, +90.0]	yes	decimal	
Lat_Max	Latitude of the survey ending point	[-90.0, +90.0]	yes	decimal	
Lon_Min	Longitude of the survey starting point (Degree.Decimal Degree of longitude) WGS84 reference system preferred	[-180.0, +180.0]	yes	decimal	

Table 14: Datasets collected during camera operations (continued).

Lon_Max	Longitude of the survey ending point	[-180.0, +180.0]	yes	decimal	
Monitoring_Length	Survey length in metres	Positive number	yes	integer	
Monitoring_Width	Survey width in metres	Positive number	yes	integer	
EPSG_code	EPSG Geodetic Parameter Dataset is a spatial reference system, Earth ellipsoids, coordinate transformations and related units of measurement		yes	character	WGS84
DateTimeStart	Start time of observation to calculate flux rate	http://vocab.nerc.ac.uk/collection/P01/current/STRT8601/	yes	date time	2024-08-22 12:00
DateTimeStop	End time of observation to calculate flux rate	http://vocab.nerc.ac.uk/collection/P01/current/ENDX8601/	yes	date time	2024-08-22 13:00
FrameRate	Number of image/time unit (#/minute)	Positive number	yes	integer	
Water_level	Water level (m)	Positive number	no	decimal	
Min_Obs_Height	Min relative hight difference between the observer (person, camera or drone) and the water level/riverbank	Positive number	no	decimal	
Max_Obs_Height	Min relative hight difference between the observer (person, camera or drone) and the water level/riverbank	Positive number	no	decimal	
Instr_Type			no	character	
No_Instr	Number of instruments used to calculate the plastic flux in this section	Positive number	no	integer	
Instr1_ID			no		

Table 14: Datasets collected during camera operations (continued).

Instr2_ID			no		
Instr3_ID			no		
Instr4_ID			no		
Instr5_ID			no		
View_Zenith_Angle	Angle between the line of sight and the zenith	Positive number	no	integer	
View_Azumith_Angle	Angle between the line of sight and due North	Positive number (from 0° to 270°)	no	integer	
Dist_Instr_Min	Min distance between two neighbouring instruments		no	decimal	
Dist_Instr_Max	Max distance between the two neighbouring instruments		no	decimal	
Flow_Rate	Flow rate of water derived from camera information, expressed in m/s		no	decimal	
No_Items(2.5-5cm)			no		
No_Items(5-10cm)			no		
No_Items(10-20cm)			no		
No_Items(20-30cm)			no		
No_Items(30-50cm)			no		
No_Items(>50cm)			no		

Additional environmental parameters, detailed in Table 15, will be obtained from nearby weather stations.

Table 15: Environmental parameters obtained from weather stations.

Parameter	Description	Admitted values	Mandatory	Unit	Example
Wind speed	The speed of wind obtained from nearby weather station	Positive number	yes	km/h	6
Wind direction	Prevailing winds (from north)	N, NE, E, SE, S, SW, W, NW	yes	/	NE
Precipitation			no	mm	
Solar irradiance			no	W/m^2	

3.3. Bridge-mounted AI camera deployment locations

In the INSPIRE project, automated observations using camera systems will be conducted at two demonstration sites: the Scheldt and the Po River. The pLitterCCT camera system, provided by AIT, will be deployed exclusively at the Po River site, while the RLC-1212a camera system, provided by VITO, will operate at both the Scheldt and Po River sites. This section details the locations of the demonstration sites and the deployment of bridge-mounted cameras.

3.3.1. The Scheldt river

The VITO camera system will be deployed in Temse, a small town in East Flanders, Belgium. A set of RLC-1212a cameras will be installed across the Temse Bridge System, which connects Bornem with Temse. The Temse Bridge System consists of two parallel bridges: the Old Scheldt Bridge (right) and the New Scheldt Bridge (left), which are 10 m apart, as shown in Figure 10.

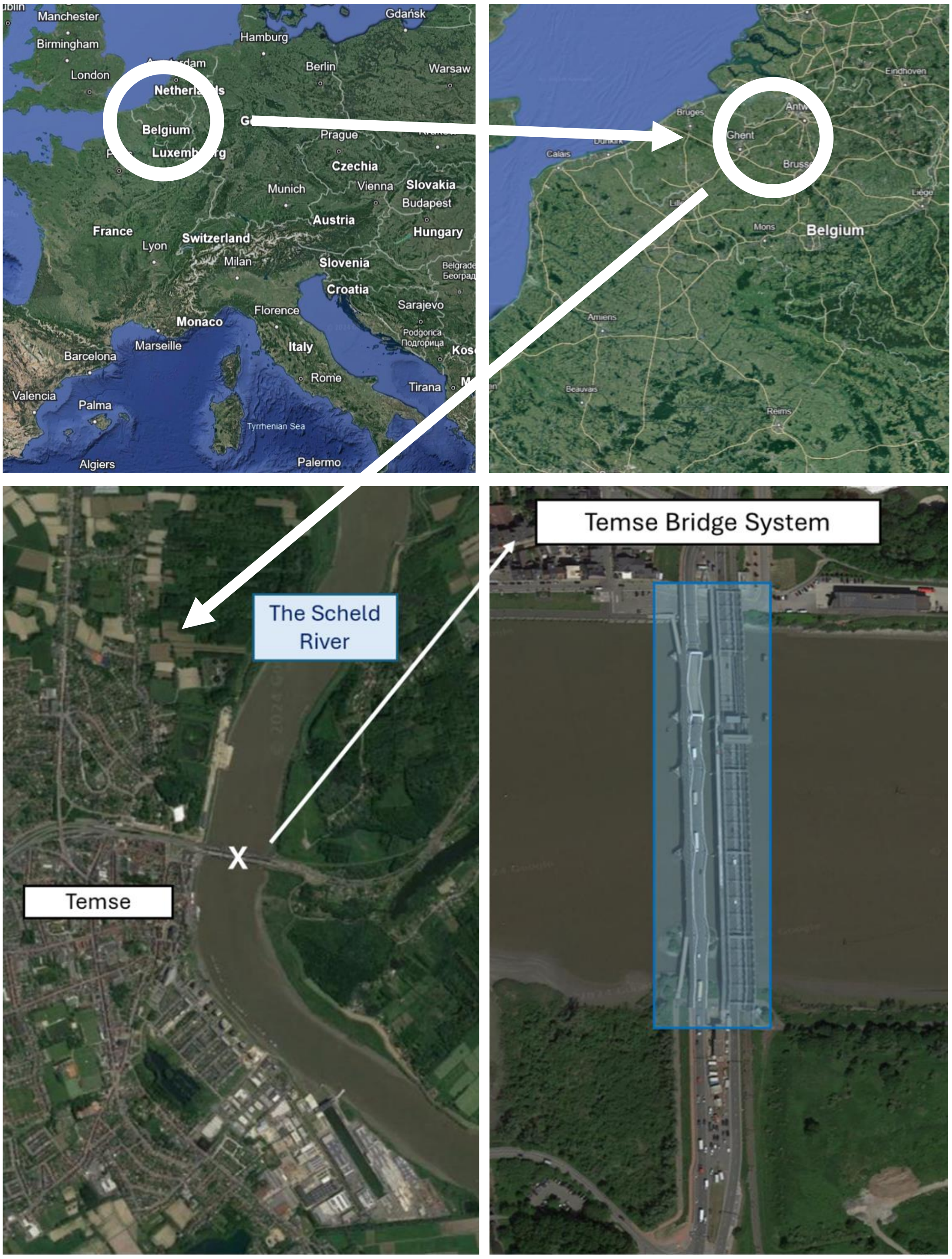


Figure 10: Location of the Temse Bridge system (top left: map of the EU, top right: map of Belgium, bottom left: Temse municipality within Belgium, bottom right: Temse Bridge system).

VITO's camera system will be mounted in-between the two bridges on the New Scheldt Bridge, a 374 m long double bascule bridge, showcased in Figure 11. The bridge is designed to permit the passage of vessels on the river by opening its gates at the northern end, allowing vessels to travel upstream or downstream. The robust tidal system of the Scheldt river results in a variation in the distance between the bridge and the water surface, dependent on the tidal cycle.

Figure 11: The New Temse Bridge (photographs provided by Mariana Miranda).

The bridge is divided into two principal sections, designated as the south and north sections, represented by the letters S and N, respectively. Each main section is further subdivided, with the north section comprising two subsections and the south section comprising six subsections. The aforementioned subsections are in alignment with the locations of the bridge's supporting pillars. Figure 12 illustrates the subsections for the Temse bridge, while Table 16 provides an overview of the number of cameras at each subsection.

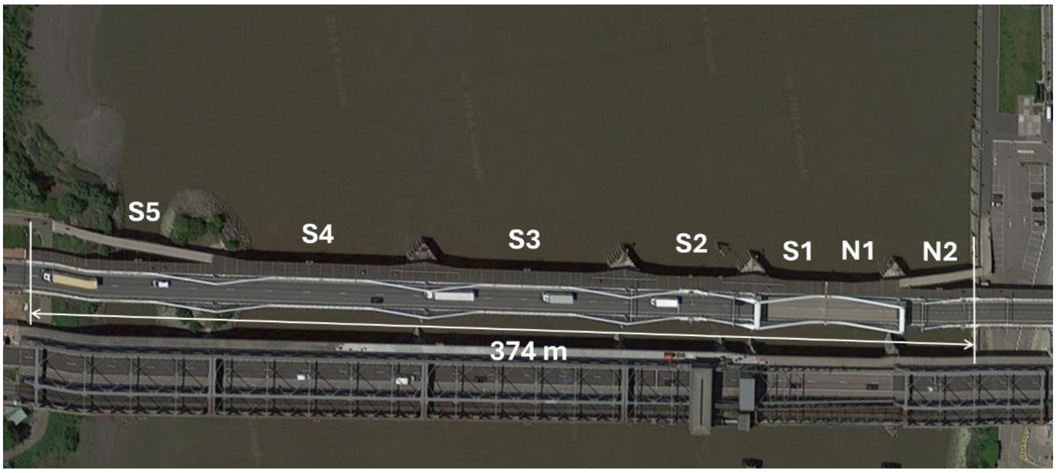


Figure 12: RCL-1212a camera locations on the New Temse bridge.

Table 16: Number of cameras at each bridge sub-location.

Bridge location	Number of cameras
N2	3
N1	2
S1	1
S2	3
S3	6
S4	5
S5	1
TOTAL	**21**

In total, 21 RLC-1212a cameras will be mounted on the New Temse Bridge. For the environmental parameters, data from the nearby weather and hydro stations will be used, as defined in Figure 7 and Table 8.

3.3.2. The Po River

The second demonstration site is the Po, a river with a length of 652 km that flows through northern Italy before flowing into the Adriatic Sea. The Po Delta Donzella River, one of the seven branches of the Po, was selected as the demonstration site for both camera systems. Two different bridges have been selected for the automatic observation of floating macro-litter in the water surface layer, as illustrated in Figure 13.

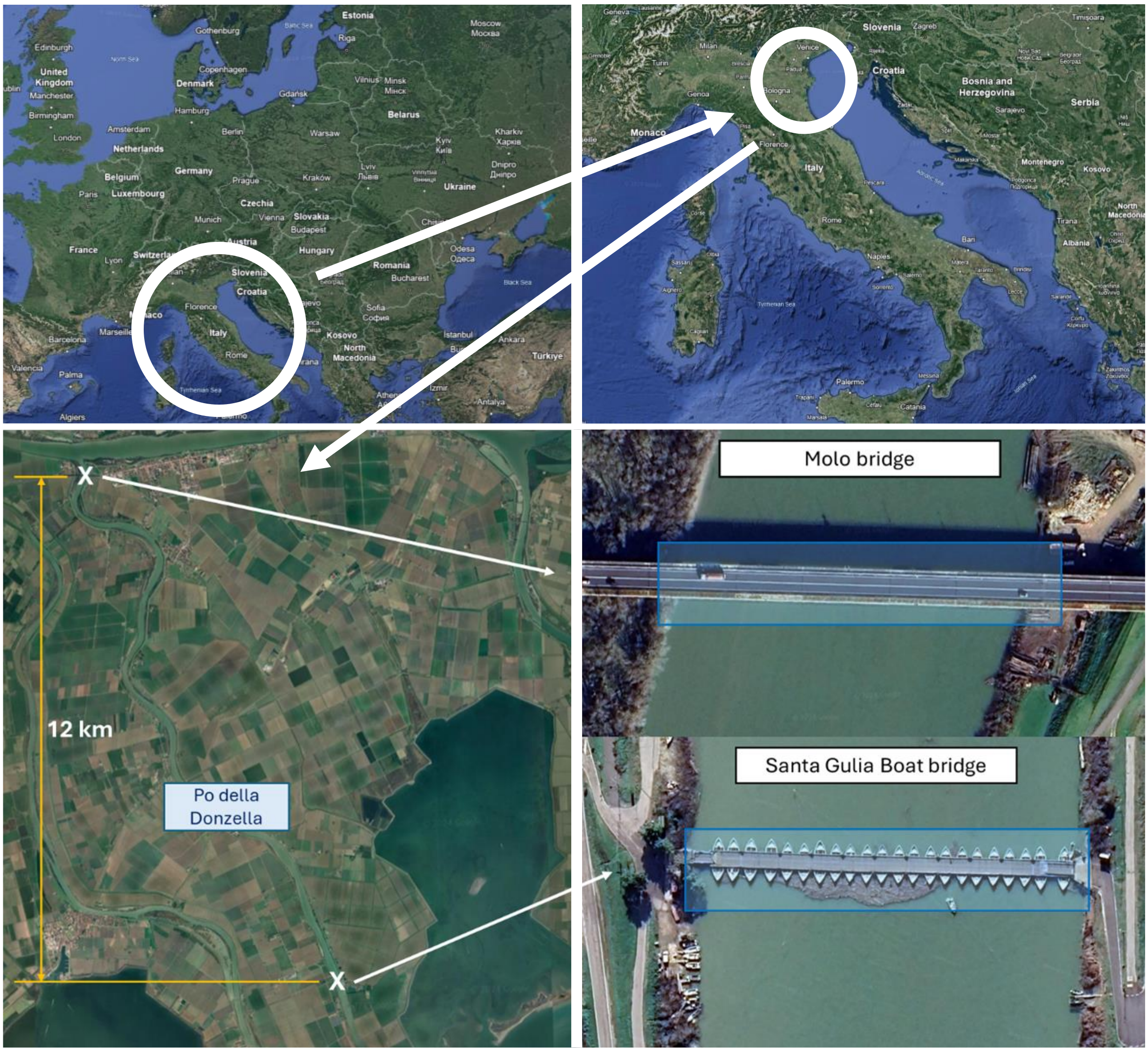


Figure 13: Italy demo site locations (top left: map of the EU, top right: map of Italy, bottom left: Po della Donzella river branch in Italy, bottom right: Location of the Molo bridge and Santa Gulia Boat bridge).

The pLitter camera system developed by AIT will be used on the nearby pontoon bridge, shown in Figure 14. This bridge is supported by 22 large boats that are connected to each other and anchored firmly in the riverbed. The bridge system is constructed from wood and extends approximately 160 m, facilitating a connection between the right and left banks of the Po della Donzella River. Furthermore, the bridge is equipped with a central opening mechanism, which is utilised for the clearance of accumulated tree branches and other debris.

Figure 14: Santa Gulia boat bridge.

The RLC-1212a system will be deployed on the Molo Bridge, located just before the main Po River splits into the Po della Donzella. It is a standard bridge, spanning approximately 170 m, and connects the island of Isola della Donzella with the mainland, as seen in Figure 15. The camera configuration on both bridges is being finalized as of September 2024.

Figure 15: Molo bridge.

The environmental parameters will be gathered from nearby weather (red) and hydro stations (blue), as seen in Figure 16.

Figure 16: Locations of weather (red circle) and hydro (blue circle) stations for Po demo site in comparison to both bridge locations, marked with an X.

Additional information on specific names, coordinates, and websites for all stations is presented in Table 17.

Table 17: Weather and hydro stations for Po demo site, Italy.

Station type	Station name	Coordinates	Website
Weather station	Pradon CMT	Lat 44.91734 Lng 12.3691	https://www.agenziaitaliameteo.it
Weather station	Vnt428	Lat 44.84931, Lng 12.35367	https://www.agenziaitaliameteo.it
Hydro station	Po, Porto Barricata	Lat 44.8471, Lng 12.4642	https://waterinfo.vlaanderen.be

3.4. Camera benchmarking

Once all the necessary operating data has been collected from both VITO's and AIT's camera observation technologies, benchmarking will be carried out. This benchmarking will identify the functionalities and potential advantages and disadvantages of the utilized camera systems. This will help decision makers to select the most appropriate observation technology for the detection of floating macro-litter items on the water surface. By comparing these technologies, insights will be gained into their effectiveness in specific scenarios. Comparisons will be made between the various environments and the types of litter items found in order to determine the optimal solution for each specific case.

The two camera systems will be evaluated based on the plastic flux, which their AI algorithms are capable of identifying from the images captured by the bridge-mounted cameras. Additionally, the comparison of the pLitterCCTV and RCL-1212a camera systems will encompass the parameters delineated in Table 18. Both AI algorithms will be benchmarked as part of T4.4.

Table 18: Description of additional parameters for system comparison.

Energy consumption	Data regarding energy consumption of the cameras will be collected to assess their power requirements and operational efficiency over time. This includes measuring power consumption during active detection periods as well as in standby mode.
Operation time	The duration for which the cameras remain operational will be recorded to evaluate their reliability and endurance in real-world conditions. This includes tracking the total uptime of the cameras as well as any instances of downtime or malfunctions.
Environmental conditions	Environmental factors such as temperature, humidity, and weather conditions will be recorded. These parameters can impact the performance and longevity of the cameras, providing valuable insights into their resilience and adaptability.
Data transmission	Information related to data transmission rates and protocols will be gathered to assess the efficiency of communication between the cameras and central observation systems. This includes measuring data transfer speeds, packet loss rates, and network stability.
Image quality	The quality and clarity of images captured by the cameras will be evaluated through telemetric analysis. This includes assessing parameters such as resolution, sharpness, and colour accuracy to ensure optimal performance in detecting and classifying macro-litter items.
System diagnostics	Parameters such as internal temperature, CPU usage, and memory utilization are part of system diagnostics. This information enables proactive maintenance and troubleshooting to address potential issues before they impact operational efficiency.
Camera orientation and alignment	Data regarding the orientation and alignment of the cameras will be collected to ensure proper coverage and visibility of the monitored area. This includes tracking pan, tilt, and zoom parameters to optimize detection capabilities.

3.5. Data collection sheet

Data from the Temse and Po demo site for bridge-mounted camera observations will be collected by partners in the following datasheets, based on methodologies and procedures presented in the preceding sections and shown in Table 19. Data will be collected for each camera system separately. This datasheet will be digitized, allowing demo site data to be streamed to the INSPIRE repository in accordance with activities of dataset collection from demo sites in T4.4, and with data storage requirements in T7.3.

Table 19: Data collection sheet for bridge-mounted camera observations of floating macro-litter in the water surface layer.

	Parameter	Unit
Location information	Country code	/
	River name	/
	Minimal latitude of the survey point	degree
	Maximal latitude of the survey point	degree
	Minimal longitude of the survey point	degree
	Minimal longitude of the survey point	degree
	Wind speed	km/h
	Wind direction	/
	Solar irradiance	W/m^2
	EPSG code	/
	Monitoring length	m
	Monitoring width	m
	Wind speed	km/h
	Wind direction	/
	Solar irradiance	W/m^2
	Precipitation	mm
Bridge-mounted camera	Start of observation	YYYY-MM-DD + HH:MM
	End of observation	YYYY-MM-DD + HH:MM
	Frame rate	#/minute
	Energy consumption	W
	Operation time	HH:MM
	Data transfer speed	Mb/s
	Image resolution	dpi
	Image sharpness	/
	Colour accuracy	%
	Tracking pan	degree
	Camera tilt	degree
	Camera zoom	/

3.6. Conclusion

Through the use of bridge-mounted AI camera systems, INSPIRE aims to demonstrate effective, scalable, and automated methods to assess the accumulation of macro-litter in rivers. This section provides a framework for extensive data collection to guide future observation efforts, with a primary focus AI camera for monitoring floating macro-litter in river surfaces. The bridge-mounted cameras are part of a broader strategy to automate the observation of plastic fluxes within river systems. The application of AI algorithms to images captured by these cameras will facilitate the detection and classification of various types of litter.

4. Floating riverine litter retention technologies

The reduction of accumulated anthropogenic macro-litter (> 2.5 cm) in marine and freshwater environments involves a range of approaches, from traditional cleanup efforts to the implementation of more technologically advanced solutions. Given that manual cleanup activities are labour-intensive, time-consuming, and challenging to sustain continuously at specific locations, researchers have increasingly focused on developing litter remediation technologies that can more effectively collect and remove waste from the environment.

These technologies can be broadly categorized based on whether they are stationary or mobile and whether they rely on external power sources (Leone et al., 2023). A comprehensive plastic retention technologies database has been created, highlighting the key advantages of each technological solution (Helinski et al., 2021). However, not all technologies are equally effective in removing plastic and other litter from every river environment. Therefore, the selection of operational sites is a crucial consideration, as emphasized by Helinski et al. (2021).

A key aspect of the D4.1 report is that it provides guidelines for conducting technology and retained litter assessments. This report will be updated to include both qualitative and quantitative perspectives that will support the achievement of the project objectives. Technology providers are responsible for the accuracy and validity of the data provided. The study provider is not responsible for any statements or conclusions regarding this study that are not stated herein.

As part of INSPIRE project, various types of plastic retention technologies will be evaluated in different environments to assess their effectiveness and behaviour under real environmental conditions. The technologies will be deployed in port and dock areas, characterized by minimal water movement, as well as in river streams. A key goal of the project is to introduce effective retention solutions for riverine litter remediation that can be applied in various contexts. Under INSPIRE's Work Package 2 (WP2), a diverse array of riverine litter retention technologies will be utilized, each with unique characteristics.

The INSPIRE project will evaluate a variety of plastic retention technologies in different environmental settings to assess their performance and behaviour in real-environmental conditions. These technologies will be used both in harbour and dock areas where water movement is minimal and in flowing river systems. A key objective of the project is to introduce effective retention solutions for riverine debris remediation that can be adapted to different contexts. Within WP2, a wide range of riverine debris retention technologies, each with different characteristics, will be implemented for testing and evaluation.

This section focuses on the evaluation of floating litter retention technologies. Section 4.1 outlines the methodology for evaluation of floating riverine litter retention technologies, part of INSPIRE project. Section 4.2 provides a detailed evaluation of the hybrid MOLD/MINDS system, while Section 4.3 covers the evaluation of the Archimedean Drum Screen and Section 4.4 focuses on the CirCleaner. In addition, Section 4.5 presents a general evaluation procedure that can be applied to floating litter retention technologies like those used in INSPIRE, but not directly included in the project.

The impact pathways specified by the case studies in this section relate to the relation between the technology, the use case, the activities of performance analysis, litter classification, and solar energy optimization, as well as the expected outputs. Figure 17 shows a brief overview of the defined impact pathway, which is the purpose of this section in D4.1.

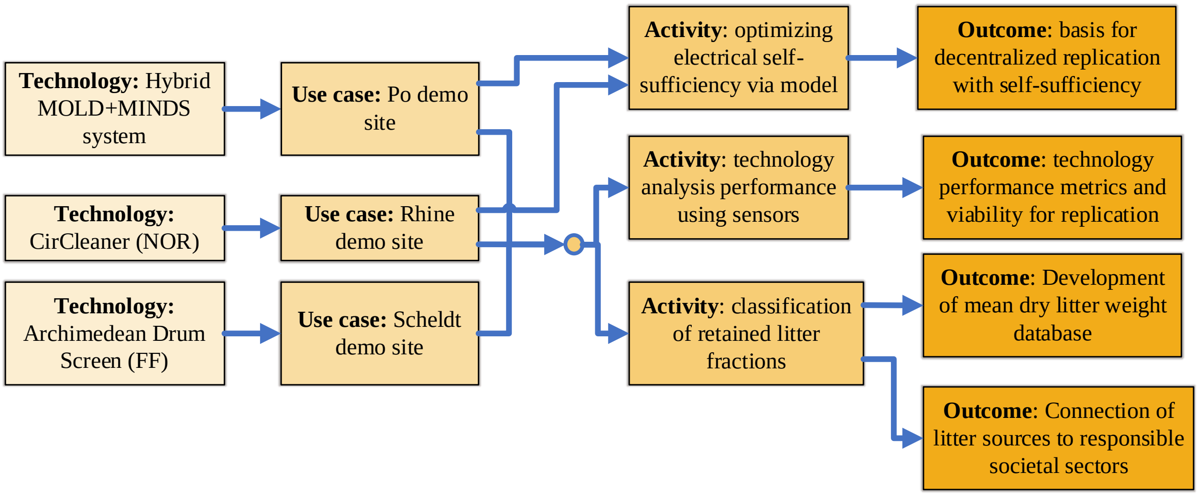


Figure 17: Impact pathway for the cases of floating macro-litter technologies.

4.1. Methodology

This section presents the methodology for evaluation of INSPIRE floating riverine litter retention technologies from the standpoints of:

1. Defining most influential parameters during operations of technologies in real environments;
2. Development of an INSPIRE sensor kit, for gathering the defined parameters;
3. Monitoring of the retained floating riverine litter;
4. The connection of retained floating riverine litter to sourced societal sectors.

The technologies selected to be evaluated as part of INSPIRE T4.1, were three key solutions related to macro-, meso- and microplastic floating riverine litter retention, described in Table 20. The technologies were selected due to their function in retaining riverine litter from two specific environments: (i) ports and docks and (ii) river stream. Additionally, the selection was also influenced by the type of riverine litter that the technologies can retain, categorized as: (i) macro-, (ii) meso-, and (iii) pellets (micro-).

Table 20: INSPIRE floating riverine litter retention technologies.

	Technological solution	Partners involved	WP and Task	Size of retained items	Fraction classification	Suitable environment
1.	Hybrid MOLD/MINDS solution	MOLD, MINDS	WP2, T2.1	>5 mm	Macro-	River stream
2.	Archimedean Drum Screen	FF	WP2, T2.2	>4 mm	Macro- and meso-	Ports and docks
3.	CirCleaner	NOR	WP2, T2.6	1 m – 2 mm	Pellets (micro-)	Ports and docks

The evaluation of hybrid MOLD/MINDS system (WP2, T2.1) is included due to its ability of capturing macro- and meso- floating riverine litter in river streams and its unique capability to operate in remote areas without energy supply. This hybrid technology partially operates in a passive way (River Cleaning buoy technology), while its combination with the collection cage (CLEAN TRASH), has a very low energy demand. The uniqueness of this combination lies in the ability of using environmental conditions for energy production, through the rotation of buoys, using river current. In this way we are proposing a 100 % energy self-sufficient floating riverine litter retention technology, suitable also for decentralized locations. Although the system comprises two distinct technologies, its evaluation will treat the system, rather than assessing the individual components separately.

Additionally, two evaluated technologies embedded in T2.2 and T2.6: (i) Archimedean Drum Screen and (ii) CirCleaner are being tested in suitable environments, like ports and docks, representing harbour conditions, consequently suitable for comparison and further benchmarking under T4.4. One of these technologies is specifically designed for the retention of plastic pellets, due to the high concentration of petrochemical industries in Rotterdam, Europe's largest port. With the significant risk of accidental plastic pellet releases into the surrounding environment, their remediation has become a top priority for the port authorities.

The following subsections describe detailed methodologies, where subsection 4.1.1 delves into the identification of the most influential parameters that would be obtained during the operation of INSPIRE floating riverine litter retained technologies. Subsection 4.1.2 describes the creation of the INSPIRE sensor kit, implemented for the floating riverine litter retention technologies. Subsection 4.1.3 delves into the protocol for conducting the assessment of the retained litter during the operation of the INSPIRE floating riverine litter retention technologies. Subsection 4.1.4, depicts the process of connecting J-List marine macro- litter categories, developed by Joint Research Centre (JRC) with their representative societal sectors, as defined in International Labour Organization (ILO) from the United Nations. Finally, subsection 4.1.5 outlines the multi-criteria model, used for conducting energy optimization of self-sufficient riverine litter retention technologies.

4.1.1. Defining influential parameters during implementation in real environments

To evaluate the performance of technologies in real environmental conditions, testing must be carried out. However, there is currently no standardised method for assessing the performance of machines or technologies designed to collect litter from the environment. In contrast, performance evaluation has been more widely applied to large industrial processes such as biogas plants (Wu et al., 2021) and wastewater treatment plants (Oliveira & von Sperling, 2011).

When testing photovoltaic system, Hemmat Esfe et al. (2023) classified technology parameters into three categories: operational, design and environmental parameters. The INSPIRE project will adopt and refine this classification to meet its specific need. In addition, a new category of biological parameters has also been introduced.

During the operation of INSPIRE floating riverine macro-litter retention technologies from WP2 (T2.1, T2.2 and T2.6), key parameters have been defined for each technological solution, and categorised into four sections:

1. **Technical parameters:** These pertain to the technical specifications of the INSPIRE floating riverine litter retention technologies. They include critical details such as dimensions of

technologies collection systems (cages, nets, and collection compartments) and their respectable mesh sizes. These parameters are necessary to determine the volume of processed water and litter retention capacity.

2. **Operational parameters:** These focus on the operational aspects of the technologies, including information on energy consumption, operation, and maintenance times (starts/stops), noises and vibrations emitted under- and above water, rotations, or other movements.
3. **Environmental parameters:** These factors include environmental conditions surrounding implemented technologies. Key environmental parameters include weather data (e.g., wind speed, wind direction, precipitation, temperature, ...) as well as data regarding the river and sea-river state (current flow, tidal changes, wave dimensions).
4. **Biological parameters:** These parameters focus on aquatic fauna and depicts, the proportion of harmed and not harmed animals, due to the operation of the technologies.

The identified parameters were selected in collaboration with partners: INFOR, NOR, FF, VLIZ, MOLD and MINDS from WP2 (T2.1, T2.2, and T2.6) and through literature review. Based on the classification of litter retention technologies in Helinski et al. (2021), key parameters such as power consumption, maintenance requirements and operating hours were defined. To assess systems fullness, the technologies' ability to retain different quantities and types of litter will also be considered. Additionally, for technologies that use electrical components, noise levels will be measured, as electric motors are often identified as a source of noise (Gonzalez et al., 2023). For the environmental parameters, factors that most significantly influence the movement of litter in rivers will be included.

After collecting the parameters, they will be further stored, processed, and displayed in the INSPIRE repository, developed under WP4, (T4.4: Impact evaluation dashboard) and described under WP7 (T7.3: project Data Management Plan (DMP)).

The identified parameters are distinguished by the frequency of retrieval for different activity scopes:

1. One-time measurements, of technical parameters of INSPIRE floating riverine litter retention technologies, including mechanical, electronic, or dimensional parameters that define the physical specifications.
2. Continuous and periodical measurements of operational and environmental parameters, will be monitored in real time during the implementation period, by:
    a) Internal sensors, which will upgrade existing INSPIRE floating riverine litter retention technologies. The types of sensors implemented at different INSPIRE floating riverine litter retention technologies are proposed in collaboration with INFOR to further feed T4.4 and are described in methodology section under Sections 2.2.
    b) External sensor, obtained from weather and hydro stations, at the respective demo sites, will retrieve real time environmental data. For the unavailable parameters additional sensors can also be applied.

An overview of identified parameters influencing the testing phase of INSPIRE floating riverine litter retention technologies, along with the specified retrieval methods, is provided in Table 21.

Table 21: Overview of parameters, universally applicable for all retention technologies.

Parameter type	Parameter	Retrieval method	Unit	Frequency
Technical	Dimensions of collection system	Manually	mm	One-time
	Mesh size of collection system	Manually	mm	One-time
Operational	Electricity consumption	Sensors (power meters)	kWh	Continuous/semi-continuous
	Renewable electricity production	Sensors (power meters)	kWh	Continuous/semi-continuous
	Working time per day	Manually/automatic	hh:mm	Continuous/semi-continuous
	Maintenance frequency	Manually/automatic	hh:mm	Semi-continuous
	Maintenance duration	Manually/automatic	hh:mm	Semi-continuous
	Retained litter weight (wet)	Manually	Kg	Semi-continuous
	Retained litter volume	Manually	m^3	Semi-continuous
	Retained macroplastic items	Manually	number	Semi-continuous

Table 21: Overview of parameters, universally applicable for all retention technologies (continued).

Operational	Retained macroplastics weight	Manually	kg	Semi-continuous
	Retained meso- and plastic weight	Manually	kg	Semi-continuous
	Retained microplastic weight	Manually	kg	Semi-continuous
	Underwater noise	Hydrophones	dB	One-time
	Above ground noise	Sensor (Sound sensor)	dB	One-time
	Fullness of the collection system	Manually/Sensors (Ultrasonic sensor)	%	Semi-continuous
	Water fill level	Manually	mm	One-time
	Motion and tilt	Sensors (Vibration acceleration sensor)	Degrees	Continuous
Environmental	Air temperature	Weather station	°C	Continuous

	Humidity	Weather station	%	Continuous
	Wind speed	Weather station	km/h	Continuous
	Wind direction	Weather station	Degrees from North	Continuous
	Precipitation	Weather station	mm	Continuous
	UV index	Weather station	num	Continuous
	High tide	Hydro station	m	Continuous
	Low tide	Hydro station	m	Continuous
	Water flow (current)	Sensors/HS	m/s	Continuous
Biological parameters	Natural material weight (algae, tree branches, leaves…)	Manually	kg	Semi-continuous
	Trapped fish	Manually	num	Semi-continuous
	Other trapped animals	Manually	num	Semi-continuous
	Alive fish	Manually	num	Semi-continuous
	Other alive animas	Manually	num	Semi-continuous

The collection of the parameters will be conducted separately for the 3 proposed INSPIRE floating riverine litter retention technologies from WP2, respective to their testing locations. Table 3 shows an overview of the 3 proposed INSPIRE floating riverine litter retention technologies and their respective testing locations. In the case of technology number 2, Archimedean Drum Screen, developed by FF (WP2, T2.2), will be tested in 3 different demo sites: The Scheldt (Belgium), Rhine (The Netherlands) and Danube (Romania), while the comprehensive assessment under T4.1 will only obtain only parameters from the Port of Ostend under the Scheldt demo site in Belgium.

Table 22: INSPIRE floating riverine litter retention technologies and their respective demonstration locations.

	Retention technology	Technology testing locations	Country	Demo site leaders
1.	Hybrid MOLD/MINDS solution	Santa Gulia (Po river)	Italy	CNR
2.	Archimedean Drum Screen	Port of Ostend*	Belgium	VLIZ
		Evides drinking water (Rhine river)	The Netherlands	FF
		Thermo power plant (Danube river)	Romania	RWA
3.	CirCleaner	Londenhaven (Rhine river)	The Netherlands	NOR

*The Archimedean Drum Screen was expected to be deployed in Temse, but due to local constrains the technology is deployed in Port of Ostend

4.1.2. INSPIRE sensor kit

A versatile set of sensor technology will be employed to continuously collect real-time data from the floating riverine litter retention technologies during their implementation period. One objective is to develop a sensor kit, which would be applicable for all floating riverine litter retention technologies and could be further replicated outside the boundaries of the INSPIRE project. The proposed sensors can measure physical properties of the parameters in real time, defined under Section 4.1.1, while transmitting data into INSPIRE repository in WP4 (T4.4) for further processing and analysis, as described under WP7 (T7.3).

Section 4.1.2 defines the most appropriate types of sensors, personalized for the environmental conditions, under which these technologies are operating. Detailed market analysis is being performed, based on which most suitable sensors will be chosen. Furthermore, the specific mounting location of the sensor types for each retention technology will also be specified.

The selected sensors will aid into design of a sensor kit, that would be tested under T4.4, and will enable a fair comparison and benchmarking across 4 technologies.

The following Table 23 provides an overview of the type of representative sensors, that would be included in the sensor kit for floating litter technologies. It showcases information on the sensor types, its connectivity options, power consumption and their measurement ranges. The latter is a crucial factor in ensuring the collection of highly reliable data. Furthermore, the measurement rage is also critical to determine the best sensors based on the environmental conditions.

Table 23: Sensor overview for floating litter technologies.

Sensor type	Nr.	Type	Image	Manufacturer (website)	Measurable range (sensitivity)	Power
Power meter	1.	Shelly Qubino Wave Pro 3		Shelly (www.shelly.com)	110 - 240 V AC, 50/60 Hz AC: 240 V, 16A per channel (48A total) DC: 30 V, 16 A per channel (48 A total)	< 0.3 W
	2.	Shelly 3EM		Shelly (www.shelly.com)	<= 120A per channel	< 1 W
	3.	ADL200 1-phase AC Energy Meter		Acrel (www.acrel.uk)	<=80A	< 4VA
	4.	VM-3P75CT Emergy Meter		Victron (www.victronenergy.com)	three-phase max. 65A single-phase max. 100A	<1.45 W / 3.1 VA

Table 23: Sensor overview for floating litter technologies (continued).

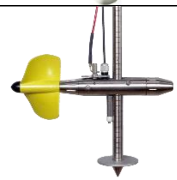
Flow meter	1.	Model 001 Flow Meter		Valeport Water (www.valeport.co.uk)	0.025 to 10 m/s	8 'C' cells (400 h)
	2.	Advanced Steam Flow meter		Nhbs (www.nhbs.com)	0.05 to 1.5 m/s	AA battery
	3.	Current meter with synthetic propeller		Royaleijkelkamp (www.royaleijkelkamp.com)	0.01 – 10 m/s	3.6V Lithium Battery
Water level meter	1.	HYDROS 21		Metergroup (www.metergroup.com)	0 – 120 dSm (10 m depth)	4.0 – 15.0 V

Table 23: Sensor overview for floating litter technologies (continued).

Water level meter	2.	WL705 Ultrasonic Water Level Sensor		YSI (www.ysi.com)	0 – 14.6 m	10 - 30 VDC at 40 mA max
Ultrasonic	1.	AU018 Ultrasonic Sensor		Autosen (www.autosen.com)	80 – 1200 mm	10 - 30 V DC supply class 2 cULus
	2.	AU008Ultrasonic sensor		Senix (www.oceancontrols.com.au)	250 – 3500 mm	10 ... 30 V DC supply class 2 cULus
	3.	Tank Level Sensor Ultrasonic Long Range Wireless		Ncd (www.store.ncd.io)	40 – 9999 mm	N.A
Sound sensor	1.	Decibel meter		Tadeto (www.amazon.com)	30 – 130 dB	Batteries 1.5V 2*AAA

Table 23: Sensor overview for floating litter technologies (continued).

Sound sensor	2.	LATNEX SM-130DB Sound Level Meter		LATNEX (www.latnex.com)	35 – 130 dB	9 V battery
	3.	R8050 Dual Range Sound Level Meter		REED instruments (www.raptorsupplies.nl)	30 – 130 dB	9 V battery
Weather stations	1.	ACCUR8 DWS5100 5-in-1 Solar-Powered Wi-Fi weather station		Weather shop (www.hhsolutions.ie)	• Humidity: 1 – 99% • Outdoor Temp: -40°C – 60°C, • Wind Speed: 0 – 112 mph, 50 • m/s • Rainfall: 0 – 9999mm • Barometric Pressure: 300 - 1100hPa	Solar power
	2.	WS-2902 WiFi Smart Weather Station		Ambient Weather (www.ambientweather.com)	• Humidity: 10 – 99% • Outdoor Temp: -40°C – 65°C, • Wind Speed: 0 – 160 km/h • Rainfall: 0 – 9999mm	0.05 W (1.25 Watts during WiFi configuration mode)

Table 23: Sensor overview for floating litter technologies (continued).

Weather stations	3.	WS-2000 Home Weather Station		Ambient Weather (www.ambientweather.com)	• Humidity: 10 – 99% • Outdoor Temp: -40°C – 65°C, • Wind Speed: 0 – 160 km/h • Wind direction: 0 – 360s • Rainfall: 0 – 9999mm	Input 5V DC; 6.5' 110-240V 50-60 Hz wall charger included, Power Consumption: 0.5 Watts
Accelerator	1.	BWT61CL		WITMOTION (www.witmotion-sensor.com)	• Acceleration (±16g), • Gyroscope (±2000°/s), • Angle (X, Z-axis: ±180°, Y ±90°)	3.3-5v (battery 3.7v, 260mAh)
	2.	GAM900		Baumer (www.baumer.com)	• Acceleration (±16g),	10...30 VDC

Table 23: Sensor overview for floating litter technologies (continued).

Camera for device monitoring	1.	RLC 1212A		Reolink (www.reolink.com)	/	< 12 W
	2.	CS-C3W-A0-3H4WFRL		Ezviz	/	DC 12 V / 1 A (Max. 6 W)
	3.	Agnus Eco 3MP		Reolink (www.reolink.com)	/	rechargeable battery (5V/2A power supply)
Underwater camera	1.	HERO11 Black		GoPro (www.gopro.com)	/	Removable 1720mAh Enduro Battery

Table 23: Sensor overview for floating litter technologies (continued).

Underwater camera	2.	Micro 3.0 Underwater Camera		SeaLife (www.sealife-cameras.com)	/	2000 mAh, 3.7v, 7.4Wh Internal Li-ion battery
	3.	HERO12 Black		GoPro (www.gopro.com)	/	Removable 1720mAh Enduro Battery

A market analysis is being conducted, to identify the most suitable sensors for the INSPIRE sensor kit, which will be integrated on the riverine litter retention technologies. For each sensor type, three examples have been proposed. Power meters will measure the electricity consumed and/or produced by the retention technologies. A set of different cameras was proposed for the overall monitoring of the technology. Motion acceleration sensors will be incorporated to track the movement of the technologies during operation, while the sound sensors will be used to gather noise pollution during operation. Additionally, flow sensors will be deployed in areas with flowing water to monitor water movement.

The INSPIRE sensor kit will include a hydrophone, to gather information on the underwater sound during the operation of the floating riverine retention technologies. Such measurements will be performed in T1.4, by partner VLIZ, and will be incorporated within the technology operational results.

For determining the right sensitivity of measurements, the environmental conditions of the retention technologies testing locations play a crucial part. This is particularly true for the flow meter, as three of the implemented technologies are deployed in dock areas, which have a lower current speed, compared to the river stream. Thus, information on the water current speed will need to be obtained before the selection of the appropriate flow meter sensor. Such information for the four deployment locations will be gathered, using the river discharge and related historical data from the European Flood Awareness System database, from Copernicus from the European Union Space Programme (Mazzetti, 2023)

After the appropriate sensors have been chosen, they will be integrated into an INSPIRE sensor kit, which would be applicable to the 3 floating riverine litter retention technologies. Due to the varying levels of technology maturity, some systems are more advanced than others. As a results, certain technologies are already equipped with sensors that continuously collect real-time data. In those cases, the data from the existing sensors will be gathered and no new INSPIRE sensors will be integrated that measure the same parameters. The following Table 24 outline the type of sensors which will be part of the INSPIRE sensors kit for each of the floating riverine litter technologies. For the instances where the data will be retried from sensors that are already implemented onto the technology are noted with a blue X in Table 24.

Table 24: Sensor overview. Black X indicates the sensors that would be integrated to individual technologies from the INSPIRE sensor kit, while blue X notes the sensors that are already present in the technology.

	Technology 1		Technology 2	Technology 3
	River Cleaning System (MOLD)	CLEAN TRASH collection cage (MINDS)	Archimedean Drum Screen	CirCleaner
Power meter 1 (energy consumption)	X	X	X	X
Power meter 2 (energy production)	X	X		X
Ultrasonic sensor 1 for cage fullness level		X	X	
Ultrasonic sensor 2 for debries detection	X			
Camera 1 (for general device monitoring)		X	X	X
Camera 2 (litter monitoring)		X	X	
Water level sensor	X			
River flow meter	X			
Processed water flow meter	**Calculated**		**Calculated**	**Calculated**
Accelometer sensor	X	X	X	X
Hydrophone	X	X	X	X
Microphone	X	X	X	X
Weather/hydro station*	X		X	X

X – sensors, mounted for the purpose of INSPIRE project
X – sensors, already in-use by INSPIRE partners
*** Using existing station from local weather observatories**

This is particularly relevant for Technology 3, CirCleaner, developed by NOR (WP2, T2.6), where the current prototype already collects energy consumption and production data and features an integrated camera, located near the entrance of the technology. Similarly, for Technology 1, the hybrid MOLD/MINDS solution developed by INSPIRE partners MOLD and MINDS (WP2, T2.1), a camera is already mounted on the CLEAN TRASH collection cage to monitor the litter, that is being retained.

4.1.3. Monitoring of retained floating riverine litter by INSPIRE technologies

The litter retained from the rivers, ports, and docks by INSPIRE floating riverine litter retention technologies, will be additionally monitored.

Under INSPIRE project, we will use the Joint List of Litter Categories that have been developed within the MSFD Technical Group on Marine Litter (MSFD TG ML), for classification of the retained floating riverine macro-litter, where J-List codes (Fleet et al., 2021) will be used.

By the end of the INSPIRE project, once sufficient data on retained floating riverine macro-litter is collected, the Joint List of Litter Categories for Marine Macrolitter Monitoring could be adapted for floating macro-litter in riverine environments. Such revised J-code list is expected to be shorter, as it will exclude items and materials denser than water, which tend to sink and as such often not be observed during the monitoring of floating macro-litter in rivers.

Subsection 4.1.3.1 describes the separation and classification protocol to monitor the retained floating riverine litter, Section 4.1.3.2 presents the monitoring frequencies, while Section 4.1.3.3 describes the developed INSPIRE monitoring App, done in collaboration with INFOR, which aligns with J-code items list.

4.1.3.1. Separation and monitoring protocols of retained floating riverine litter

The protocol for separation of retained floating riverine litter, developed by VLIZ under D2.1 Plastic Removal Efficiency Protocols (WP2, T2.1), is used to assess the mass efficiencies of the INSPIRE floating riverine litter retention technologies. At D4.1, the protocol has been adapted for the use in real environments, which outlines a multi-step process, specifying all the necessary steps required for assessing the retained floating riverine litter, by four proposed INSPIRE technologies. Monitoring will be performed by the J-list, developed by the JRC (Commission et al., 2021), based on the emptying frequency described under the respective sections for each INSPIRE floating riverine litter retention technologies, following a 4 step approach.

Step 1: Separation of natural items from anthropogenic floating riverine retained litter

Riverine litter refers to litter found in rivers and along riverbanks (Commission et al., 2021) and consists of both natural and anthropogenic materials (Garaba & Park, 2024). Some examples of natural not-litter riverine items include (Mohsen et al., 2023):

1. Tree branches;
2. Algae;
3. Grass;
4. Roots;
5. Leaves;
6. Plant remnants.

Anthropogenic litter refers to any human-made or human-used items that are found in the environment (Rangel-Buitrago et al., 2020). For instance, tree branches naturally occur in the environment and are therefore classified as natural not-litter items. In contrast, processed wood products, such as those that have been sawed, painted, or sanded, are considered anthropogenic litter. Similarly, food waste is also considered anthropogenic litter, as it is a byproduct of human activity and does not naturally occur in the environment.

As the INSPIRE project focuses only on anthropogenic plastic riverine litter items, the first step is to separate the naturally occurring not-litter riverine items ($m_N(wet)$) from the anthropogenic ones ($m_A(wet)$)). After separation, both fractions are weighted, by placing them into:

1. Trays;
2. Standard 100 L garbage bags.

The empty trays and garbage bags should be weighted beforehand ($m_{container,empty}$).

Table 25 presents an overview of different types of weighting containers used to weight both natural and anthropogenic fractions, depending on the scale type available on the field at different demo sites.

Table 25: Type of container used for litter weighing.

Retention technology	Demo site location	Demo site leader	Type of container used for weighing	Scale types
Hybrid MOLD/MINDS	Santa Gulia (Italy)	CNR	Standard 100 L garbage bags	Hanging scale
Archimedean Drum Screen	Port of Ostend (Belgium)	VLIZ	Trays	Hanging scale
CirCleaner	Londenhaven (the Netherlands)	NOR (in partnership with VLIZ)	Standard 100 L garbage bags	Hanging scale

The weight of natural not-litter items ($m_N(wet)$) and anthropogenic ($m_A(wet)$) retained floating riverine litter is calculated by subtracting the weight of the weighing container, as shown in Equations 2 and 3.

$$m_N(wet) = m_{N,container,full}(wet) - m_{container,empty} \quad (2)$$

$$m_A(wet) = m_{A,container,full}(wet) - m_{container,empty} \quad (3)$$

The total weight of the retained riverine litter ($m_{total}(wet)$) is the sum of the natural (($m_N(wet)$) and anthropogenic weights ($m_A(wet)$), as given in Equation 4:

$$m_{total}(wet) = m_N(wet) + m_A(wet) \quad (4)$$

In this way, we obtained the total mass of the retained fractions and the mass of the natural not-litter and anthropogenic fractions. After weighing the natural, non-litter fraction is returned to the river environment.

Step 2: Separation of anthropogenic floating riverine litter into subfraction

The anthropogenic floating riverine litter is further subdivided into 3 categories:

1. Macro-fraction (> 25 mm);
2. Meso-fraction (5 - 25 mm);
3. Pellets (micro-fraction) (< 5 mm).

After the separation of macro-, meso- and micro-fractions, they are all individually weighed using the weighing equipment, as defined in Table 25. For the smaller meso- and micro- fractions, a portable kitchen balance can also be used. The total weight of the retained anthropogenic floating riverine litter ($m_A(wet)$) is calculated by summing the weights of the macro-fraction ($m_{A,macro}(wet)$), meso-fraction ($m_{A,meso}(wet)$), and micro-fraction ($m_{A,micro}(wet)$), as outlined in Equation 5.

$$m_A(wet) = m_{A,macro}(wet) + m_{A,meso}(wet) + m_{A,micro}(wet) \quad (5)$$

The obtained fraction is then analysed. The meso- and micro-litter fraction is further evaluated according to the procedure outlined in Step 3a, while the macro-litter fractions are assessed as described in Step 3b.

Step 3a: Assessment of anthropogenic floating riverine meso- and micro- litter fraction

The meso- and micro-litter fractions will be separately washed to remove any riverine debris and then set aside to dry. Once dried, these fractions will be weight to determine the total dry mass of the retained meso- and micro-litter fractions. The dry fractions will undergo further analysis, as depicted in the Standard Procedure for Riverbank quadrat sampling protocol. The following parameters in Table 26, which are aligned with T1.2, will be analysed for both meso- and micro-litter fraction.

Table 26: Meso- and micro-litter fraction analysis parameters

Parameter	Unit
Polymer type	/
Length	mm
Width	mm
Size class	/
Mass	mg
Colour	/
Transparency	/
Shape	/

The type of polymer will be determined using laboratory analytical methods, specifically Fourier transform infrared spectroscopy (FTIR).

For larger quantities of retained meso- and micro-litter fractions, a representative sub-sample of the dried fractions will be collected. The meso- and micro-fraction sub-sample will be weighed separately and analysed based on the parameters specified in Table 26.

Step 3b: Classification of anthropogenic floating riverine macro-litter fraction

The anthropogenic riverine macro-litter fraction is further categorized using the EU Marine Strategy Framework Directive Technical Group on Marine Litter (MSFD TG ML) Joint List of Litter Categories for Marine Macro Litter Monitoring (J-list), developed by JRC (Commission et al., 2021). Each item listed in the J-list can be broadly grouped into one of the eight proposed material categories:

1. Chemicals;
2. Clothes/textile;
3. Food waste (organic);
4. Glass/ceramics;
5. Artificial polymers/plastics;
6. Paper/cardboard;
7. Rubber;
8. Processed/worked wood

Each anthropogenic floating riverine macro-litter item is individually observed and classified into one of the 181 categories, defined by the J-list:

1. Cover the ground with a tarp or canvas;
2. The retained floating riverine macro-litter items should be grouped, as defined by the J-list;
3. The grouped litter categories are counted and added to the inventory using the monitoring App created by INFOR.

4. The litter items are then distributed onto a flat and homogeneous coloured surface (single coloured tarp or canvas), where an overlay image of the grouped litter categories is photographed in and uploaded to the Inspire web repository using the monitoring App. The overlay image should include a reference meter to assist in determining the size of the recorded anthropogenic macro-litter items. An example of the image can be seen in Figure 18.

Figure 18: Example of picture with meter of litter J23 (Photograph by Rok Pučnik).

5. Each material group of J-List categories is weighted separately, using the weighting equipment, defined in Table 25. For smaller groups of materials, a portable weighting scale can also be used.

This classification protocol will determine the number of grouped items and their corresponding wet mass, in accordance with the J-code list. Additionally, it is important to analyse the dry weight of the litter, as water content can increase the total mass of the litter items. Given that monitoring will take place in decentralized locations, drying the litter items presents certain challenges. Therefore, we have adopted the following methodology to determine the water content of the collected litter:

1. **Development of an INSPIRE mean dry litter weight database in collaboration with VLIZ**

An internal INSPIRE inventory of the mean dry litter weight for J-List items will be created based on litter analysis, obtained during the field monitoring of retained litter. VLIZ will collect samples during the litter monitoring of the Archimedean Drum Screen, as it is in their proximity of their laboratories, where it will be washed and dried. Once dried, the litter items will be sorted according to the categories described in the J-List. Each litter group of J-List will be individually weighed ($m_{average,J}(dry)$) and the number of items in each category (N_J) will be recorded, as seen in Table 27, and the mean weight per litter category ($m_{total,J}(dry)$) will be calculated using the Equation 6.

$$m_{mean,J}(dry) = \frac{m_{total,J}(dry)}{N_J} \quad (6)$$

Table 27: INSPIRE average dry weight litter database parameters.

Parameter	Unit
J-code list category	/
Total dry weight	kg
Number of items	Num
Mean weight per item	kg
Standard deviation	kg

The collected mean weight of J-List litter categories will be refined and further developed throughout the INSPIRE project.

2. Calculating the water content for the retained wet litter fraction

Once the INSPIRE database of the mean dry weights of J-List categories is established, the water content ($\Delta m_J(water)$) of the previously retained litter items can be calculated. This will be done by subtracting the mean dry weight of each J-List category ($m_{mean,J}(dry)$) from the mean wet weight of the same category ($m_{mean,J}(wet)$), obtained during the monitoring activities for retained litter, as described in Equation 7.

$$\Delta m_J(water) = m_{mean,J}(wet) - m_{mean,J}(dry) \quad (7)$$

Those calculations will be done for all demo site locations, after the monitoring activities of the retained litter have been concluded.

3. Validation of INSPIRE mean dry weight of J-code category list with Global Litter Observation (GLO) project

Measuring plastic litter in mass units often leads to inaccuracies, because plastics collected in nature are often covered with dirt and/or contain water. Thus, the litter mass data collected by INSPIRE will be evaluated in a double way, by weighing and by image analysis, through the collaboration with an additional research project from UCA, the Global Litter Observatory (GLO) (https://www.marinelitterlab.eu/projects/9-projects/67-glo). This project, funded by the Government of Spain and sponsored by United Nations, is generating a series of algorithms for mass estimation from digital image analysis. Litter data collected by INSPIRE will be classified using the European Commission's J-code category list and documented using images for size measurement. It is expected that the collaboration with GLO will allow testing of its tools in the course of 2025, once published.

Step 4: Polymer identification of the anthropogenic floating riverine macro-litter items (OPTIONAL)

For anthropogenic macro-litter items categorized under artificial polymers/plastics in the J-List, the polymer type will be determined. This can be accomplished by conducting visual inspections of the item's surface for resin identification codes, according to the Resin Identification Code (RIC). These codes are usually found on packaging labels or directly imprinted on the plastic surface. Table 28 provides an overview of polymer types. Some of the polymers can be identified and their corresponding recycling symbols.

Table 28: Resin identification codes.

Polymer type	Polymer type abbreviation	Resin Identification Code
Polyethylene terephthalate	PET	
High-density polyethylene	HDPE	
Polyvinyl chloride	PVC	
Low-density polyethylene	LDPE	
Polypropylene	PP	
Polystyrene	PS	
Other	Other	

For macro-litter items lacking an identifiable RIC, due to the conditions of litter items, spectroscopy techniques can be utilized. In-field analysis could be conducted using a portable Near Infrared (NIR) sensor to obtain polymer type on the field. Alternatively, a sub-sample of the collected macro-litter items could be sent to the laboratory for detailed analysis using FTIR.

4.1.3.2. Monitoring frequency

Monitoring of the retained litter is conducted preferably on a seasonal basis, up to 4 times per year, and will be based on frequency of emptying of the INSPIRE floating riverine litter retention technologies. Table 29 outlines the specific months for each season.

Table 29: Seasons for conducting the first and seconds retained litter monitoring.

Season	Months
Winter	December – February
Spring	March – May
Summer	June – August
Autumn	September - November

Wherever possible, monitoring of the retained floating riverine litter will be carried out throughout all four seasons. The timing of these monitoring efforts will be influenced by the deployment schedules of each technology. Given that some technologies may not be active year-round, the distribution of monitoring activities will be adjusted accordingly, as detailed in the evaluation sections for each technology.

4.1.3.3. Retained floating riverine litter monitoring datasets

During the monitoring of retained floating riverine litter, a custom smartphone interface developed by INFOR will be used, based on the J-List classification (Commission et al., 2021). The INSPIRE project utilizes two applications for monitoring of macro-litter, the JRC Floating Litter Monitoring Application (used for monitoring of floating litter in the sea and rivers through the vantage points of ships and bridges) and EEA Marine LitterWatch Application (used for the monitoring of riverbanks). These two applications are designed to collect data on the quantity of macro-litter items present in the surface water layer of rivers and on riverbanks, based on the J-List categories. However, they are not intended to provide the quantity of litter items, retained by retention technologies. Furthermore, the applications specifically target macro-litter, while retention technologies capture a wider range of litter sizes, from macro- to micro-litter, depending on the technology's design characteristics. Therefore, an internal mobile interface, developed by INFOR will be used. This interface will facilitate the following functions:

1. Classification of anthropogenic riverine macro-litter, including recording item quantities as detailed in Section 4.1.3.1.
2. Capturing overlay images of grouped riverine macro-litter items according to J-list categories, as described in Section 4.1.3.2.
3. Storing information about the weight of retained riverine litter fractions, categorized by size and origin, as outlined in Section 4.1.3.3.
4. Inputting specific data related to the retained floating riverine litter monitoring, as detailed in Section 4.1.3.3 and Table 30.

In collaboration with INFOR, Table 30 lists the data points identified for collection during the monitoring of retained floating riverine litter. This represents the general survey points.

Table 30: Datasets collected during the retained litter monitoring activities.

Parameter	Unit	Vocabulary
Primary identifier	Text	
Demo site location	Text	
Country code	Text	ISO3166 alpha-2
Institution name	Text	
Name of main contact person	Text	
Email of main contact person	Text	
Campaign identifier code	Text	
Description of campaign area	Text	
Type of campaign	Text	
Campaign start date	yyyy-mm-dd	
Campaign end date	yyyy-mm-dd	
Start time of observation	hh:mm	
End time of observation	hh:mm	
Number of sampling stations	Num	
Target litter category		
Name of river	Text	
Longitude coordinate	Decimal coordinates	
Latitude coordinate	Decimal coordinates	
Length of the river section	Num	
Width of the river section	Num	
Coordinate system	Text	

Additional notes	Text	
Retained litter mass (wet)	kg	
Biological compounds (wet)	kg	
Retained macro-litter fraction weight	kg	
Retained meso-litter fraction weight	kg	
Retained micro-litter fraction weight	kg	
Retained macro plastic fraction weight	kg	
Retained macro non-plastic fraction weight	kg	
Retained macro-litter fraction q.ty	Num	
Retained meso-litter fraction q.ty	Num	
Retained micro-litter fraction q.ty	Num	
Retained macro plastic fraction q.ty	Num	
Retained macro non-plastic fraction q.ty	Num	

Additional biological parameters, pertaining to captured animals will also be gathered, as depicted in Table 31. This data will qualitatively describe the animas that may be present inside the technology during its operation. This will be done during the technology's inspections.

Table 31: Biological parameters gathered during the operation of floating riverine litter retention technology.

Parameter	Unit
Survey code	/
Animal	/
State	/
Sex	/
Age	/
Entanglement	text
Entanglement nature	text
Comments	text

During the inspections of the INSPIRE floating riverine litter retention technologies, the datasets, depicted in Table 32 will be gathered.

Table 32: Additional parameters, obtained during the inspections of the INSPIRE riverine floating litter retention technologies.

Parameter	Unit
Date	YYYY-MM-DD
Time	hh:mm
Operator	Text
Comments	Text
Photos	/

4.1.4. Connection of J-List items with societal sectors according to International Labour Organization (ILO)

The objective of this research is to identify the most burdening societal sectors , contributing to floating riverine litter pollution. The findings will enhance our understanding of the most impactful sectors responsible for riverine pollution and further mitigation strategies to achieve the goal of the EU Mission: Restore our Ocean and Water of reducing plastic litter by 50% in the ocean by 2030.

The separated anthropogenic macro-litter fraction of the retained floating riverine litter is classified according to EU Marine Strategy Framework Directive Technical Group on Marine Litter (MSFD TG ML) Joint List of Litter Categories for Marine Macro Litter Monitoring (J-list), developed by the JRC (Commission et al., 2021). This procedure is described in section 4.1.3.1.

The connection of the J-list litter categories with societal sectors will be achieved using the International Labor Organization (ILO) classifications of societal sectors. ILO is a United Nations agency which mandate is to advance social and economic justice by setting international labour standards, aimed to ensure accessible, productive, and sustainable working environments around the world (ILO, 2024). A total of 22 industries and sectors are identified, each with their specific standards:

1. Agriculture, plantations; other rural sectors;
2. Basic metal production;
3. Chemical industries;
4. Commerce;
5. Construction;
6. Education;
7. Financial services, professional services;
8. Food, drink, tobacco;
9. Forestry, wood, pulp and paper;
10. Health services;
11. Hotels, tourism, catering;
12. Mining (coal, other mining);
13. Mechanical and electrical engineering;
14. Media, culture, graphical;
15. Oil and gas production, oil refining;
16. Postal and telecommunications services;
17. Public service;
18. Shipping, ports; fisheries, inland waterways;
19. Textiles, clothing, leather, footwear;
20. Transport (including civil aviation, railways, road transport);
21. Transport equipment manufacturing;
22. Utilities (water, gas, electricity).

The beforementioned societal sectors will be used for conducting the connectivity of floating riverine macro-litter items with most impactful societal sectors. Table 33 gives an overview of the aggregated J-list codes with the 22 ILO societal sectors.

Table 33: Overview of J-List macro-litter categories and the proposed societal sectors.

ILO societal sectors	J-list plastic material	J-list other materials
Agriculture, plantations; other rural sectors	J220, J221, J223	J90
Basic metal production;		J188, J190, J178, J186, J191, J179
Chemical industries;	J11, J12, J9, J17, J22, J3, J101, J5, J36, J91, J257, J243	J216, J217, J40, J167
Commerce;	J67, J66, J87	J147, J148, J160
Construction;	J222, J69, J256, J89	J204, J248
Education;		
Financial services, professional services;		
Food, drink, tobacco;	J8, J7, J224, J21, J225, J1, J226, J227, J228, J229, J230, J231, J30, J31, J85, J58, J57, J24, J13, J238, J4, J27, J26, J25	J215, J200 J201, J175 J176, J181 J177, J150, J151, J244, J245, J152, J159, J165
Forestry, wood, pulp and paper;		
Health services;	J41, J252, J95	J246, J133
Hotels, tourism, catering;		
Mining (coal, other mining);		
Mechanical and electrical engineering;	J70, J29, J98, J96, J144, J237, J253, J211, J100, J99, J84	J205, J202, J194, J180, J174, J195
Media, culture, graphical;	J166, J28	J154
Oil and gas production, oil refining;		
Postal and telecommunications services;		J88
Public service;		
Shipping, ports; fisheries, inland waterways;	J46, J45, J47, J92, J06, J62, J59, J54, J53, J232, J234, J235, J61, J42, J64, J43,	J184, J182, J187, J164, J163
Textiles, clothing, leather, footwear;	J102, J136	J137, J138, J141, J140, J143, J145, J139, J127
Transport (including civil aviation, railways, road transport);	J15, J14, J16, J72	
Transport equipment manufacturing;	J19	J193, J130 J250, J251
Utilities (water, gas, electricity).		

Each category defined by J-List is connected to specific societal sectors where it comes from. This link is made using the detailed descriptions found within the J-list categories to identify the purpose and use of each item. For item categories which are not adequately described or for categories where its use cannot be identifies (e.g. for miscellaneous fragments of different size fractions), the connection to societal sectors has not been made. For a better understanding of the merging of J-List categories with societal sector, refer to Table 34.

Table 34: The merged dataset combines J-List litter categories with societal sectors. The initial table was sourced from The Joint List of Litter Categories for Marine Macro litter Monitoring technical report, done by JRC (Fleet et al., 2021). This table includes the litter category names, their corresponding G- and J-code, and category description. An additional column was added to the J-list table, aligning the categories with 22 societal sectors, defined by the ILO.

Type-Code	J-Code	G-Code	Name	Definition	J-CODE number	Suggested sector (listed according to ILO - International Labor Organization)
ch_nn_drk_	J216		Unidentified generally dark-coloured oil-like chemicals	Unidentified generally dark-coloured oil-like chemicals, i.e. no chemical analysis carried out.	216	Chemical industries
ch_nn_lig_	J217		Unidentified generally light-coloured paraffin-like chemicals	Unidentified generally light-coloured paraffin-like chemicals, i.e. no chemical analysis carried out.	217	Chemical industries
ch_nn_uch_	J218		Unidentified chemicals	Any unidentified chemicals, i.e. no chemical analysis carried out.	218	
ct_cl_clg_	J137	G137	Clothing	Any type of clothes, garments and headwear made of natural or artificial polymer materials.	137	Textiles; clothing; leather; footwear
ct_cl_ftw_	J138	G138	Shoes & sandals made of leather and/or textile	Various types of footwear such as shoes and sandals made of leather and/or textile.	138	Textiles; clothing; leather; footwear
ct_nn_cpt_	J141	G141	Cloth textile carpet & furnishing	Thick woven fabric used for covering the floor or other fabric used for furniture, fittings, and other decorative house accessories such as curtains.	141	Textiles; clothing; leather; footwear
ct_nn_sac_	J140	G140	Hessian sacks/packaging	Sacks and other packaging items made of a strong, coarse fabric from hemp or jute (Hessian).	140	Textiles; clothing; leather; footwear
ct_nn_sal_	J143	G143	Sails, canvas	A heavy durable cloth made of cotton, hemp, or jute, used for sails, tents, etc.	143	Textiles; clothing; leather; footwear
ct_nn_tex_	J145	G145	Other textiles	Other textile items, including pieces of cloth, rags, etc. that are unidentifiable, as well as other identifiable cloth textile items, which do not fit in any other category of this list.	145	Textiles; clothing; leather; footwear
ct_re_bps_	J139	G139	Cloth textile backpacks & textile bags	Textile receptacles with an opening at the top, shoulder straps or a handle, used for carrying things.	139	Textiles; clothing; leather; footwear
fw_	J215	G215	Organic food waste	All types of non-packaged food and food remains.	215	Food; drink; tobacco
gc_co_btc_	J204	G204	Glass ceramic construction materials (bricks, tiles, cement)	Any glass and ceramic material which is used for construction purposes such as brick, roof tiles, floor tiles, bricks, cement, etc.	204	Construction

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

gc_fc_tab_	J203	G203	Glass and ceramic tableware (plates/cups/glasses)	Glass or ceramic dishes or dishware used for serving food and dining, plates, cups, glassware, serving dishes and other useful items for practical as well as decorative purposes.	203	
gc_nn_b&c _bott_	J200	G200	Glass bottles	Glass or ceramic containers with a narrow neck, used for storing drinks or other liquids. Includes pieces of glass that can be identified as coming from a bottle.	200	Food; drink; tobacco
gc_nn_b&c _jars_	J201	G201	Glass jars	Wide-mouthed cylindrical containers made of glass or pottery, especially used for storing food. Includes pieces of glass that can be identified as coming from a jar.	201	Food; drink; tobacco
gc_nn_gfr_	J208	G208	Pieces of glass/ceramic (glass or ceramic fragments ≥ 2.5 cm)	Fragments of pottery or glass items that cannot be identified (≥ 2.5 cm).	208	
gc_nn_lit_fl bu_	J205	G205	Glass fluorescent light tube	A low-pressure mercury-vapour gas-discharge lamp that uses fluorescence to produce visible light.	205	Mechanical and electrical engineering
gc_nn_lit_li bu_	J202	G202	Glass light bulbs	A glass bulb inserted into a lamp or a socket in a ceiling, which provides light by passing an electric current through a filament or a pocket of inert gas. Includes all types, also halogen, LED, etc.	202	Mechanical and electrical engineering
gc_nn_occ_ ocet_	J219		Other ceramic items	Other identifiable ceramic items, which do not fit in any other category of this list.	219	
gc_nn_occ_ ogli_	J210	G210	Other glass items	Other identifiable glass items, which do not fit in any other category of this list.	210	
me_co_cab _	J194	G194	Metal cables	A thick metal wire or a group of wires usually inside a rubber or plastic covering, which is used to carry electricity or electronic signals.	194	Mechanical and electrical engineering
me_fc_b&c _cans_bevg _	J175	G175	Metal drinks cans	Metal containers that are used for storing and selling, e.g. beer or soft drinks.	175	Food; drink; tobacco
me_fc_b&c _cans_fcan _	J176	G176	Metal food cans	Metal containers that are used for storing and selling food such as beans, soup, fish, corn, etc.	176	Food; drink; tobacco
me_fc_tab_	J181	G181	Metal tableware (e.g. Plates, cups & cutlery)	Metal dishes or dishware used for serving food and dining, including cutlery, plates, cups, serving dishes and other useful items.	181	Food; drink; tobacco
me_fi_trp_	J184	G184	Metal lobster/crab pots	A portable trap that traps lobsters or crayfish. It can be constructed of wire or metal and netting. An opening permits the lobster or crab to enter a tunnel of netting.	184	Shipping; ports; fisheries; inland waterways

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

me_fi_wsl_	J182	G182	Metal fisheries related weights/sinkers, and lures	fisheries related items such as: weights/sinkers (a metal weight used in conjunction with a fishing lure or hook to increase its rate of sink, anchoring ability, and/or casting distance); lures (any bright artificial bait consisting of metal mounted with hooks and trimmed with feathers.	182	Shipping; ports; fisheries; inland waterways
me_nn_app_	J180	G180	Metal appliances (refrigerators, washers, etc.)	Metal (mostly electrical) devices or pieces of equipment designed to perform a specific task such as air conditioners, dishwashers, clothes dryers, freezers, refrigerators, kitchen stoves, water heaters, washing machines, trash compactors, microwave oven, etc.	180	Mechanical and electrical engineering
me_nn_b&c_barl_	J187	G187	Metal drums & barrels	Large cylindrical metal containers used for storing or shipping bulk cargo, i.e. oil, chemicals, etc.	187	Shipping; ports; fisheries; inland waterways
me_nn_b&c_cans_aesp_	J174	G174	Metal aerosol/spray cans	A type of dispensing system which creates an aerosol mist of liquid particles; used with a can or bottle that contains a payload and propellant under pressure. Indicative examples of such items are: spray paints, cleaning spray foam, engine oil spray, etc.	174	Mechanical and electrical engineering
me_nn_b&c_cans_ocan_	J188	G188	Other metal cans	Other metal containers that are used for storing and selling products that are not food or drinks or paints	188	Basic Metal Production
me_nn_b&c_cans_ptin_	J190	G190	Metal paint tins	Metal containers that are used for paint	190	Basic Metal Production
me_nn_b&c_lids_	J178	G178	Metal bottle caps, lids & pull tabs from cans	Metallic caps and lids from bottles and containers, including the pull tabs from cans	178	Basic Metal Production
me_nn_bat_	J195	G195	Metal household batteries	Small-sized batteries that are typically used in small electronic devices such as flashlights, cameras, etc.	195	Mechanical and electrical engineering
me_nn_foi_	J177	G177	Metal foil wrappers, aluminium foil	Thin aluminium sheeting or leaves used, especially, to cover and wrap food.	177	Food; drink; tobacco
me_nn_ome_larg_	J199	G199	Other metal pieces > 50cm	Other identifiable metal items that are bigger than 50 cm in the longest dimension and do not fit in any other item category of this list.	199	
me_nn_ome_smal_	J198	G198	Other metal pieces 2.5cm ≥≤ 50cm	Other identifiable metal items that are smaller than 50 cm in the longest dimension and do not fit in any other item category of this list.	198	
me_nn_srp_	J186	G186	Metal industrial scrap	Metal resulting from the disuse of metal products such as parts of vehicles, building supplies, and surplus materials.	186	Basic Metal Production
me_nn_wir_	J191	G191	Wire, wire mesh, barbed wire	A metal mesh woven, knitted, welded, expanded, photo-chemically etched or electroformed steel or other (wire mesh); a metal wire with or without clusters of short, sharp spikes set at short intervals along it, used to make fences.	191	Basic Metal Production

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

me_re_bbq_	J179	G179	Metal disposable bbqs	A single-use barbecue grill made from lightweight aluminium material.	179	Basic Metal Production
me_vk_prt_	J193	G193	Metal vehicle parts / batteries	Any part of a car or other transport vehicle (i.e., boat) made predominantly of metal, including vehicle batteries. Excluding wheels.	193	Transport equipment manufacturing
me_vk_whl_	J130	G130	Wheels with metal hub	A circular object that revolves on an axle and is fixed below a vehicle or other object to enable it to move easily over the ground. Includes the hub with the tyre or just the hub.	130	Transport equipment manufacturing
pl_ag_ghs_	J220		Plastic sheeting from greenhouses	Plastic sheeting used to cover greenhouses generated during the construction, renovation, and demolition. This category is possibly only separable from other plastic sheeting by experienced workers.	220	Agriculture; plantations; other rural sectors
pl_ag_irg_	J221		Plastic irrigation pipes	Plastic irrigation pipes from agriculture generated during construction, renovation, and demolition.	221	Agriculture; plantations; other rural sectors
pl_ag_oag_	J222		Other plastic items from agriculture	Other plastic items from agriculture generated during construction, renovation and demolition.	222	Construction
pl_ag_pot_	J90	G90	Plastic flowerpots	A plastic container in which plants are grown.	90	Agriculture; plantations; other rural sectors
pl_ag_tra_	J223		Trays for seedlings of foamed plastic	A foamed plastic tray in which seedlings are grown.	223	Agriculture; plantations; other rural sectors
pl_aq_shf_oyst_	J46	G46	Plastic oyster trays	A special tray made of square mesh used for growing oysters. Trays may be single, double or triple stacked, with or without feet, doors, v-braces and hooks.	46	Shipping; ports; fisheries; inland waterways
pl_aq_shf_sack_	J45	G45	Plastic mussels/oyster mesh bags, net sack, socks	A special bag or sack made of extruded net which is used for growing (underwater) oysters and other shellfish species. These bags can have different sizes and shapes, e.g. sack-like and tubular and the mesh net can have different sizes.	45	Shipping; ports; fisheries; inland waterways
pl_aq_shf_tahi_	J47	G47	Plastic sheeting from mussel culture (Tahitians)	Pieces of plastic sheeting about 50X40 cm which are cut at one end into fringes or stripes, so they look a little like a grass skirt from Hawaii. They are used to protect mussel cultures from animals that feed on mussels.	47	Shipping; ports; fisheries; inland waterways
pl_cl_ftw_flip_	J102	G102	Plastic flip-flops	A light sandal made of plastic, with a thong between the big and second toe.	102	Textiles; clothing; leather; footwear

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

pl_cl_ftw_shoe_	J136	G136	Footwear made of plastic - not flip flops	Items of footwear made of plastic - not flip flops.	136	Textiles; clothing; leather; footwear
pl_cl_glv_hogl_	J40	G40	Plastic gloves (household/dishwashing, gardening)	Gloves used to do household chores such as dishwashing gardening, etc. They are typically made of different polymers, including latex, nitrile rubber, polyvinyl chloride. Less heavy-duty than industrial gloves.	40	Chemical industries
pl_cl_glv_ingl_	J41	G41	Plastic gloves (industrial/professional applications)	Gloves specifically dedicated to industrial applications, mechanical, engineering, agriculture, fisheries and aquaculture and construction. They are typically made of different polymers, including latex, nitrile rubber, polyvinyl chloride and neoprene.	41	Health services
pl_cl_glv_sugl_	J252		Single-use plastic gloves	Single-use plastic gloves used for example in relation to the COVID-19 pandemic.	252	Health services
pl_cl_hdw_helm_	J69	G69	Plastic hard hats/helmets	A hard or padded protective hat, various types of which are worn by construction workers, workers from offshore installations, soldiers, police officers, motorcyclists, sports players, and others.	69	Construction
pl_co_fom_pain_insu_	J256		Foamed plastic insulation including spray foam	Lightweight cellular foam (mainly foamed PU and PE materials) used especially for insulation (i.e., in walls, roofs, and foundations as thermal insulation and water barrier). Includes spray foam.	256	Construction
pl_co_oco_	J89	G89	Plastic construction waste (not foamed insulation)	Plastic waste materials generated during the construction, renovation, and demolition of buildings or structures. These may include drainage pipes, waste pipes, plastic tubes for cables, etc. Not foamed insulation materials.	89	Construction
pl_fc_b&c_dbot_lage_	J8	G8	Plastic drink bottles >0.5 l	Plastic bottles and containers with a volume larger than 0.5 litres, used to hold water, juice or other drinks for consumption.	8	Food; drink; tobacco
pl_fc_b&c_dbot_smll_	J7	G7	Plastic drink bottles ≤ 0.5 l	Plastic bottles and containers with a volume of 0.5 litres or less, used to hold water, juice or other drinks for consumption.	7	Food; drink; tobacco
pl_fc_b&c_ffmd_	J224		Plastic food containers made of foamed polystyrene	Foamed polystyrene containers used for carrying or storing food, such as fast-food containers, lunchboxes, etc.	224	Food; drink; tobacco
pl_fc_b&c_lids_drnk_	J21	G21	Plastic caps/lids drinks	Plastic caps and lids from bottles and containers, used to hold water, juice or other drinks for consumption	21	Food; drink; tobacco
pl_fc_b&c_pfoc_	J225		Plastic food containers made of hard non-foamed plastic	Plastic containers used for carrying or storing food, such as fast-food containers, Tupperware, lunchboxes, etc. Made of non-foamed plastic.	225	Food; drink; tobacco
pl_fc_sxp_	J1	G1	Plastic 4/6-pack yokes & six-pack rings	Four or six-pack rings or yokes are a set of connected plastic rings that are used in multi-packs of drinks, particularly of drinks cans, to hold the cans together.	1	Food; drink; tobacco

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

pl_fc_tab_cups_fcup_	J226		Cups and cup lids of foamed polystyrene	Single-use cups and their lids for coffee and other drinks; made of foamed polystyrene. They have a wide range of uses in restaurants, bakeries, or catering settings.	226	Food; drink; tobacco
pl_fc_tab_cups_hpcp_	J227		Cups and lids of hard plastic	Single-use cups and their lids for coffee and other drinks; made of non-foamed artificial polymer materials. They have a wide range of uses in restaurants, bakeries, or catering settings.	227	Food; drink; tobacco
pl_fc_tab_cupt_cutl_	J228		Plastic cutlery	Single-use knives, forks, and spoons.	228	Food; drink; tobacco
pl_fc_tab_cupt_plat_	J229		Plastic plates and trays	Single-use plates and trays made of artificial polymer material.	229	Food; drink; tobacco
pl_fc_tab_stst_stir_	J230		Plastic stirrers	Stirrers are used when serving hot drinks such as tea and coffee or other drinks such as cocktails.	230	Food; drink; tobacco
pl_fc_tab_stst_strw_	J231		Plastic straws	A drinking straw or drinking tube is a small pipe that allows its user to more conveniently consume a drink.	231	Food; drink; tobacco
pl_fc_wrp_cwls_crsp_	J30	G30	Plastic crisps packets/sweets wrappers	Plastic food packets and wrappers created and designed in various colours, materials, shapes, sizes and styles for crisp food products (i.e. potato chips, etc.) or sweets (i.e. chocolates, candy, ice-creams, etc.).	30	Food; drink; tobacco
pl_fc_wrp_cwls_loly_	J31	G31	Plastic lolly & ice-cream sticks	A plastic stick attached to the bottom of a popsicle/lolly/ice-cream or lollypop used as a handle to facilitate the eating process.	31	Food; drink; tobacco
pl_fi_bag_hdsa_salt_	J85	G85	Plastic commercial salt packaging	Heavy-duty sacks and other containers used for packaging and shipping salt.	85	Food; drink; tobacco
pl_fi_box_fbox_	J58	G58	Fish boxes - foamed polystyrene	Boxes made of foamed polystyrene, which are used for packaging fish or other seafood.	58	Food; drink; tobacco
pl_fi_box_plbx_	J57	G57	Fish boxes - hard plastic	Boxes made of plastic materials (other than expanded polystyrene), which are used for packaging fish or other seafood.	57	Food; drink; tobacco
pl_fi_bte_	J92	G92	Plastic bait containers/packaging	Plastic packaging (pouches, bags) and plastic containers suitable for storing, transporting, selling fishing baits.	92	Shipping; ports; fisheries; inland waterways
pl_fi_fil_	J60	G60	Plastic fishing light sticks / fishing glow sticks incl. Packaging	An item that is used by anglers to make baits more attractive to fish. Fishing light sticks or glow sticks are typically tubes filled with fluorescent fluid. They can be found in a variety of sizes.	60	Shipping; ports; fisheries; inland waterways
pl_fi_flb_	J62	G62	Plastic floats for fishing nets	An item attached to the top of some types of fishing nets, like seine and trammel that keeps them hanging vertically in the water. Floats come in different sizes and shapes.	62	Shipping; ports; fisheries; inland waterways

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

pl_fi_lin_	J59	G59	Plastic fishing line	A long nylon thread, usually attached to a baited hook, with a sinker or float, and used for catching fish. The fishing line may be found tangled or not and with or without hooks, sinkers and floats.	59	Shipping; ports; fisheries; inland waterways
pl_fi_net_la rg_	J54	G54	Plastic nets and pieces of net > 50cm	Pieces of plastic open-meshed material made of twine, cord, or something similar, used typically for catching fish; bigger than 50 cm in the longest dimension.	54	Shipping; ports; fisheries; inland waterways
pl_fi_net_s mal_	J53	G53	Plastic nets and pieces of net 2.5 cm ≥≤ 50 cm	Pieces of plastic open-meshed material made of twine, cord, or something similar, used typically for catching fish; smaller than 50 cm in the longest dimension.	53	Shipping; ports; fisheries; inland waterways
pl_fi_net_st rg_drop_	J232		Plastic string and filaments exclusively from dolly ropes	Strings and filaments from blue, black or orange string that are used to protect bottom trawling nets against wear and tear. A dolly rope consists of around 30 strings; each string has around 25 threads.	232	Shipping; ports; fisheries; inland waterways
pl_fi_net_st rg_fish_	J233		Other plastic string and filaments exclusively from fishery	Other string and filaments exclusively from fishery.	233	Shipping; ports; fisheries; inland waterways
pl_fi_net_ta ng_mixd_	J234		Plastic tangled nets and rope without dolly rope or mixed with dolly rope	Tangled pieces of plastic open-meshed material made of twine, cord, or something similar, used typically for catching fish. They may be found tangled with rope or dolly rope.	234	Shipping; ports; fisheries; inland waterways
pl_fi_net_ta ng_tadr_	J235		Plastic tangled dolly rope	Tangles of blue, black or orange rope that are used to protect bottom trawling nets against wear and tear. A dolly rope consists of around 30 strings; each string has around 25 threads. The dolly rope string as well as the separated threads can occur in tangles in the marine environment. Tangles of dolly rope should consist entirely of dolly rope.	235	Shipping; ports; fisheries; inland waterways
pl_fi_ofi_	J61	G61	Other plastic fisheries related items not covered by other categories	Other fisheries related litter items that are not explicitly addressed by the fisheries related items included on this list, e.g. soft and hard plastic baits such as wobblers, spinners, etc.	61	Shipping; ports; fisheries; inland waterways
pl_fi_trp_cr ab_	J42	G42	Plastic crab/lobster traps (pots) and tops	Stationary plastic traps or pots used to catch crustaceans such as lobsters and crabs. Though the size and shape of the traps may vary, most feature a net covering and a cone-shaped entrance tunnel through which a crab or lobster is enticed with bait but cannot escape from.	42	Shipping; ports; fisheries; inland waterways
pl_hu_car_	J70	G70	Plastic shotgun cartridges	A shotgun cartridge is a self-contained cartridge often loaded with multiple metallic "shot", which are small, generally spherical projectiles. The shells consist of a plastic tube mounted on a brass base holding a primer. Also, plastic wads from shotgun cartridges can be found on their own.	70	Mechanical and electrical engineering

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

pl_hy_b&c_bech_	J11	G11	Plastic beach use related body care and cosmetic bottles and containers	Bottles and containers of body care and cosmetics products used at the beach such as sunscreen, suntan or after sun lotion, etc.	11	Chemical industries
pl_hy_b&c_obch_	J12	G12	Plastic non-beach use related body care and cosmetic bottles and containers	Bottles and containers of body care and cosmetics products such as shampoo, shower gel, toothpaste, perfume and others that are not explicitly used at the beach.	12	Chemical industries
pl_hy_cbs_	J95	G95	Plastic cotton bud sticks	A short plastic stick with a small amount of cotton on each end that is used for cleaning, especially the ears. The cotton is usually no-longer attached. The ends are rough when touched, where the cotton was attached. This feature can be used to separate from lolly sticks.	95	Health services
pl_hy_com_	J29	G29	Plastic combs/hair brushes/sunglasses	Plastic items used for untangling or arranging the hair, as well as plastic glasses tinted to protect the eyes from sunlight or glare.	29	Mechanical and electrical engineering
pl_hy_dap_	J98	G98	Plastic diapers/nappies	Basic garments for infants consisting of absorbent synthetic polymer material drawn up between the legs and fastened about the waist, used to retain urine and faeces.	98	Health services
pl_hy_ohy_	J236		Other plastic personal hygiene and care items	Other identifiable personal hygiene and care items that do not fit in any other category of this list. Can be made of other materials than artificial polymers.	236	
pl_hy_stt_sant_	J96	G96	Plastic sanitary towels/panty liners/backing strips	Sanitary towels/panty liners/backing strips.	96	Health services
pl_hy_stt_tamp_	J144	G144	Plastic tampons and tampon applicators	A feminine hygiene product designed to absorb the menstrual flow or a plug of material used to stop a wound or block an opening in the body and absorb blood or secretions. The tampon applicator should be recorded within this category.	144	Health services
pl_hy_tfr_	J97	G97	Plastic toilet fresheners	Toilet bowl fresheners, which are attached inside the toilet bowl to keep it smelling fresh.	97	
pl_hy_wws_	J237		Plastic wet wipes	A small disposable synthetic cloth treated with a cleansing agent, used especially for personal hygiene.	237	Health services
pl_md_msk_	J253		Plastic single-use face-mask	Single-use facemask used to protect against for example dust, chemicals and pathogens (e.g. COVID-19 pandemic).	253	Health services
pl_md_omd_	J211	G211	Other plastic medical items (swabs, bandaging, adhesive plasters etc.)	Items deemed necessary for the treatment of an illness or injury. These may include swabs, bandaging, adhesive plasters, etc. Can be made of other materials than artificial polymers.	211	Health services

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

pl_md_pha_	J100	G100	Plastic medical/ pharmaceuticals containers/tubes/ packaging	A wide variety of artificial polymer packages used for the packaging of a wide variety of pharmaceutical solids, liquids, and gasses. Some of the common primary plastic packages are: blister packs, small bottles and containers, tubes, ampoules, etc.	100	Health services
pl_md_syg_	J99	G99	Plastic syringes/needles	A plastic tube with a nozzle and piston or bulb for sucking in and ejecting liquid in a thin stream, used for cleaning wounds or body cavities, or fitted with a hollow needle for injecting or withdrawing fluids. Included all parts of syringes (e.g. syringe plunger and the metal needle with plastic adapter) found separately.	99	Health services
pl_nn_b&c_clng_	J9	G9	Plastic bottles and containers of cleaning products	Bottles and containers of cleaning products such as detergents, toilet cleaners, glass cleaners, etc.	9	Chemical industries
pl_nn_b&c_eoil_larg_	J15	G15	Plastic engine oil bottles & containers >50cm	Plastic bottles and containers bigger than 50 cm in any dimension, used for packaging motor oil, engine oil, or engine lubricant.	15	Transport (including civil aviation; railways; road transport)
pl_nn_b&c_eoil_smal_	J14	G14	Plastic engine oil bottles & containers 2.5 cm ≥ ≤ 50 cm	Plastic bottles and containers smaller than 50 cm in any dimension, used for packaging motor oil, engine oil, or engine lubricant.	14	Transport (including civil aviation; railways; road transport)
pl_nn_b&c_injn_	J17	G17	Plastic injection gun containers/cartridges	A cartridge made of plastic for devices that are used to inject grease, silicone, or other fluids. Includes their nozzles.	17	Chemical industries
pl_nn_b&c_jery_	J16	G16	Plastic jerry cans	Large plastic flat-sided containers with a handle used for storing or transporting liquids, typically petrol or water.	16	Transport (including civil aviation; railways; road transport)
pl_nn_b&c_lids_dtgt_	J22	G22	Plastic caps/lids chemicals, detergents (non-food)	Plastic caps and lids from bottles and containers of cleaning products (i.e. detergents, toilet cleaners, glass cleaners, etc.) and chemicals.	22	Chemical industries
pl_nn_b&c_lids_olid_	J23	G23	Plastic caps/lids unidentified	Plastic caps and lids from unidentified bottles and containers.	23	
pl_nn_b&c_lids_ring_	J24	G24	Plastic rings from bottle caps/lids	Plastic structures around the circumference (usually) of the closure that is often found attached below a closure in bottles, jars, and tubs. The bottom part of a cap that breaks off when the cap is screwed off.	24	Food; drink; tobacco

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

pl_nn_b&c_ ob&c_	J13	G13	Other plastic bottles & containers (drums)	Other plastic bottles and containers such as drums (cylindrical containers) generally used for the transportation and storage of liquids and powders.	13	Food; drink; tobacco
pl_nn_bag_ cabg_	J3	G3	Plastic shopping/carrier/grocery bags	Shopping bags are medium-sized bags, typically around 10–20 litres in volume (though much larger versions exist, especially for non-grocery shopping), that are used by shoppers to carry home their purchases. Shopping bags can be made with a variety of plastics.	3	Chemical industries
pl_nn_bag_ dogb_	J101	G101	Plastic dog/pet faeces bag	A plastic bag used for picking up and removing the faeces of a dog or other pet.	101	Chemical industries
pl_nn_bag_ ends_	J5	G5	The part that remains from tear-off plastic bags	Plastic packing bags are commonly found on the market in packs of 10, 20, 50, etc. This litter item refers to the part that remains after tearing-off the bags.	5	Chemical industries
pl_nn_bag_ hdsa_ohds_	J36	G36	Other plastic heavy-duty sacks	Non-salt heavy duty plastic sacks for content such as animal feed, fertilizers, garden rubbish, etc.	36	Chemical industries
pl_nn_bag_ mesh_vege _	J238		Plastic mesh bags for vegetable, fruit and other products	A special mesh bag made out of polypropylene, polyethylene or high-density polyethylene used for packaging and transporting agricultural products such as vegetables, fruit, bird feed, etc.	238	Food; drink; tobacco
pl_nn_bag_ smbg_	J4	G4	Small plastic bags	Small plastic bags refer to small-sized bags such as freezer bags, zip-lock re-sealable food bags, poly bags, etc.	4	Food; drink; tobacco
pl_nn_bio_	J91	G91	Plastic biomass holder from sewage treatment plants and aquaculture	Plastic Filter Media or Biofiltration Media are small (1-4 cm diameter ca. 1 cm high) usually round plastic items that look a bit like a cake. https://www.bing.com/images/search?q=Plastic+Filter+Media+or+Biofiltration+Media&FORM=HDRSC2	91	Chemical industries
pl_nn_box_	J18	G18	Plastic crates, boxes, baskets	Plastic containers typically used to transport or store different types of items and products, other than fisheries and aquaculture related.	18	
pl_nn_buc_	J65	G65	Plastic buckets	A roughly cylindrical open container with a handle made of plastic and used to hold and carry liquids	65	
pl_nn_cbt_	J93	G93	Plastic cable ties	A cable tie (also known as a wire tie, hose tie, steggel tie, zap strap or zip tie, and by the brand names Ty-Rap and Panduit strap) is a type of fastener, for holding items together, primarily electrical cables or wires.	93	
pl_nn_cds_	J84	G84	Plastic cds & dvds	Small plastic discs (and their keep cases) on which sound and data can be stored (CDs & DVDs).	84	Mechanical and electrical engineering

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

pl_nn_cpa_shet_	J67	G67	Plastic sheets, industrial packaging, sheeting	Large plastic packaging or sheeting used for the protection or covering/wrapping of large cargo objects. Plastic sheeting is used for a variety of industrial and commercial applications. It comes in many sizes, strengths, styles, and colours depending on the application.	67	Commerce
pl_nn_fen_	J64	G64	Plastic fenders	Plastic cushions (such as foam rubber) placed between a boat and a dock or between two boats to lessen shock and prevent chafing.	64	Shipping; ports; fisheries; inland waterways
pl_nn_fib_	J68	G68	Fibre glass items	Items made of fibreglass, a common type of fibre-reinforced plastic using glass fibre. Examples of fibreglass items include water pipes, pods, domes, traffic lights, pieces of boats etc.	68	
pl_nn_flb_	J63	G63	Plastic floats/buoys other source than fishing or not known	Plastic floats/buoys other source than fishing or not known. Floating devices that serve as navigation marks, marking reefs or other hazards, mooring locations. They can be anchored (stationary) or allowed to drift with ocean currents.	63	
pl_nn_fom_nfpy_	J239		Other foamed plastic items and fragments not made of foamed polystyrene	Items and fragments not made of foamed polystyrene (other than packaging or insulation related) made out of foamed sponge-like plastic, such as mattresses, bathing sponges, etc.	239	
pl_nn_fom_pain_pack_	J257		Foamed plastic packaging	Lightweight cellular foam (mainly foamed PU and PE materials) used as a packing material.	257	Chemical industries
pl_nn_frg_fopy_larg_	J83	G83	Fragments of foamed polystyrene > 50cm	Fragments of foamed polystyrene that are bigger than 50 cm in the longest dimension and originate from unidentifiable polystyrene items.	83	
pl_nn_frg_fopy_smal_	J82	G82	Fragments of foamed polystyrene 2.5 cm ≥ ≤ 50 cm	Fragments of foamed polystyrene that are bigger than 2.5 cm and smaller than 50 cm in the longest dimension and originate from unidentifiable polystyrene items.	82	
pl_nn_frg_nofp_larg_	J80	G80	Fragments of non-foamed plastic > 50cm	Fragments of plastic that are larger than 50 cm in the longest dimension and originate from unidentifiable plastic non-foamed polystyrene items.	80	
pl_nn_frg_nofp_smal_	J79	G79	Fragments of non-foamed plastic 2.5cm ≥ ≤ 50cm	Fragments of plastic that are bigger than 2.5 cm and smaller than 50 cm in the longest dimension and originate from unidentifiable plastic non-foamed polystyrene items.	79	
pl_nn_idp_idfd_	J240		Other identifiable foamed plastic items	Items that are made of foamed polystyrene, which are identifiable but do not fit in any other litter type category in this list.	240	
pl_nn_idp_idnf_	J241		Other identifiable non-foamed plastic items	Items that are made of non-foamed artificial polymers, which are identifiable but do not fit in any other litter type category in this list.	241	
pl_nn_pai_	J166	G166	Plastic paint brushes	A brush used for painting, typically consisting of bristles fastened into a wooden or plastic handle. Can be made of a mixture of materials including metal.	166	Media; culture; graphical

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

pl_nn_rps_rope_	J49	G49	Plastic rope (diameter more than 1cm)	A stout cord of strands of plastic fibres twisted or braided together, with a diameter larger than 1 cm.	49	
pl_nn_stb_	J66	G66	Plastic strapping bands	Plastic bands and straps used for fastening any type of package. Polypropylene and polyester strapping is the most commonly used plastic strapping on the market. Usually made of quite hard plastic.	66	Commerce
pl_nn_tag_	J43	G43	Plastic tags (fishing, shipping, farming and industry)	Plastic tags used to mark fish and shellfish such as lobsters and plastic cargo seals (pull-tight) both usually with a serial number. Also, animal tags from farming.	43	Shipping; ports; fisheries; inland waterways
pl_nn_tap_	J87	G87	Plastic masking/duct/packing tape	Different sorts of plastic adhesive tape: used in painting, to cover areas on which paint is not wanted (masking tape); strong cloth-backed waterproof adhesive tape (duct tape); box-sealing tape, parcel tape or packing tape used for closing or sealing corrugated fibreboard boxes.	87	Commerce
pl_nn_tel_	J88	G88	Telephone	Mobile phone devices and any other type of telephones.	88	Postal and telecommunications services
pl_nn_tfk_	J72	G72	Plastic traffic cones	Plastic cone-shaped objects that are used to separate off or close sections of a road.	72	Transport (including civil aviation; railways; road transport)
pl_re_div_	J86	G86	Plastic fin trees (from fins for scuba diving)	The plastic supports placed inside diving flippers or fins to keep them in shape.	86	
pl_re_fwo_	J243		Plastic remains of fireworks	The plastic remains of fireworks such as caps of rockets, covers for fuses, exploding parts of battery fireworks.	243	Chemical industries
pl_re_toy_	J32	G32	Plastic toys and party poppers	Any plastic object that children play with, as well as objects commonly used at parties. Party poppers are small devices used as an amusement at parties, which explode when a string is pulled, ejecting thin paper streamers.	32	
pl_sm_but_	J27	G27	Tobacco products with filters (cigarette butts with filters)	A cigarette filter, also known as a filter tip, is a component of a cigarette, placed at the one tip of the cigarette in order to absorb vapours and accumulate particulate smoke components. The filter is commonly made from synthetic plastic cellulose.	27	Food; drink; tobacco

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

pl_sm_lht_	J26	G26	Plastic cigarette lighters	Small objects that produce a flame, commonly used for lighting cigarettes or cigars.	26	Food; drink; tobacco
pl_sm_tob_	J25	G25	Plastic tobacco pouches / plastic cigarette packet packaging	Plastic containers (pouches, boxes) used for cigarettes and tobacco.	25	Food; drink; tobacco
pl_vk_prt_	J19	G19	Plastic vehicle parts	Any part of a car or other transport vehicle made of artificial polymer materials and fibre glass. This can also include pieces of boats.	19	Transport equipment manufacturing
pp_fc_b&c_tpak_milk_	J150	G150	Paper cartons/Tetrapak milk	Containers made of carton with a plastic-lining used for milk.	150	Food; drink; tobacco
pp_fc_b&c_tpak_otpk_	J151	G151	Paper cartons/Tetrapak (non-milk)	Containers made of carton with a plastic-lining used for food products, other than milk.	151	Food; drink; tobacco
pp_fc_tab_cups_	J244		Paper cups	Cups for coffee and other drinks; made of cardboard. They have a wide range of uses in restaurants, bakeries, or catering settings.	244	Food; drink; tobacco
pp_fc_tab_tray_	J245		Paper food trays, food wrappers, drink containers	Single-use food trays, food wrappers and drink containers, made of paper.	245	Food; drink; tobacco
pp_hy_cbs_	J246		Paper cotton bud sticks	A short paper stick with a small amount of cotton on each end that is used for cleaning, especially the ears.	246	Health services
pp_nn_b&c_	J247		Other paper containers	Other paper containers.	247	
pp_nn_bag_	J147	G147	Paper bags	A small bag made of paper, commonly used as shopping bags, packaging, etc.	147	Commerce
pp_nn_box_	J148	G148	Cardboard boxes	Boxes made of cardboard (a thick, stiff paper or material containing multiple layers of corrugated paper).	148	Commerce
pp_nn_frg_	J156	G156	Paper fragments	Fragments of paper items that cannot be identified.	156	
pp_nn_new_	J154	G154	Paper newspapers & magazines	Printed publications consisting of paper sheets and containing news, articles, advertisements.	154	Media; culture; graphical
pp_nn_opp_	J158	G158	Other paper items	Other identifiable paper and cardboard items, which do not fit in any other category of this list.	158	
pp_re_fwo_	J155	G155	Paper tubes and other pieces of fireworks	Small paper/cardboard containers/tubes filled with explosive chemicals that produce bright coloured light patterns or loud noises when they explode (fireworks).	155	

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

pp_sm_cig_	J152	G152	Paper cigarette packets	A rectangular container made of paperboard, used as packaging for cigarettes. It may also include a plastic covering.	152	Food; drink; tobacco
ru_cl_ftw_rubo_	J127	G127	Rubber boots	A tall boot that is made of rubber and that keeps the feet and lower legs dry.	127	Textiles; clothing; leather; footwear
ru_hy_con_	J133	G133	Rubber condoms (incl. Packaging)	A thin rubber sheath, used during sexual intercourse as a contraceptive or as a protection against infection. Within this category also the packaging should be recorded.	133	Health services
ru_nn_bnd_	J131	G131	Rubber band (small, for kitchen/household/post use)	A thin, flexible loop that is made of rubber and used to hold things together.	131	
ru_nn_its_rush_	J248		Rubber sheet	Rubber sheeting made of rubber (or rubber-like artificial polymer). Rubber sheets are used for varied purposes, e.g. flooring, under shower pans, drainage systems, as lining for water containers and in construction.	248	Construction
ru_nn_oru_	J134	G134	Other rubber pieces	Other identifiable rubber pieces, which do not fit in any other category of this list.	134	
ru_nn_tyr_belt_	J249		Rubber belts	Rubber belts are elongated rectangular rubber items.	249	
ru_re_bln_	J125	G125	Rubber balloons	A small, coloured, rubber sack-like object which is inflated with air or gas and then sealed at the neck, used as a child's toy or for decoration. Within this category balloon ribbons, strings, plastic valves and balloon sticks that are or were attached to balloons are included.	125	
ru_re_bls_	J126	G126	Rubber balls	A spherical toy ball, usually fairly small, made of elastic material which allows it to bounce against hard surfaces.	126	
ru_vk_its_intu_	J250		Rubber inner-tubes	An inflatable usually ring-shaped rubber tube designed for use inside a pneumatic tire.	250	Transport equipment manufacturing
ru_vk_tyr_tyre_	J251		Rubber tyres	Rubber tyres from all types of vehicles.	251	Transport equipment manufacturing
wo_fc_b&c_cork_	J159	G159	Wooden corks	A bottle stopper made of cork or a similar material. Note that plastic corks should be recorded under plastic caps and lids	159	Food; drink; tobacco
wo_fc_ice_	J165	G165	Wooden ice-cream sticks, chip forks, chopsticks, toothpicks	Various wooden sticks, including sticks from ice-creams, small wooden forks from fast food suppliers (chip forks), tapered sticks of wood held together in one hand and used as eating utensils in Asian cuisine (chopsticks), short pointed pieces of wood used for removing bits of food lodged between the teeth (toothpicks).	165	Food; drink; tobacco

Table 34: The merged dataset combines J-List litter categories with societal sectors (continued).

wo_fi_box_	J164	G164	Wooden fish boxes	Boxes made of wood, which are used for storing or transferring fish or other seafood.	164	Shipping; ports; fisheries; inland waterways
wo_fi_trp_	J163	G163	Wooden crab/lobster pots	Stationary wooden traps used to catch crustaceans such as lobsters and crabs. Usually covered in a net.	163	Shipping; ports; fisheries; inland waterways
wo_nn_box_	J162	G162	Wooden crates, boxes, baskets for packaging	Wooden containers typically used to transport or store different types of items and products. Not fish boxes.	162	
wo_nn_owo_larg_	J172	G172	Other processed wooden items > 50cm	Other identifiable processed, worked or treated wooden items larger than 50 cm in the longest dimension, which do not fit in any other category of this list, e.g., planks, boards, beams.	172	
wo_nn_owo_smal_	J171	G171	Other processed wooden items 2.5 cm ≥ ≤ 50 cm	Other identifiable processed, worked or treated wooden items smaller than 50 cm in the longest dimension, which do not fit in any other category of this list, e.g. planks, boards, beams.	171	
wo_nn_pal_	J160	G160	Wooden pallets	A flat wooden structure on which heavy goods are put so that they can be moved using a fork-lift truck.	160	Commerce
wo_re_fwo_	J167	G167	Wooden fireworks & matches	A small thin piece of wood or cardboard tipped with flammable chemicals that catch fire with friction (match); any wooden remains of fireworks, e.g. sticks from rockets.	167	Chemical industries

4.1.5. Multi-criteria optimisation model

This section outlines the methodology for the optimisation of floating riverine litter technologies, focusing on energy self-sufficiency of technology. The following two floating riverine litter retention technologies have been selected to be part of the optimization model:

1. Technology 1, hybrid MOLD/MINDS solution, developed by partners MOLD and MINDS (WP2. T2.1);
2. Technology 3, CirCleaner, developed by partner NOR (WP2, T2.6).

The forementioned technologies are active systems that rely on electricity for its operation. A key distinction between these two technologies and the active Technology 2, the Archimedean Drum Screen developed by partner FF (WP2, T2.2), is that they generate their own electricity using renewable energy sources, such as solar energy.

A multi-objective optimization model will determine the optimal sizing of the photovoltaic system, based on the specific power requirements of technologies and the prevailing environmental conditions by also considering the environmental emissions related to the photovoltaics system. This optimization will be conducted using the General Algebraic Modelling System (GAMS), a high-level modelling platform designed for formulating and solving linear, nonlinear, and mixed-integer optimization problems (Ćalasan et al., 2021). The optimisation model will follow the work, which has been conducted by Okoye and Solyalı (2017), on the optimal sizing of stand-alone photovoltaic system in residential buildings. This proposed model will be upgraded to a multi-objective optimisation model, by also considering the environmental emissions, connected to the used photovoltaics, using the for the two chosen INSPIRE technologies.

4.1.5.1. Stand-alone photovoltaic system

A typical off-grid stand-alone photovoltaic (PV) system consist of a PV panel array, a battery storage system, a charge controller and a inverter for DC/AC conversion (Ali et al., 2018), as seen in Figure 19.

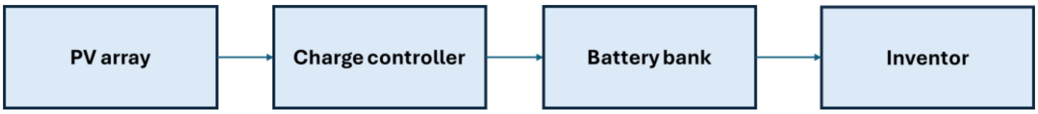


Figure 19: Typical stand-alone PV system, based on (Ali et al., 2018).

The PV array captures solar irradiance and converts it into direct current electrical power. The electricity is then used to directly power devices, while the excess energy, that is produced by PV array, is stored in battery. When electricity is needed, the stored energy flows from the battery through the inverter, which converts the DC power into alternating current power, ready to operate devices (Bataineh & Dalalah, 2012).

The energy that is generated by one PV module in a month can be estimated using Equation 8

$$E_t = a_{pv} I_{tilt,t} \eta_{wire} \eta_{PV} \qquad (8)$$

Where a_{pv} is the area of one PV module, I_{tilt} is the average monthly solar irradiance, η_{wire} is the efficiency of the wire and η_{PV} is the efficiency of the PV module.

For the solar irradiance an average monthly value will be taken, using past data up to 2020 derived from Photovoltaic Geographical Information System (PVGIS), developed by JRC (PVGIS, 2022). The average monthly values will be determined based on the average irradiance at each hour in the month. To determining the average daily irradiance, the following technology parameters will be used:

1. Latitude and longitude coordinates of the deployment location
2. The slope angle of PV modules, installed on individual technologies.
3. The azimuth angle of the PV modules, installed on individual technologies.

The efficiency of the PV system can be obtained using Equation 9

$$\eta_{PV} = \eta_{ref}\left(1 - \beta_{ref}(T_c - T_{stc})\right) \tag{9}$$

The efficiency of the PV system is dependent on the reference efficiency (η_{ref}), the temperature correction factor/power temperature coefficient of module (β_{ref}), the cell temperature (T_c) and standard testing temperature (T_{stc}). The reference efficiency will be based on the manufacturer's information.

The cell temperature of PV is determined using Equation 10

$$T_c = T_a + \frac{NOCT-20}{800} * I_{till} \tag{10}$$

where T_a is the average ambient temperature of location, I_{till} is the average solar radiation and $NOCT$ is the nominal operating cell temperature. The latter will be provided from the manufacturer of the PV panel.

Based on the number of average sunny hours per month (h) , the total number of solar panels (N) can be determined by the following Equation 11 (Bataineh & Dalalah, 2012).

$$N = \frac{E_t \cdot h}{P_N} \tag{11}$$

Where P_N is the peak power of the module, provided by the PV manufacturer. The number of average sunny days per month will be obtained from PVGIS.

Emissions, associated with the production of PV panels, will be calculated using Equation 12

$$X_E = N \cdot e_{PV} \tag{12}$$

N represents the total number of PV panels in use, while e_{PV} refers to the emissions associated with the production of these PV modules. Emission data for various types of PV panels will be sourced from SimaPro software (PRé, 2020), using the Ecoinvent database (Weidema et al., 2013) and the Environmental Footprint method (PRé, 2020), as shown in Table 35. These emission factors will then be adjusted according to the size of the PV systems installed at the demonstration sites.

Table 35: Emissions obtained from Ecoinvent database, using the Environmental Footprint method.

Ecoinvent dataset	Emission factor
Photovoltaic panel, multi-Si wafer (RER)| photovoltaic panel production, multi-Si wafer|Cut-off, U	218 kg CO_2 eq / m^2
Photovoltaic panel, ribbon-Si (RER)| photovoltaic panel production, ribbon-Si |Cut-off, U	173 kg CO_2 eq / m^2
Photovoltaic panel, single-Si wafer (RER)| photovoltaic panel production, single-Si wafer|Cut-off, U	283 kg CO_2 eq / m^2

4.1.5.2. GAMS multi-criteria optimisation model

The following presents the initial structure of the model intended for optimizing the electrical self-sufficiency of technologies. This model structure will undergo further refinement during its developmental phase. Overall, the aim of the optimisation model is to minimize the number of solar panels, that each technology would need for their operation by simultaneously including the emission factors associated with the production of such PV panels. The multi-criteria optimisation model will follow the Epsilon Constraint method, where one objective function is optimized using the other objective function as constraints (GAMS). This model has the following parameters and variables:

Parameters:

E_t	Energy generated by one PV module in month t
$I_{tilt,t}$	Average monthly solar irradiance
P_N	Nominal power of PV module
T_a	Ambient temperature of location
T_c	Cell temperature of PV module
T_{stc}	Standard testing temperature
X_E	CO_2 emissions of PV system
$X_{e.lo}$	Minimal acceptable CO_2 emissions
a_{PV}	Area of one PV module
d_t	Energy demand of technology in month t
e_{PV}	CO_2 emissions of one PV module
n_{PV}^{max}	maximum number of PV modules that can be installed
n_b^{max}	maximum number of batteries that can be installed
s_l	minimum storage level of battery
s_u	maximum storage level of battery
β_{ref}	Temperature correction factor of PV module
η_{PV}	Efficiency of PV module
η_{inv}	Efficiency of inverter
η_{ref}	Reference efficiency
η_{wire}	Efficiency of wire
Δ	minimum storage level of battery
H	Number of months in a year
$NOCT$	Nominal operating cell temperature
f	Number of iterations

Variables:

B	Number of batteries to install
N	Number of PV modules to install
Y_t	Amount of energy stored from the generated energy of PV in a month t
U_t	Amount of load demand that is unsatisfied in month t
S_t	Amount of accumulated energy stored by the battery bank at the end of month t

To determine the optimal number of PV modules the following structure will be employed.

Min N

Objective function $N = \frac{E_t \cdot h}{Peak\ power\ of\ a\ module}$

Subject to

$$S_t = S_{t-1} + Y_t - \frac{d_t}{\eta_{inv}} \qquad \forall\ 1 \le t \le H \qquad (13)$$

$$Y_t \le E_t N \qquad \forall\ 1 \le t \le H \qquad (14)$$

$$s_l B \le S_t \le s_u B \qquad \forall\ 0 \le t \le H \qquad (15)$$

$$B \le n_b^{max} \qquad (16)$$

$$X \le n_{PV}^{max} \qquad (17)$$

$$Y_t \ge 0, \qquad \forall\ 0 \le t \le H \qquad (18)$$

$$B \ge 0, N \ge 0 \qquad (19)$$

$$X_E = X_{e.lo} + \Delta \cdot f \qquad (20)$$

$$X_E > X_{e.lo} \qquad (21)$$

Equation 13 specifies that the total energy stored in the batteries at the end of month t is equal to the sum of the energy stored at the end of previous month, the energy generated by the PV system during month t, and the load demand in month t. Equation 14 indicates that the amount of energy produced by the PV system and stored in the batteries cannot exceed the total energy generated by the PV system. Equation 15 ensures that the battery's energy level at the end of the month remains within its lower and upper storage capacity limits. Equation 16 and Equation 17 imposes upper limits on the number of batteries and PV modules that can be installed. Equation 18 requires all variables to be non-negative, while Equation 19 ensures that the number of batteries and PV modules are non-negative integers. Equation 120 describes the adjusted emission factors, calculated by increments $(\Delta \cdot f)$ to the lower emission factor and Equation 21 defines the emission factor to be greater than the minimum emission factor.

This multi-objective optimization model will be applied to two specific technologies: the hybrid MOLD/MINDS solution and CirCleaner. Detailed specifications of the PV modules, including type, area, installation angle, efficiency, nominal power, and other relevant parameters, will be provided by the technology provider and are defined in Table 36. Environmental data, such as average monthly ambient temperatures and solar irradiation, will be sourced from PVGIS (PVGIS, 2022) for each of the two demonstration sites: Santa Gulia (Po river) and Londenhaven (Rhine river).

Table 36: Technical parameters of the PV.

Parameter	Symbol	Unit
Type of PV module		/
Size of PV module	a_{PV}	m^2
Reference efficiency of PV module	η_{ref}	%
Standard testing temperature	T_{stc}	°C
Nominal operating cell temperature of PV module	$NOCT$	°C
Slope of PV module	α	°
Azimuth angle of PV module	ω	°
Nominal power of PV module	P_N	kW
Efficiency of the inverter	η_{inv}	%
Minimal battery capacity	s_l	kWh
Maximal battery capacity	s_u	kWh

4.2. Evaluation of Hybrid MOLD/MINDS system

This section outlines the evaluation of the hybrid MOLD/MINDS system, a floating riverine macro-litter retention technology developed by partners MOLD and MINDS. This system integrates two distinct technologies:

1. The River Cleaning System, provided by MOLD, which has been used in REMEDIES – Co-creating strong uptake of REMEDIES for the future of our oceans through deploying plastic litter valorization and prevention pathways, a Horizon EU Mission "Restore our Ocean and Waters" program.
2. The CLEAN TRASH Collection cage, provided by MINDS, which has been developed in the previously successful Cleaning Litter by developing and Applying Innovative Methods in European sea (CLAIM), part of the H2020 Project EU.

In INSPIRE, both technologies have been upgraded and combined into a hybrid system capable of capturing floating riverine macro-litter. This integrated system is 100% electricity self-sufficient, making it particularly useful in decentralized locations with limited access to the electrical grid. A detailed description of the technology's characteristics can be found in WP2, T2.1.

4.2.1. Technology overview and testing location

a) The preliminary MOLD's River Cleaning system overview

This section describes the technology to be implemented in Tirana as part of the REMEDIES project under the Horizon EU Mission. The technology will be deployed in late 2024 and will remain in use for the duration of the REMEDIES project and beyond. The system consists of a modular barrier made up of floating buoys, designed to intercept and redirect litter carried by river currents. Figure 20 shows a MOLD River Cleaning system similar to the one being deployed in Tirana, previously installed in Milan, Italy.

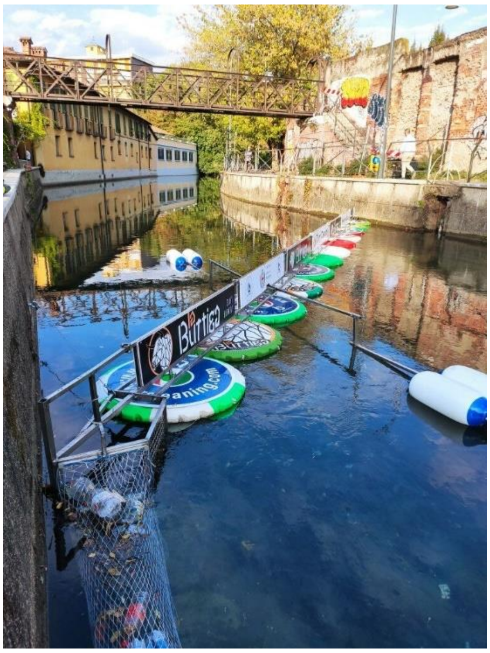


Figure 20: The River Cleaning system in Milan, Italy.

These buoys are specifically engineered to operate in flowing waters, where the natural force of the stream causes each buoy module to rotate around its axis. As they spin the buoys effectively guide floating litter towards a collection system positioned at the rear of the setup. The River Cleaning system can be configured to cover either the entire width of the river or just portions of it. By positioning the buoys diagonally, the system leverages their natural rotation to direct incoming litter towards the collection point located near the riverbank.

b) Preliminary MINDS CLEAN TRASH collection cage overview

The CLEAN TRASH collection cage was developed under the CLAIM project, part of Horizon 2020 program. It comprises a floating boom system and a collection cage designed to capture and retain floating litter, specifically in river mouths and waterways. The collection cage is constructed from hot-dipped galvanized steel and features three separate chambers that can be raised or lowered to trap floating debris as small as 5 mm. Additionally, the cage is equipped with lifting points and a sliding door, as shown in Figure 21.

Figure 21: CLEAN TRASH collection cage, developed in CLAIM project.

c) INSPIRE upgraded and combined solution

For the INSPIRE project, a hybrid solution combining an upgraded River Cleaning system and the CLEAN TRASH collection cage was proposed. Building on insights from previous projects, the following updates have been implemented:

- The construction material for the floating buoys has been upgraded from plastic to stainless steel.
- Solar energy are now utilized to power the lifting of the buoy barrier.
- A camera system has been integrated to monitor the entrance of the CLEAN TRASH collection cage.
- The collection cage has been modified to include two compartments instead of three.
- An automated lifting cycle, which represents a part of the standard operating and maintenance procedure, will be included. Given that the rivers can transport significant amounts of organic material (such as wood chunks, vegetation, and algae), this process ensures the barrier remains clean and operational over extended periods without requiring manual intervention.

As the system is not yet developed, Figure 22 showcases an image rendering of the hybrid MOLD/MINDS solution, developed, and deployed under INSPIRE project.

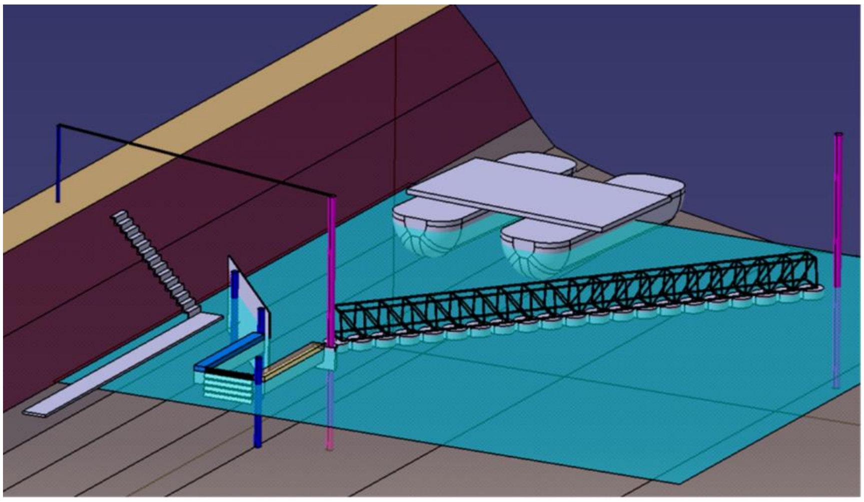


Figure 22: Rendering of the combined River Cleaning system and CLEAN TRASH collection cage, developed under INSPIRE project (Provided by Nicola Rubini).

Testing locations

As part of the INSPIRE project, the new hybrid MOLD/MINDS technology, will be deployed near the Santa Gulia boat bridge, located on the Po della Donzela river, Italy. The INSPIRE testing location is marked with an orange X (44.8383, 12.3743) in Figure 23.

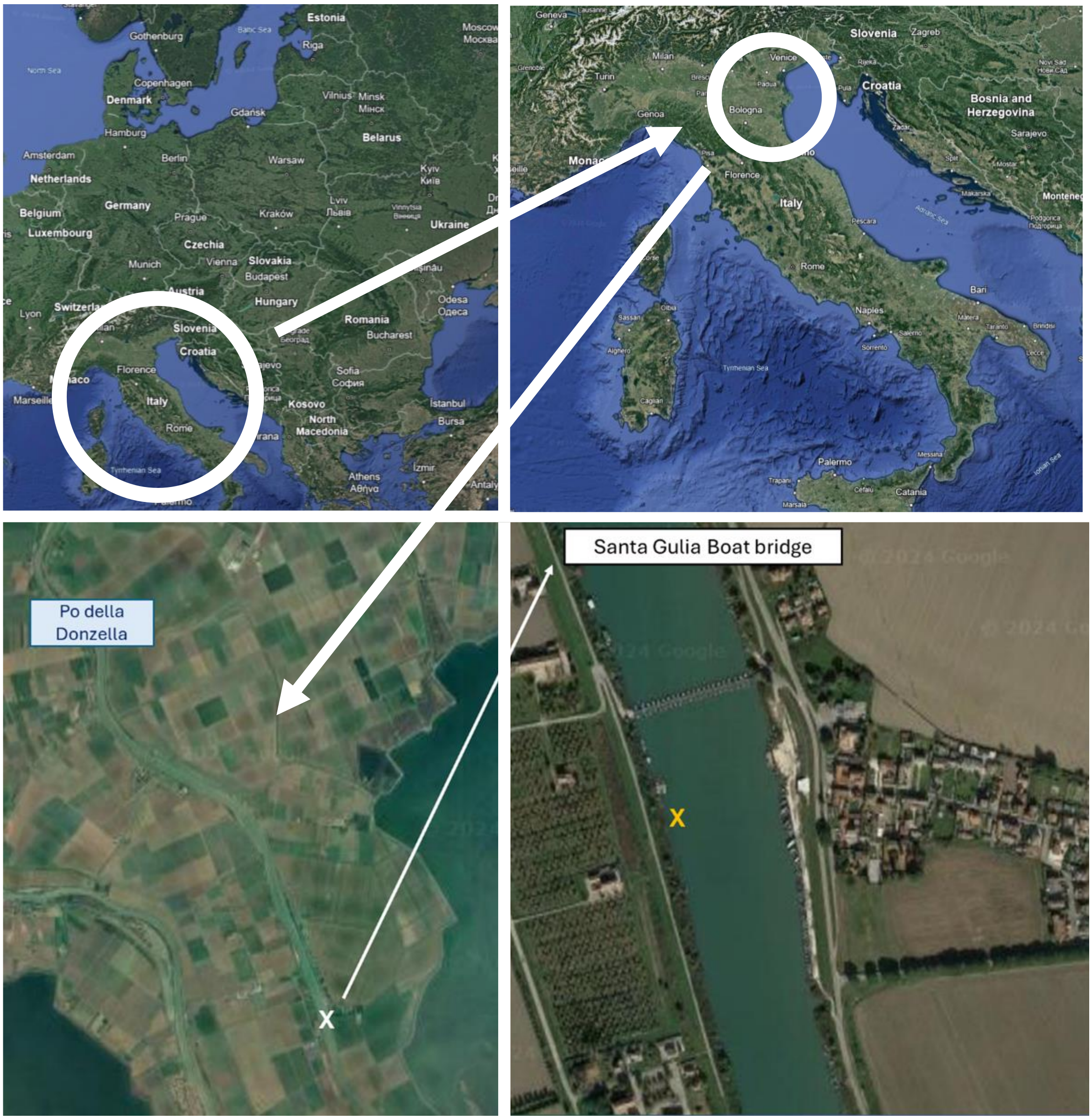


Figure 23: Hybrid MOLD/MINDS solution deployment location (top left: map of the EU, top right: map of Italy, bottom left: Po della Donzella within Italy, bottom right: detailed satellite image of the location, marked with X).

4.2.2. Integration of sensors for optimisation of hybrid MOLD/MINDS operation

During the operation of the hybrid MOLD/MINDS solution, the technical, operational, environmental, and biological parameters, defined in Section 4.1.1 will be gathered.

4.2.2.1. Technical parameters

The technical parameters for the hybrid MOLD/MINDS solution will be obtained when the technology will be deployed on the Po River. It will include information on the dimensions of the CLEAN TRASH collection cage and its mesh size, as well as the number of floating buoys. Preliminary parameters are defined in Table 37 but will be adequately changed after the final design of the hybrid MOLD/MINDS system will be determined.

Table 37: Technical specifications of the hybrid MOLD/MINDS system.

CLEAN TRASH collection cage (MINDS)	Length	5724 mm
	Hight	3097 mm
	Width	2473 mm
	Mesh size	5 mm
River Cleaning system (MOLD)	Number of buoys	20
	Buoys diameter	1000 mm
	Barrier length	20 m

4.2.2.2. Operational parameters

The operational parameters of hybrid MOLD/MINDS will be retrieved from 2 different types of sensors: (i) integrated and (ii) surroundings sensors.

Integrated sensors

a) River Cleaning System (MOLD)

Four types of integrated sensors have been identified to be mounted on River Cleaning System, provided by MOLD, which will gather continuous data during the operation of the technology. Table 38 provides an overview of the type of sensors with their corresponding mounting locations. As this system can produce its own electricity, two power meters will also be used to gather information on the amount of energy that is being produced from solar panels and the amount of electricity being consumed during the daily operation.

Table 38: Parameters and sensor specification of integrated sensors.

Sensor type	Parameter	Location of installation
Vibration accelerator sensor	Movement of system	Railing of the structure
Power meter 1	Energy consumption	Near the electrical compartment of MOLD
Power meter 2	Energy production	Near solar panels
Water current sensor	Water current speed	Near the entrance of the hybrid system
Water level sensor	Depth of the river	Near the entrance of the hybrid system
Ultrasonic sensor	Detection of large debris	Railing of the structure

1. Power meters

Two power meters will be used to measure the energy production and energy consumption during the operation of MOLD system. One power meter will be installed near the solar panel, used to produce electricity, while the other power meter will be used for measuring the energy consumption during the lifting of MOLD system from water.

2. Water current sensor

A water current sensor will be installed near the entrance of the hybrid technologies site. This flow meter will measure the water stream current in the Po Donzella river section where the technology is being deployed

3. Accelerator

An accelerometer will be mounted on the connection frame at the top of the MOLD River Cleaning system. This device will measure the movement and vibrations induced by the water flow.

4. Water level sensor

A water level sensor will be employed near the entrance of the hybrid technologies. This sensor will measure the water depth of at any given moment, giving information on the water depth and tidal impact at the location.

b) CLEAN TRASH collection cage (MINDS)

Three types of integrated sensors have been identified to be mounted on CLEAN TRASH collection system, provided by MINDS, which will gather continuous data during the operation of the technology. Table 39 provides an overview of the type of sensors with their corresponding mounting locations. As this system can produce its own electricity, 2 power meters will also be used to gather information on the amount of energy that is being produced from solar panels and the amount of electricity being consumed during the daily operation. Additionally, the system is already equipped with a camera, which will be used to gather information on the type of litter that enters the CLEAN TRASH collection cage.

Table 39: Parameters and sensor specification of integrated sensors. X indicates the sensors that are already part of the technology.

Sensor type	Parameter	Location of installation	Already integrated in system
Accelerometer sensor	Movement and vibrations of system	On floating MINDS frame	
Power meter 1	Energy consumption	At electrical compartment of MINDS	
Power meter 2	Energy production	Near solar panel	
Device monitoring camera	Visualization of system operation	On riverbank or nearby Santa Gulia bridge	X
Litter monitoring camera	Number of items entering the system	On riverbank	X
Ultrasonic sensor 1	Fullness of the system	On the MINDS collection cage	
Ultrasonic sensor 2	Water current speed	On floating MINDS frame	

1. **Power meters**

   Two power meters will be used to measure the energy production and energy consumption during the operation of MINDS system. One power meter will be installed near the solar panel, used to produce electricity, while the other power meter will be used for measuring the energy consumption during the lifting of MINDS collection compartments, when it would reach full capacity.

2. **Ultrasonic sensor**

   An ultrasonic sensor will be part of the CLEAN TRASH collection cage, which would measure the fullness of the system. This sensor will work in combination with the AIT monitoring camera, where a signal would be triggered when the system would reach a predefined threshold depth value. This signal will be validated using the AIT monitoring camera.

3. **Accelerometer**

   An accelerometer will be mounted on the floating frame of the MINDS CLEAN TRASH collection system. This device will measure the movement and vibrations induced by the water flow.

To monitor the hybrid MOLD/MINDS solution, a camera system will be utilized. Here an additional camera will be either position on the nearby riverbank, or the AIT camera, used for the monitoring of CLEAN TRASH litter items will be used. Additionally, AIT camera mounted on the Santa Giulia bridge.

Surrounding sensors

Two surrounding sensors will be used in the near proximity of the hybrid MOLD/MINDS solution, which will be used to gather noise pollution during its operation.

One-time underwater noise measurements will be conducted using a hydrophone by partner VLIZ as part of their T1.4 activities. Similarly to underwater noise, above-ground noise will be measured using a sound sensor, as depicted in Table 23. Both sound measurements will be based on one-time recordings.

4.2.2.3. Environmental parameters

The environmental parameters will be obtained from the weather and hydro station. Figure 24 shows the location of the weather (red) and hydro (blue) station in relation to the deployment location of the hybrid MOLD/MINDS solution (orange X).

Figure 24: Location of the weather (red circle) and hydro (blue circle) stations in comparison to the deployment location of the hybrid MOLD/MINDS technology (orange X).

The station name, coordinates and their websites are presented in Table 40.

Table 40: Overview of weather and hydro station for Po River.

Stations	Station name	Station coordinates	Website
Weather station	Vnt428	Lat 44.84931, Lng 12.35367	https://www.agenziaitaliameteo.it/
Hydro station	Po, Porto Barricata	Lat 44.8475, Lng 12.4648	https://earlyfloodalert.com/

4.2.2.4. Biological parameters

During the operation of hybrid MOLD/MINDS system, the biological parameters, as identified in Section 4.1.1, will be assessed. The proportion of harmed and not harmed animal by-catch will be conducted during the monitoring of retained litter. If no animals will be present, this will be clearly documented.

4.2.3. Processed water

The volume of water processed will be calculated using the technical, operational, and environmental parameters gathered during the operation of the MOLD/MINDS solution. The distance from the starting point of the MOLD buoy system to the riverbank will determine the width of the water the system can process. Additionally, the volume of water processed by the combined MOLD/MINDS solution can be estimated based on the fill depth of the MINDS collection system. These values will then be multiplied by the current flow rate data obtained from the current flow meter installed near the technology.

4.2.4. Retained litter monitoring frequency

The monitoring of the retained floating riverine litter will be done based on the implementation duration of hybrid MOLD/MINDS system, following the protocols described in D4.1, section 4.1.3.2. Table 41 gives an overview of the start and end month of hybrid MOLD/MINDS system's operation period under INSPIRE project. The planned operational period for this technology is 12 months.

Table 41: Overview of the Implementation period or hybrid MOLD/MINDS.

Task	Technology	Demo site leader	Implementation start	Implementation end	Operation interval
T2.1	Hybrid MOLD/MINDS	CNR	Spring 2026	Currently in discussion as of September 2024	12 months

The emptying intervals will be determined when the hybrid solution will be deployed. The monitoring of the retained floating riverine litter will be conducted 4 times, following the months chosen for each season, as described in Section 4.1.3.2. The monitoring of the retained floating riverine litter will be conducted by the demo site leaders. Table 42 gives an overview of the retained floating riverine litter monitoring process.

Table 42: Overview of the retained litter monitoring activities for hybrid MOLD/MINDS system.

Demo site leader	CNR
Monitoring timeline (based on operational period)	M13-M25
Number of retained floating riverine litter monitoring campaigns	4 (each season) • Winter (Dec – Feb) • Spring (Mar – May) • Summer (Jun – Jul) • Autum (Sep – Nov)
Equipment used	Trays, garbage bags, hanging scale, small weighting scale tarp or canvas, mobile phone,
Litter separation and classification	Protocols developed in Section 4.1.3.1
Retained floating riverine monitoring data	Datasets, defined in Section 4.1.3.3 for each monitoring campaign
Data input methods	Datasheet, INFOR's mobile interface

4.3. Evaluation of Archimedean Drum Screen

This section describes the evaluation of Archimedean Drum Screen, a floating riverine macro- and meso-litter retention technology, developed by partner FF. A detailed description of the technology and its characteristics are described under WP2, T2.2.

4.3.1. Technology overview and testing location

Technology overview

Archimedean Drum Screen working operation resembles the well-known Archimedean screen used for water transport. It is comprised of mesh cylinder with a screen surface installed in the inner cylinder, as seen in Figure 25. For a detailed description of the Archimedean Drum Screen operation, refer to T2.2 of WP2.

The inlet of the rotating screen includes an additional metal structure, as seen in Figure 25 a), where the strobe lights are installed to deter the fish from entering the system. Litter items, that enter the rotating screen are moved to litter outlet and are retained using a net, as shown in Figure 25 b). Water which has been processed flows through the designated water outlet, the larger circular outlet, shown in Figure 25 c), while the smaller circular outlet in the same image represents the bypass system that the fish can use if they enter the system.

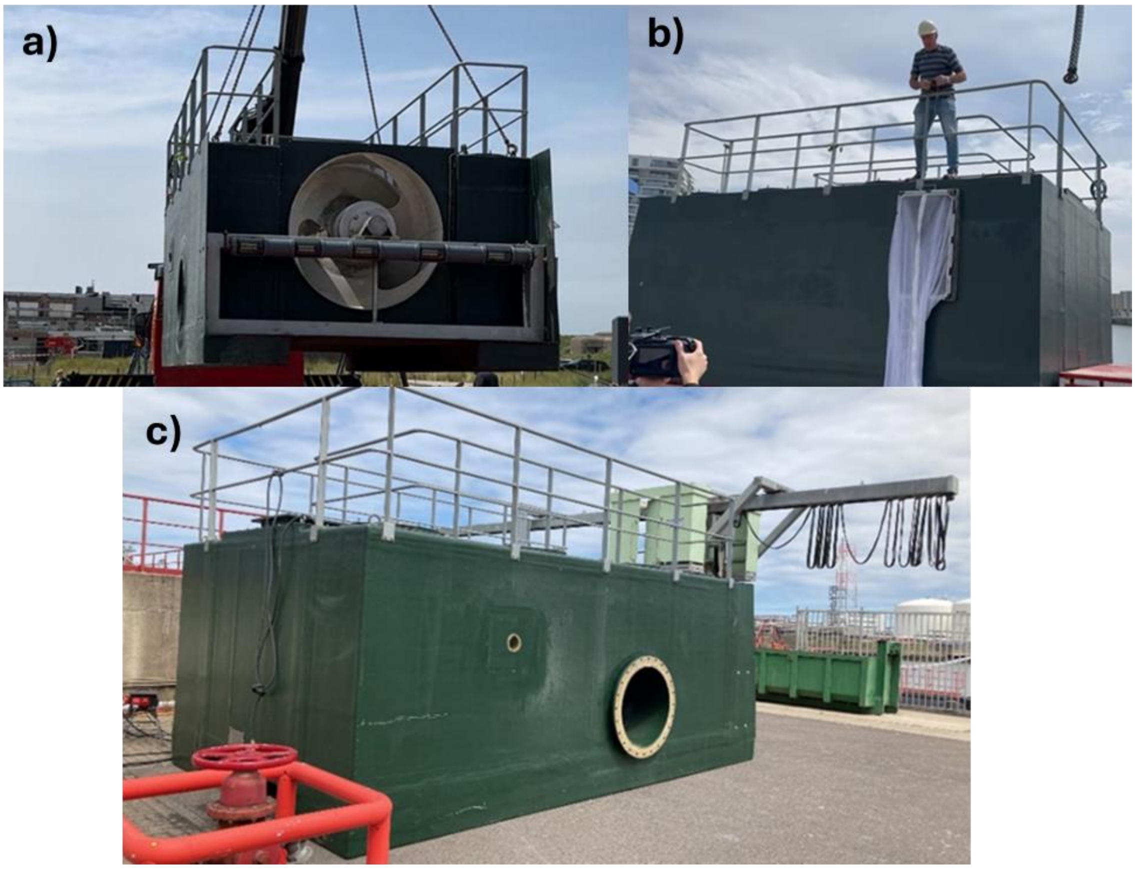


Figure 25: Different perspective of the Archimedean Drum Screen a) front view of the intel and strobe lights, b) right side view for the litter outlet and collection net and c) left side view for water outlet and fish bypass system (Photographs by Annamaria Vujanović).

Testing location

Archimedean Drum Screen will be tested in 3 different demo sites: port of Ostend (Belgium), Rhine (The Netherlands) and Danube (Romania). The assessment under T4.1 will focus only on one location, on the Scheldt demo site, where the technology is located in the Port of Ostend, depicted with an orange X (51.2360, 2.9292) on Figure 26.

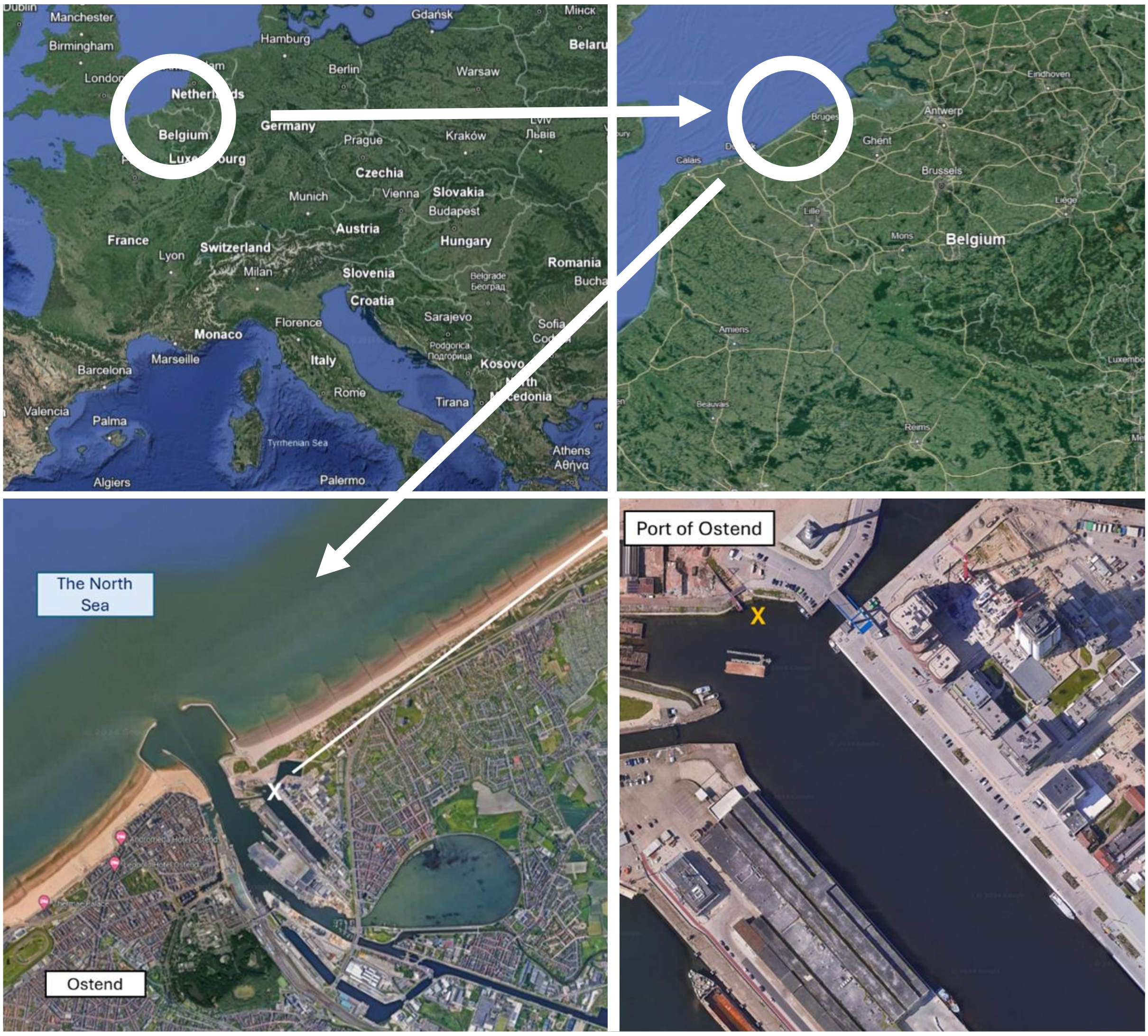


Figure 26: Implementation location of the Archimedean Drum Screen (top left: map of the EU, top right: map of Belgium, bottom left: Ostend within Belgium, bottom right: satellite image of the port of Ostend, location marked with X).

The deployment of the Port of Ostend was conducted on June 3rd, 2024. Figure 27 a) present the transportation of Archimedean Drum Screen from Dissel 4, 1671 NG Medemblik, The Netherlands – FishFlow Innovations (52.76488, 5.09445) to Slipwaykaai 2, 8400 Oostende, Belgium – VLIZ Marine Station Oostende (MSO) (51.2360, 2.9292). Figure 27 b) shows the unloading of Archimedean Drum Screen with a crane and its deployment to the dock.

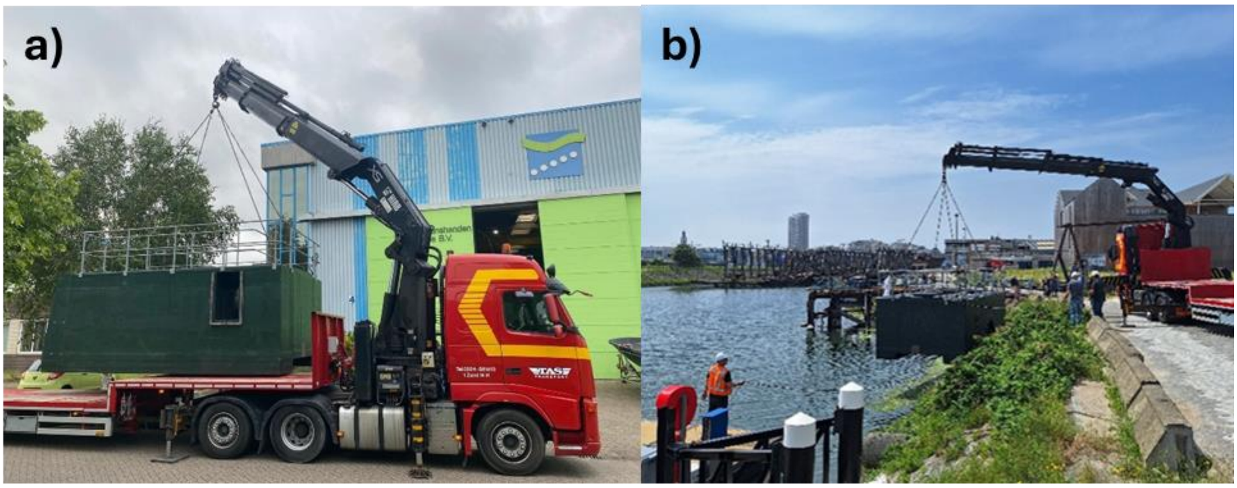


Figure 27: Unloading of Archimedean Drum Screen from the truck (a) and its deployment to the dock (b) (Photographs by Annamaria Vujanović and Mariana Miranda).

Lastly, Figure 28 shows the dock location before and after the deployment of the technology.

Figure 28: Testing location before (a) and after (b) the deployment of Archimedean Drum Screen (Photograph by Mariana Miranda).

4.3.2. Integration of sensors for optimisation of Archimedean Drum Screen operation

During the operation of Archimedean Drum Screen, the technical, operational, environmental, and biological parameters, defined in Section 4.1.1 will be gathered.

4.3.2.1. Technical parameters

The technical parameters for the Archimedean Drum Screen have already been during the initial testing phase under INSPIRE project, held in July 2024. Table 43 outlines the dimensions of the rotating screen and the additional information of the auxiliary equipment.

Table 43: Technical specifications of the Archimedean Drum Screen and auxiliary equipment.

Archimedean Drum Screen dimensions	Length	2000 mm
	Diameter	1650 mm
	Mesh size	8 mm
Retention net	Volume	Variable
	Mesh size	5 mm

4.3.2.2. Operational parameters

The operational parameters of Archimedean Drum Screen will be retrieved from two different types of sensors: (i) integrated and (ii) surroundings sensors.

Integrated sensors

Five types of integrated sensors have been identified to be mounted on Archimedean Drum Screen, which will gather continuous data during the operation of the technology. Table 44 provides an overview of the type of sensors with their corresponding technical specifications.

Table 44: Parameters and sensor mounting location for the integrated sensors on Archimedean Drum Screen.

Sensor type	Parameter	Location of installation
Power meter	Electricity consumption	Electrical compartment of technology
Ultrasonic sensor	Number of items entering the system	Strobe light structure
Accelerometer sensor	Movement and vibrations of system	Railing of the structure
Device monitoring camera	Visualization of system operation	In nearby locations on land or on the railing at the corner.
Underwater camera	Visuals of items entering the system	Strobe light structure
Water flow sensor	Flow of processed water	Water outlet

Figure 29 shows the mounting position of the 6 integrated sensors.

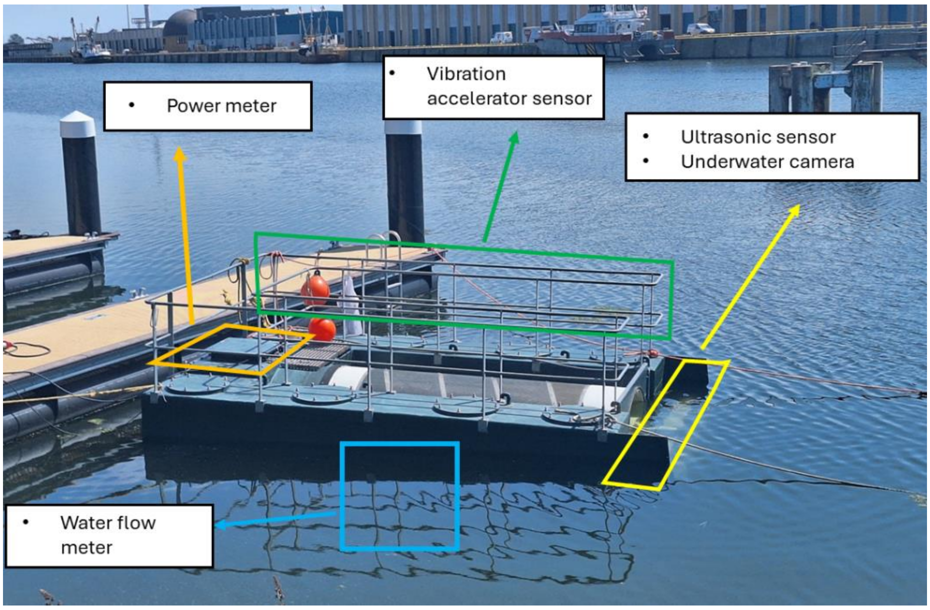


Figure 29: Integrated sensor locations on the Archimedean Drum Screen: Power meter, water flow meter, ultrasonic sensor and vibration accelerator sensor.

1. Power meter

The electrical compartment of the technology will house the plug sensor, which will gather continuous data on the amount of electricity that Archimedean Drum Screen consumes. The electrical compartment houses the rotor, used for the rotating of the mesh drum, axial pumps for pumping the chambers of water and additional electrical wirings of the strobe lights.

2. Ultrasonic sensor

The ultrasonic sensor will be installed at the entrance of the Archimedean Drum Screen, positioned just before the rotating screen. It will be mounted on the metal bar of the structure used for strobe lights and will remain submerged underwater.

3. Accelerometer sensor

The accelerometer sensor will be mounted on the railing of the Archimedean Drum Screen.

4. Device monitoring camera

The monitoring camera, which will oversee the device during operation, will be mounted near the deployment location of Archimedean Drum Screen, on land. However, if some location would be unavailable, the camera, will be installed on the railing at the corner of Archimedean Drum Screen.

5. Underwater inspection camera

The underwater inspection camera will be installed on a metal bar just under the water level, at the entrance point of the device.

6. Water flow sensor

The water flow sensor will be mounted on the outlet of the Archimedean Drum Screen and will be used to calculate the volume of water the technology would process.

Surrounding sensors

Two surrounding sensors will be used in the near proximity of the Archimedean Drum Screen, which will be used to gather noise pollution during the operation of Archimedean Drum Screen.

One-time underwater noise measurements will be conducted using a hydrophone by partner VLIZ as part of their T1.4 activities. Similarly to underwater noise, above-ground noise will be measured using a sound sensor, as depicted in Table 23. Both sound measurements will be based on one-time recordings.

4.3.2.3. Environmental parameters

The environmental parameters will be obtained from the weather and hydro station. Figure 30 shows the location of the weather (red) and hydro (blue) station in relation to the deployment location of Archimedean Drum Screen (orange X).

Figure 30: Location of the weather (red circle) and hydro (blue circle) stations in comparison to the deployment location of Archimedean Drum Screen (orange X).

The station name, coordinates and their websites are presented in Table 45.

Table 45: Weather and hydro station overview.

Stations	Station name	Station coordinates	Website
Weather station	Station van Oostende - Het Weer In België	51.2290, 2.9257	https://www.meteobelgie.be/
Hydro station	Oostende MVB tij/Noordzee (OST-1069)	51.2343, 2.9266	https://www.waterinfo.vlaanderen.be/

4.3.2.4. Biological parameters

As the technology is designed to be non-harmful to fish, additional tests will be conducted to assess such claims. The number of fish and other aquatic animals that may potentially enter the Archimedean Drum Screen will be recorded using an underwater camera, mounted at the entrance. Additionally, a small net will be deployed in the bypass (see Figure 25 c)) to capture any fish that move through the system. Monitoring of the net will occur daily or every other day during the operation of the Archimedean Drum Screen. During these inspections, the parameters outlined in Section 4.1.3.3 will be documented.

An additional test could be conducted to identify the species passing through the system. In this test, the Archimedean Drum Screen would operate under normal conditions, with a small net being placed at the fish bypass. During such testing phase, both the species passing through the bypass and those entering the litter collection system will be documented.

4.3.3. Processed water

The calculation on the volume of process water will be based on the technical, operational, and environmental parameters, obtained during the operation of Archimedean Drum Screen. The fill depth of the technology will be used to determine the water fullness level in Archimedean Drum Screen, while the volume of the rotating screen will be determined through geometrical calculations using technical parameters of the technology. Based on the data, gathered from flow meter, the amount of water, that Archimedean Drum Screen could process, during its operation, will be determined.

4.3.4. Retained litter monitoring frequency

The monitoring of the retained floating riverine litter will be done based on the implementation duration of Archimedean Drum Screen, following the protocols described in D4.1, section 4.1.3.2. Table 46 gives an overview of the start and end month of Archimedean Drum Screen operation period under INSPIRE project. The planned operational period for this technology is 12 months.

Table 46: Overview of the Implementation period or Archimedean Drum Screw.

Task	Technology	Demo site leader	Implementation start	Implementation end	Operation interval
T2.2	Archimedean Drum Screen	VLIZ	M13	M25	12 months

The monitoring of the retained floating riverine litter will be conducted 4 times, following the months chosen for each season, as described in Section 4.1.3.2. The monitoring of the retained floating riverine litter will be conducted by the demo site leaders. Table 47 gives an overview of the retained floating riverine litter monitoring process.

Table 47: Overview of the retained litter monitoring activities for Archimedean Drum Screen.

Demo site leader	VLIZ
Monitoring timeline (based on operational period)	M13-M25
Number of retained floating riverine litter monitoring campaigns	4 (each season) • Autum 2024 (Oct – Nov) • Winter 2024/2025 (Dec – Feb) • Spring 2025 (Mar – May) • Summer 2025 (Jun)
Equipment used	Trays, litter bags, hanging scale, small weighting scale, tarp or canvas, mobile phone
Litter separation and classification	Protocols developed in Section 4.1.3.1
Retained floating riverine monitoring data	Datasets, defined in Section 4.1.3.3 for each monitoring campaign
Data input methods	Excel Datasheet, INFOR’s data input app

4.4. Evaluation of CirCleaner

This section describes the evaluation of CirCleaner, a technology originally designed to collect riverine macro-, and meso-litter, developed by partner NOR. However, CirCleaner will be further developed, modified and tested under the INSPIRE project to see if it is able to collect floating plastic pellets (2 – 5 mm). A detailed description of the technology and its characteristics is provided under WP2, T2.6.

The technology, that is described in Section 4.4.1 is currently commissioned by the Municipality of Rotterdam as part of their efforts to reduce litter entering the sea and to achieve cleaner urban waters. This project marked the first-ever litter retention technology owned by the Municipality of Rotterdam to remove litter from their waterways.

Rotterdam, recognized as the largest port in Europe, also serves as the largest hub for plastic manufacturing. This industrial activity involves the production of plastic pellets, essential for creating a wide range of materials. However, due to their small size, these pellets are at high risk of being lost during handling, leading to their release into the environment. Rotterdam has been actively working to reduce the number of pellets in the port area and has conducted several cleaning campaigns (Plastic Soup Fondation, 2020). The Londenhaven port has also been selected as the testing site for the upgraded CirCleaner under INSPIRE project, due to abundance of plastic pellets present in the dock's riverbanks, as seen in Figure 31.

Figure 31: Plastic pellets contamination at Londenhaven riverbank (Photograph by Parshva Mehta).

As part of the INSPIRE project, CirCleaner will undergo an upgrade from the version previously purchased by the Municipality of Rotterdam. The enhanced system is designed specifically to capture plastic pellets, which are highly prevalent in the Ports of Rotterdam.

4.4.1. Technology and testing location description

a) Preliminary technology overview

The current CirCleaner is a floating riverine macro-, meso-, and large micro-litter retention system, designed with a boom that directs debris towards a central litter scooping mechanism as illustrated in Figure 32.

The system features 5 rotating blades that scoop litter from the water with each rotation. The current design of blades have a 5 mm mesh size, allowing water to pass through while capturing macro- and meso-litter. Once a blade reaches a near-vertical position, gravity pulls the collected litter downward into a collection chamber located at the centre of the rotating axis, as shown in Figure 32. The collection compartment can be pulled outward for easy retrieval of the litter.

Figure 32: CirCleaner's collection compartment (Photograph by Jan Puhar).

The system is fully self-sufficient, powered by solar panels. Additionally, a camera, mounted on a pole at the front of CirCleaner' s floating structure (seen in Figure 32), enables continuous monitoring during operation.

b) Adjusted version of CirCleaner under INSPIRE project

For the INSPIRE project, the current CirCleaner design, will undergo several adjustments to enhance its ability to capture and retain plastic pellets larger than 2 mm. The planned alterations include the following:

1. The mesh size of the rotating blades and the collection compartment will be reduced from 5 mm to 2 mm.
2. Additional rubber hammers will be installed to periodically hit the perforated mesh when the rotating blades approach a near-vertical position, aiding the plastic pellets in falling into the collection compartment.
3. A secondary 2 mm mesh will be added to the back of the CirCleaner to capture any pellets that remain on the blades after the hammer-induced impact. When the blades are submerged again, any remaining pellets will be collected by this additional mesh.

Deployment location of current CirCleaner

The current CirCleaner technology was deployed in June 2024 in De Keilehaven, Rotterdam and is in full possession of the Municipality of Rotterdam. Figure 33 showcases the deployment location just in front of the Keilehaven tidal park (51.9075, 4.4294)

Figure 33: CirCleaner location, deployed and installed in June 2024 (Photograph by Jan Puhar).

Testing location under INSPIRE project

As part of the INSPIRE project, the adjusted CirCleaner, designed to collect and retain plastic pellets, will be tested in Londenhaven, located in the Port of Rotterdam. The preliminary test site location is marked with a white X (51.8931, 4.2312) in Figure 34.

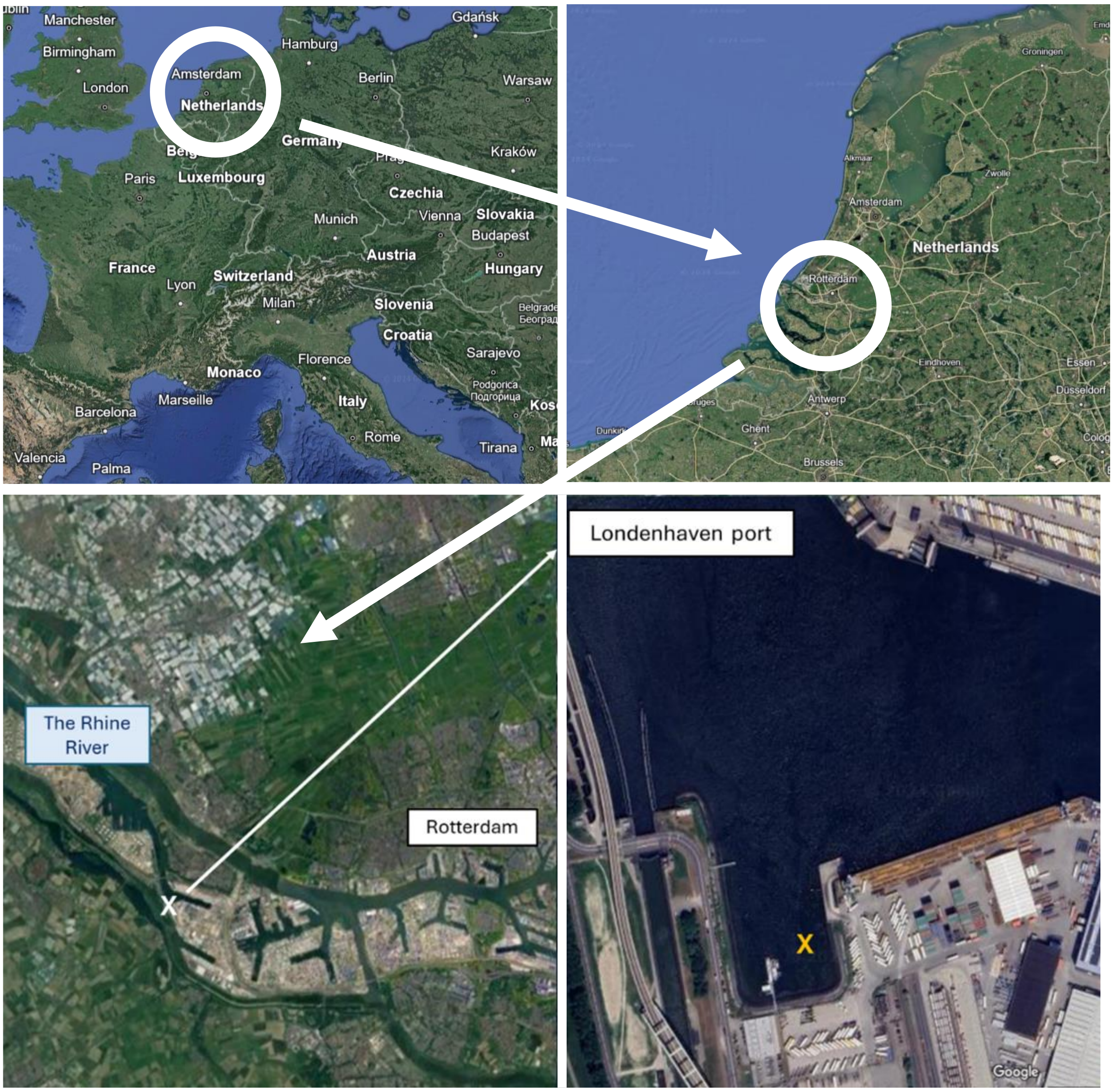


Figure 34: Deployment location of NORIA's CirCleaner (top left: map of the EU, top right: map of the Netherlands, bottom left: Rotterdam within the Netherlands, bottom right: Londenhaven port, location marked with orange X).

4.4.2. Obtaining the most influential parameters for optimisation of technologies

During the operation of the CirCleaner, the technical, operational, environmental, and biological parameters, defined in Section 4.1.1 will be gathered.

4.4.2.1. Technical parameters

Table 48 provides the technical specifications, on the mesh size as well as for the CirCleaner system which will be deployed under INSPIRE project. The missing data will be collected after the system is deployed at the demonstration site.

Table 48: Technical specification of CirCleaner system.

Collection compartment	Volume	600 L
	Mesh size	2 mm
Rotating blades	Mesh size	2 mm
Mesh size of additional retention system in the back		2 mm
Opening width of CirCleaner		

4.4.2.2. Operational parameters

The operational parameters of CirCleaner will be retrieved from 2 different types of sensors: (i) integrated and (ii) surroundings sensors.

Integrated sensors

Three types of sensors will be used to collect operational data from the CirCleaner system. However, since the system is already equipped with sensors for monitoring energy consumption and production, as well as cameras located on a pole near the entrance, no additional INSPIRE sensors measuring these same parameters will be installed. Consequently, only one sensors from the INSPIRE sensor kit will be used to gather data during CirCleaner's operation. Table 49 provides an overview of the sensor types and their mounting locations.

Table 49: Parameters and sensor mounting locations for the integrated sensors on CirCleaner. X indicates the sensors that are already part of CirCleaner, prior to the instalment of INSPIRE sensor kit.

Sensor type	Parameter	Mounting location	Already integrated with the system
Device monitoring camera	Visualization of system operation	Near the entrance of the system	X
Accelerometer sensor	Movement and vibrations of the system	On the floating frame of the system	
Power meter 1	Power consumption meter	Electrical compartment	X
Power meter 2	Power production meter	Electrical compartment	X

Figure 35 shows the mounting position of the integrated sensor vibration acceleration sensor, which will be attached on the floating framework that supports the CirCleaner system.

Figure 35: INSPIRE's vibration acceleration sensor mounting location on CirCleaner.

Surrounding sensors:

Two surrounding sensors will be used to measure noise pollution during the operation of CirCleaner.

One-time underwater noise measurements will be conducted using a hydrophone by partner VLIZ as part of their T1.4 activities. Similarly to underwater noise, above-ground noise will be measured using a sound sensor, as depicted in Table 23. Both noise measurements will be based on one-time recordings.

4.4.2.3. Environmental parameters

The environmental parameters will be obtained from the weather and hydro station. Figure 36 shows the location of the weather (red) and hydro (blue) station in relation to the deployment location of CirCleaner (orange X).

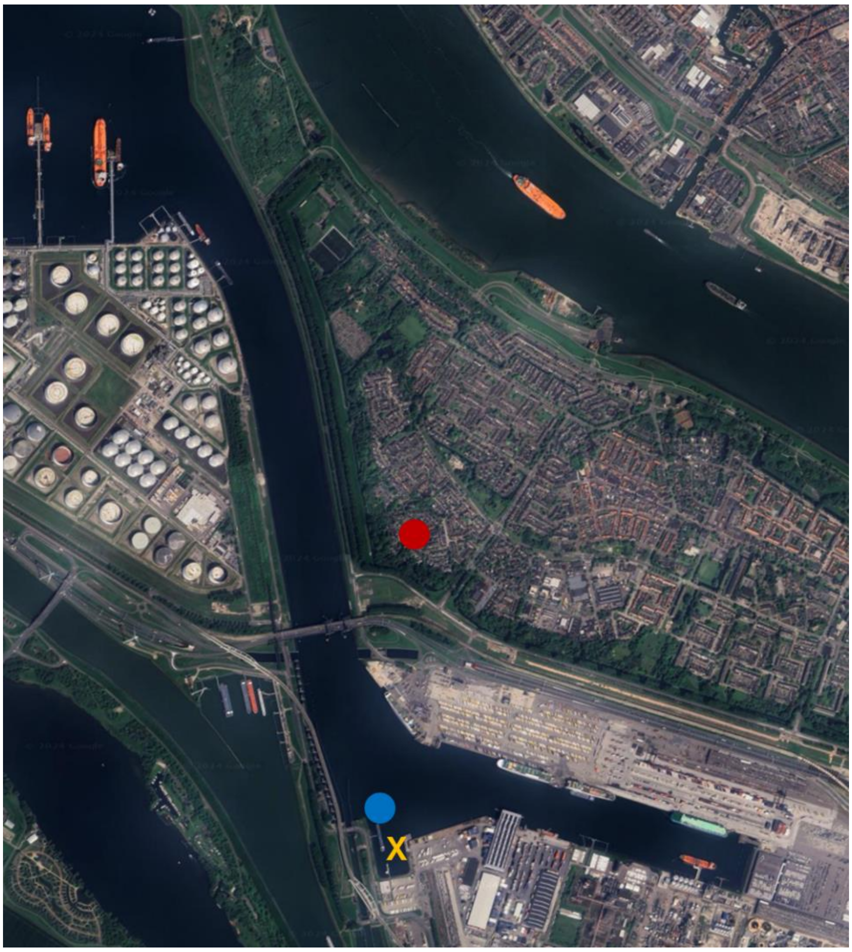


Figure 36: Location of the weather (red circle) and hydro (blue circle) stations in comparison to the deployment location of CirCleaner.

The station name, coordinates and their websites are presented in Table 50.

Table 50: Weather and hydro station overview for Londenhaven.

Stations	Station name	Station coordinates	Website
Weather station	Weerstation14	51.9051, 4.2319	https://www.wunderground.com/
Hydro station	ROZESCK/H10	51.8946, 4.2284	https://weather-tide.portofrotterdam.com/desktop/

4.4.2.4. Biological parameters

During CirCleaner operation, the biological parameters, as identified in Section 4.1.1, will be assessed. The proportion of animal harmed and not harmed by-cashed will be conducted during the monitoring of retained litter.

4.4.3. Processed water

The volume of process water will be calculated based on the technical, operational, and environmental parameters obtained during the operation of CirCleaner. The amount of water, that the system can process will be determined based on the width and submerge depth of the floating barrier line. The obtained volume of water will then be correlated with the speed of the surface water at the location. This information will be gathered from either direct measurement on site, from nearby hydro station or through hydrodynamical models.

4.4.4. Retained litter monitoring frequency

The monitoring of retained floating riverine litter will take place during the testing phase of CirCleaner. An additional test will be conducted during the catch-and-release experiment with plastic pellets, separate from the efficiency tests outlined in D2.1. During this experiment, the technology will operate under the same conditions as the catch-and-release trials, for a duration of two to three days. After this test period, the collection compartment will be emptied and handed over to VLIZ, who will then separate, classify, and analyse the litter as detailed in Section 4.1.3.1. The assessment will be done during summer 2025.

4.5. General evaluation procedure for passive systems

Sections 4.2 to 4.4 provide a detailed process for evaluating INSPIRE technologies under real environmental conditions, focusing on technology operation and the characterization of retained floating riverine litter. However, this evaluation procedure can also be applied to other floating riverine litter retention technologies beyond INSPIRE project. As such, this section outlines a general evaluation procedure for the assessment and characterization of retained floating riverine litter under real, which could be adapted for technologies of similar nature.

In this instance, the general evaluation procedure will focus on a passive boom-receptacle system, which can be implemented in various riverine environments. The retained litter monitoring protocols, developed in D4.1, Section 4.1.3.1, will be used to quantitatively assess the retained floating riverine litter. This includes measuring the quantity (by mass and number of items) of retained macro-litter, along with the mass of meso- and micro-litter fractions.

Subsequently, macro-, meso-, and micro-litter fractions will be evaluated and analysed according to the methodology outlined in Section 4.1.3. For macro-litter, further assessment will link the retained litter categories to specific societal sectors as defined previously in Section 4.1.4. Additionally, flow properties at the deployment location will be examined to determine the correlation between volume of process water and litter quantity.

This general protocol will be tested on Patje Plastik, a technology developed as part of the LIFE project "Sustainable Riverine Plastic Removal and Management" (SouPLess). The SouPLess project, which ran from July 2018 to December 2022, was coordinated by Allseas Engineering B.V., a leading contractor in the offshore energy sector, based in Delft, Netherlands. Since December 2020, the Port of Antwerp has owned the Patje Plastik technology.

4.5.1. Patje Plastik

Patje Plastic is a boom-receptacle system, which collects surface floating litter and litter up to 1.5 m of depth from the surface. It is comprised of a boom system (Figure 37 a) which guides litter into the litter collection compartment (Figure 37 b) It is comprised of 2 collection cages which are equipped with rectangular profiles and mesh bulkheads that can retain the litter that is trapped inside the Patje Plastik and simultaneously filtering the differently sized fraction. The additional rectangular profiles and mesh bulkhead also prevent the litter from escaping the cages, during sudden shifts in wind direction.

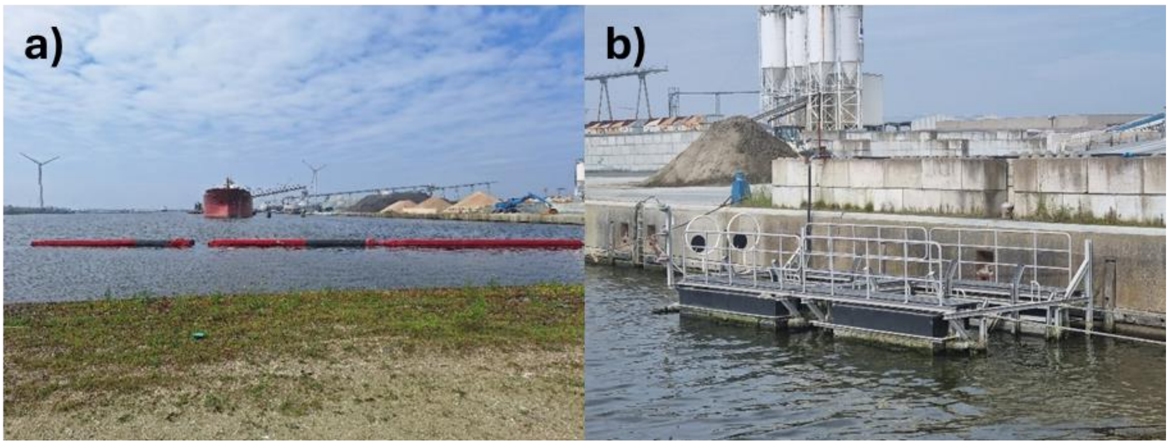


Figure 37: Deployed Patje Plastik boom (a) and collection cage (b) at the Port of Antwerp (Photograph by Mariana Miranda).

For a more detailed description of the technology please refer to the SouPLess LIFE project.

Testing location

This technology was deployed in the Port of Antwerp already in 2019 under previously founded SouPLess LIFE project. The Port of Antwerp-Bruges is the leading hub in Europe for both the production, handling and distribution of plastic pellets (Port of Antwerp). With the daily handling of plastic pallets, there is a risk of accidental loss into the surrounding environment.

The deployment location is depicted with an orange X (51.2909, 4.2352) on Figure 38.

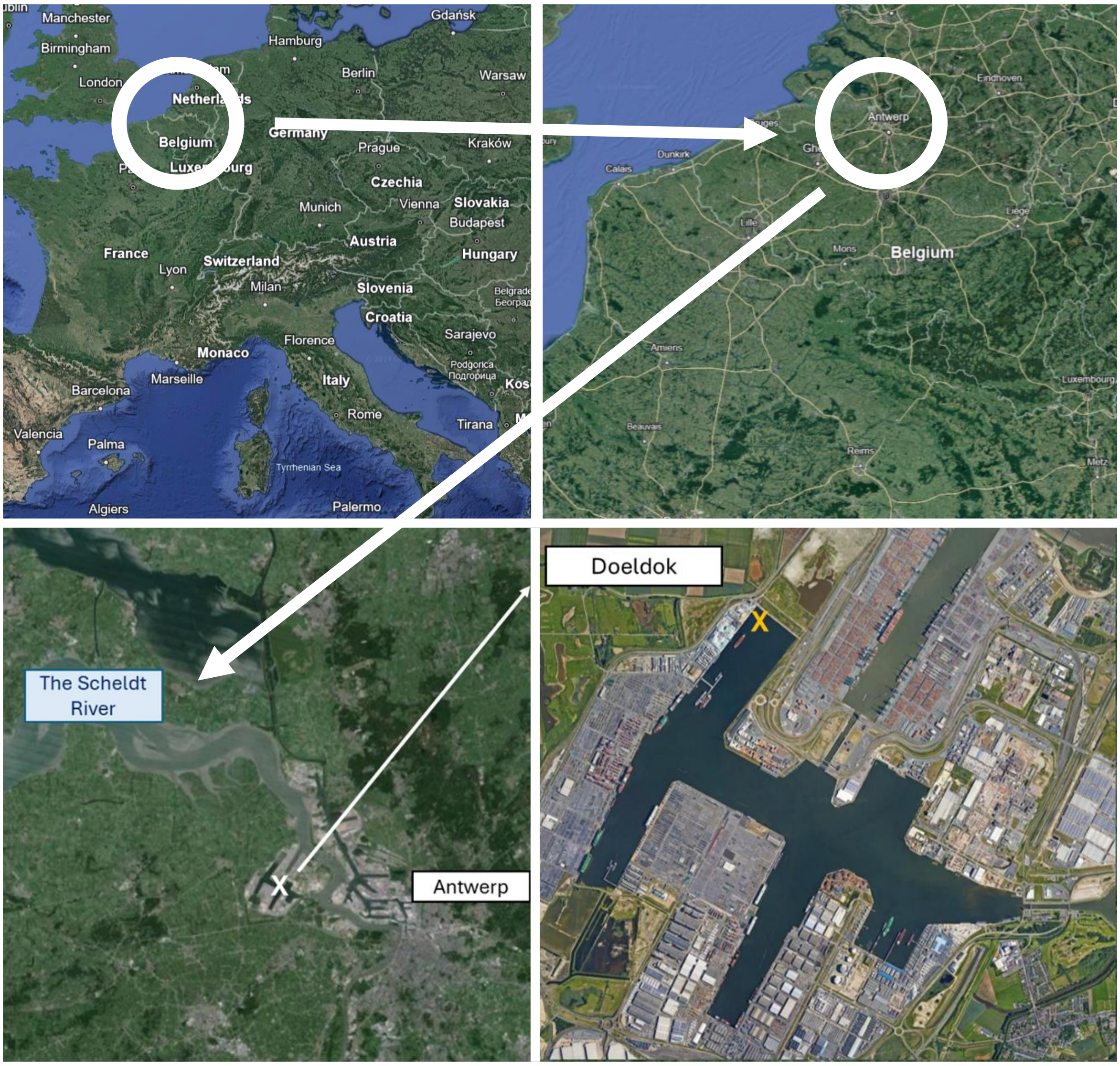


Figure 38: Deployment location of Patje Plastik under INSPIRE project (top left: map of the EU, top right: map of Belgium, bottom left: Antwerp within Belgium, bottom right: satellite image of the location, marked with X).

4.5.2. Processed water

The volume of processed water will be calculated based on the technical and environmental parameters obtained during the operation of Patje Plastik. The fill depth of the technology will determine the water level in the Patje Plastik collection cages, while the cage dimensions, will be used to calculate the system's water capacity during the operation. Additionally, a correlation between the wind speed and the surface movement of water will be made, to determine the surface flow of the docked water (Henderson-Sellers, 1988). This will aid into calculating the amount of water that Patje Plastik can process.

The environmental parameters will be obtained from the weather and hydro station. Figure 39 shows the location of the weather (red) and hydro (blue) station in relation to the deployment location of Patje Plastik (orange X).

Figure 39: Location of the weather and hydro stations.

The station name, coordinates and their websites are presented in Table 51.

Table 51: Weather and hydro station overview.

Stations	Station name	Station coordinates	Website
Weather station	Station van Antwerpen	51.2169, 4.4214	https://www.meteobelgie.be/
Hydro station	Kallosluis tij/Zeeschelde	51.2681, 4.2984	https://www.waterinfo.vlaanderen.be/

4.5.3. Retained litter monitoring frequency

The monitoring of retained floating riverine litter will follow the protocols outlined in D4.1, Section 4.1.3. These protocols will be tested on-site the deployment location of Patje Plastik. The separation of litter materials and their classification into size fractions and macro-litter groups will be carried out by INSPIRE partner VLIZ. These protocols will be tested at least once during the INSPIRE project's duration, providing valuable feedback on their effectiveness and applicability beyond the project's framework.

During the monitoring of retained floating riverine litter, the following equipment should be used:

- Litter bags;
- Hanging scale;
- Small kitchen scales;
- Tarp or canvas to cover the ground;
- Rulers or other reference items;
- Mobile phone.

During the monitoring of retained floating riverine litter, data as defined in 4.1.3.3 will be collected using INFOR's mobile interface.

4.6. Data collection sheet

Data from the floating riverine litter retention technologies will be collected by partners in the following datasheet (provided in Excel format), based on methodologies and procedures presented in the preceding sections. Additional metadata will be collected according to INSPIRE T1.1.1 Macro Litter protocol. Table 52 indicates the parameters which will be gathered during the assessment period, while Table 53 showcases parameters which would be obtained during the monitoring of the retained riverine litter. The data collection will follow the assessment frequency, which are depicted in detail in Section 4.2 to 4.4. This datasheet will be digitized, allowing demo site data to be streamed to the INSPIRE repository in accordance with activities of dataset collection from demo sites in T4.4 – Impact evaluation dashboard, and with data storage requirements in T7.3 – Data Management.

Table 52: Data collection sheet for the evaluation of floating riverine litter retention technologies.

Parameter type	Parameter	Unit
	Technology name	/
	River name	/
	Assessment period start	YYYY:MM:DD
	Assessment perioed end	YYYY:MM:DD
Operational	Electricity consumption	kWh
	Renewable electricity production	kWh
	Working time per day	hh:mm
	Maintenance frequency	hh:mm
	Maintenance duration	hh:mm
	Retained litter weight (wet)	Kg
	Retained litter volume	m^3
	Retained macroplastic items	number
	Retained macroplastics weight	kg
	Retained meso- and plastic weight	kg
	Retained microplastic weight	kg
	Underwater noise	dB
	Above ground noise	dB
	Fullness of the collection system	%
	Water fill level	mm
	Motion and tilt	Degrees
Environmental	Air temperature	°C
	Humidity	%
	Wind speed	km/h
	Wind direction	Degrees
	Precipitation	mm
	UV index	num
	High tide	m
	Low tide	m
	Water flow (current)	m/s
Biological parameters	Natural material weight (algae, tree branches, leaves…)	kg
	Trapped fish	num
	Other trapped animals	num
	Alive fish	num
	Other alive animas	num

Table 53: Data collection sheet for the monitoring of the retained floating riverine litter.

	Parameter	Unit
Monitoring of retained macro-litter	Number of items per J-List category	/
	Wet weight of items per J-List category	kg
	Dry weight of items per J-List category (if applicable)	kg
Analysis of retained meso- and micro-litter fraction	Polymer type	/
	Length	mm
	Width	mm
	Size class	/
	Mass	mg
	Colour	/
	Transparency	/
	Shape	/

4.7. Conclusion

This section of D4.1 outlines the evaluation of INSPIRE's floating riverine litter retention technologies under real environmental conditions. A framework has been established to assess three INSPIRE technologies: the hybrid MOLD/MINDS solution, Archimedean drum screen, and CirCleaner. The evaluation focuses on key performance parameters and the quantification and qualification of retained litter. Automated methods will be employed to collect data on operating conditions of the technologies, while protocols have been developed to classify the retained litter in accordance with the Joint List of Litter Categories for Marine Macro Litter Monitoring (J-list), developed by the JRC. The findings will also enable the connection of litter type to relevant societal sectors, as defined by the ILO.

Additionally, the energy self-sufficiency of the hybrid MOLD/MINDS solution and CirCleaner will be optimized using the GAMS optimization model, providing valuable insights into the number of PV panels required for their continuous operation.

The developed evaluation methodology for floating riverine litter retention technologies will also be tested on a passive technology outside the scope of the INSPIRE project. This will provide insights into the applicability of the litter classification protocols to non-INSPIRE technologies.

5. Collection of macro- litter items from riverbeds

Litter items have the potential to sink to riverbeds, where they can gradually accumulate over time. The removal of litter items from seafloor and riverbeds can be achieved through various approaches: (i) underwater robots (ROVs and AUVs), (ii) Magnetic and Electromagnetic System, (iii) Volunteer and Community-Led River Clean-Ups (iv) Sediment-Based Filtering and (v) Selective removal through new technologies, such as the MAELSTROM robotic seabed cleaning platform. Although diving surveys are often viewed as a more cost-effective option, their effectiveness is contingent on factors such as operational depth, visibility, and current speed. Additionally, diving is a labour-intensive process, requiring significant manpower (Madricardo et al., 2019; Madricardo et al., 2020). In contrast, bottom trawling, a technique commonly employed in fishing to catch fish and shellfish residing near the seafloor (Sainsbury, 1997), offers an alternative approach for litter removal. In the sea, cone-shaped nets are towed by cables behind a fishing vessel, either along the seafloor or through the water column (He et al., 2021). This method can cover more area on the seafloor due to technological specifications, in comparison to individual diving expeditions.

Additionally, the bottom-trawling method can also be used for the removal of litter items, present on riverbeds. Under INSPIRE only one technology is focused on the removal of litter items present in riverbeds. Here, a Fish Friendly Trawling Net, provided by partner FF (WP2, T2.2) will be used to retrieve the macro-litter, located on the bottom of the rivers or ports. The removal of litter items from seafloor and riverbeds is desired for restoring aquatic habitats and benthic ecosystems (Williams & Rangel-Buitrago, 2019).

Under the INSPIRE project, the Fish Friendly Trawling Net will be evaluated based on its effectiveness in removing litter from riverbeds, classification of the retrieved litter, and assessment of its potential to impact on the aquatic community. This evaluation aims to identify methods to minimize the environmental impact of bottom trawling. The assessment will involve an initial screening of riverbed locations to ensure trawling is conducted only in areas with high litter accumulation. Additionally, the evaluation will consider the time required for the aquatic ecosystem to recover to its original state. If a significant impact in the ecosystem is detected, trawling operations at such location will be stopped.

The impact pathway specified by the case study in this section relates to the relation between the technology, the use case, the activities of riverbed mapping and environmental screening and the expected outputs. Figure 40 shows a brief overview of the defined impact pathway, which is the purpose of this section in D4.1.

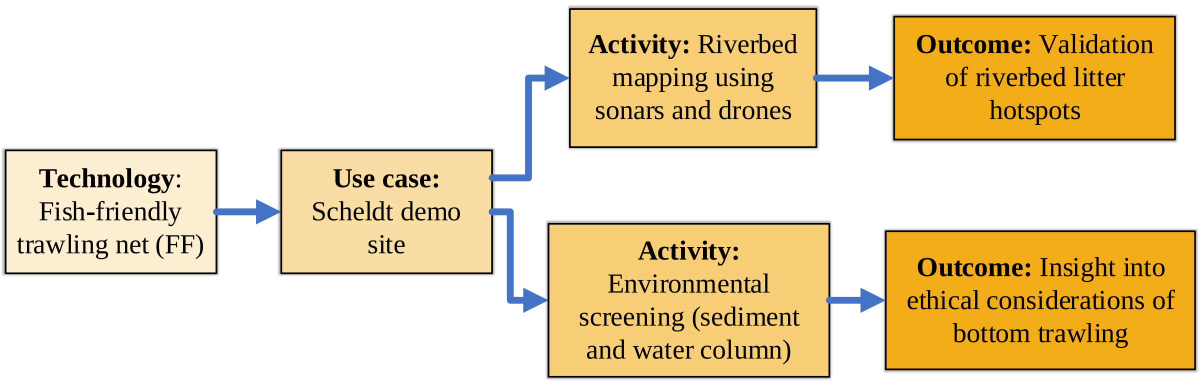


Figure 40: Impact pathway for the case of collection of macro-litter items from riverbeds.

5.1. Technology description

The Fish-Friendly Trawling Net presents an innovative approach to cleaning the beds of docks, canals, and rivers. Designed to allow fish and other aquatic life to pass through safely, the net effectively removes plastics and other litter from the waterway floor. Figure 41 illustrates the deployment of this trawling net, previously tested in the Netherlands. In Rotterdam's canals, a 4 m wide net with a mesh size of 40 cm was trawled by the 16 m ME-1 GUSS vessle, to collect litter from the bottom of the canals, a seen in Table 54.

Table 54: Technical specifications for Fish Friendly Trawling Net.

Trawling net's metal framework width	4 m
Size of trawling net	Intake 4 m x 0,6 m
Trawling net material	Nylon, steel chain, steel beam
Trawling net mesh size	40 cm
Velocity of operation	6 km/h
Trawling distance*	250 – 500 m
Video	Mounted camera and/or underwater drone

*trawling distance will depend on the selected sites.

Figure 41: Fish Friendly Trawling Net.

Preliminary testing location

The Fish Friendly Trawling Net has been previously tested in the North Holland Canal, which spans 80 km in length and 40 m in width with an average depth between 6 m and 7 m. The specific deployment site was in the city of Alkmaar.

The previously described trawling net was trawled for a maximum distance of 500 m and the net with litter items was retrieved using a crane with a weight capacity of 8.5 t. Figure 42 showcases the process of removing the trawling net from the canal and depicts the type of items that have been collected during the deployment.

Figure 42: Removing of trawling net from canal (left) and collected litter (right).

5.2. Ethical considerations regarding bottom trawling

Under the INSPIRE project, the Fish Friendly Trawling Net will be deployed to remove litter from riverbeds.

1. Unburdening effect

This technology enables the collection of significantly larger volumes of litter compared to conventional diving methods. By removing anthropogenic litter, which does not naturally belong in river and marine ecosystems, the direct harm to marine fauna may be mitigated. This includes reducing the likelihood of macro-litter being ingested or causing accidental entanglements (Fossi et al., 2018). Additionally, the risk of larger macro-plastic litter items breaking down and fragmenting into microplastics, which can be ingested by zooplankton and other aquatic species (Lusher et al., 2017), is also diminished with the removal of litter from the seafloor or riverbed.

While the technology is effective at removing litter from difficult-to-reach riverbed compartments, its operational principles can potentially lead to negative environmental impacts.

2. Burdening effect

The use of a trawling net for litter removal resembles bottom trawling techniques used in fishing, which are known to be detrimental to seafloor environments. The European Commission considers bottom trawling "among the most widespread and damaging activities to the seabed and its associated habitats" and seeks to mitigate the negative impacts of bottom trawling by encouraging the adoption of more sustainable fishing practices (Sea at Risk, 2023). Bottom trawling is associated with numerous negative impacts, including serial resource depletion, damage to seafloor integrity and habitats, alterations to species composition and balance, disruption of biogeochemical cycles, and effects on carbon storage. Additionally, it can contribute to overfishing (WWF, 2020).

Mitigation strategies are therefore essential to reduce by-catch during fishing activities. This issue is being explored in the MarineBeacon project, part of the Horizon Europe Program, which seeks to assess the impact of by-catch on marine biodiversity and develop tools to effectively reduce the by-catch and associated mortality (MarineBeacon, 2024). Similarly, the Horizon Europe initiative REDUCE aims to unite stakeholders across sectors to apply innovative approaches to minimize by-catch of marine megafauna, which remains the leading cause of human-induced mortality in these species (REDUCE, 2023).

Furthermore, during the trawling process, the abrasion process may generate smaller plastic particles. These microplastics pose a significant risk to the ecosystem, as they can be directly ingested by aquatic organisms.

Since the movement of the trawl net for collecting litter items relates to the movement of bottom trawling used in fishing, the same burdening impacts are also assumed for the removal of litter items. Careful consideration during the design and planning phase of the Fish Friendly Trawling Net technology is essential to identify potential damages from such activities, and steps should be taken to minimize its burden on the aquatic environment. Within the INSPIRE project, the following measures will be considered, to minimise the potential impact on the environment:

1. **Baseline riverbed screening**

Detailed screening of baseline riverbed pollution will be performed by multi-beam sonar. After establishing accumulated litter hotspots, underwater drones will be used to conduct visual observations of the area. Only areas established as having large quantities of detected litter will be considered for further assessment.

2. **Baseline ecosystem screening**

Description of riverbed characteristics as well as identification of main species will be conducted during the pre-screening of the deployment location. Additionally, parameters listed in Table 55 have been identified, by INSPIRE partners CIIMAR and CNR, as critical indicators and will be measured to assess potential disturbances to riverbed biota, before and after the deployment of Fish Friendly Trawling Net.

Table 55: Overview of the parameters identified for analysis.

Sediments	Water column
Organic matter	Total, fixed and volatile suspended solids
Grain size	Light extinction coefficient
Benthic macroinvertebrates community	Nutrients, metal, and micro-organic contaminant content
Microplastics and other micro and macro litter	Chlorophyll *a* concentration
Metals and micro-organic contaminants	Coloured Dissolved Organic Matter (CDOC)
	Transparency
	Temperature
	pH
	Dissolved oxygen
	Salinity (transitional water regions)

3. **Trawling**

Bottom trawling will be only conducted in waterways that are not protected, containing high litter accumulation as confirmed in the previous step. Trawling will be conducted:

- A maximum 500 m distance or less, to be determined by *in-situ* information when the net is full, which will be obtained through signals from crane.
- The speed of the vessel will be carefully optimized to minimize disruption to the riverbed.
- Trawling will be restricted to the upper most layer of the riverbed.
- Mesh size of the trawling net will be adjusted based on the location's benthic macroinvertebrates community and other ecosystem factors.

After the trawling, the content of the net will be analysed to check the possible presence of accidentally collected organisms (by-catch) during the sampling activities (Broadhurst et al., 2006). Those organisms will be registered and living ones will be returned to the ecosystem.

INSPIRE annual ethics reports which describe all ethic issues and the mitigation actions taken by the project will consider the trawling net technology and the identified ecosystems of the testing areas.

5.3. Regulations and authorisations

The collection of riverine litter requires careful consideration of the environmental impact. Any intervention should not cause a greater harm than the remediation it aims to achieve. Therefore, participants must comply with national or regional regulations that outline permissible actions in river environments. This necessitates obtaining permits prior to system deployment. For instance, in the case of the Fish Friendly Trawling Net, the following permissions should be secured in advance:

1. **Vessel registration and certification** requires that every vessel must be properly registered and certified to ensure its compliance with national and local waterway laws. This includes official documents showing vessel registrations as well as seaworthiness certificates, to ensure the vessel is fit to use on rivers and comply to safety standards.
2. **Authority permits** ensures that vessel can operate in a specific section of the river without disrupting other users or causing environmental damage. This is issued by the authorities which manage and regulate the river.
3. **Waste collection permit** as litter removal is conducted from riverbed, a permit for its collection may be required. This ensures that the handling and disposal of collected water complies with environmental regulations. Furthermore, contact need to be made with the local waste management companies.

Table 56 outlines the potential permits required for conducting bottom trawling activities at specific locations, along with the respective governmental authorities responsible for issuing them. The Port of Ostend has been chosen as the deployment and testing location for the evaluation of Fish Friendly Trawling Net.

Table 56: Authorisations and representative governmental bodies for Rhine and Scheldt

	Port of Ostend
Authority permits	De Vlaamse Waterweg Port of Ostend
Vessel registration	De Vlaamse Waterweg Port of Ostend
Waste collection permits	Municipality of Ostend and Public Waste Agency of Flanders

5.4. Methodology

This section presents the methodology for evaluating the INSPIRE Fish Friendly Trawling Net, from the standpoint of:

1. Monitoring of the litter accumulated in riverbeds;
2. The connection of retained riverbed litter to sourced industrial sectors;
3. Potential negative impact to riverine communities due to the bottom trawling operation.

The potential impact of bottom trawling on benthic communities will be assessed through experiments using field-collected samples. Two types of samples will be gathered from the affected area: (i) sediment samples and (ii) water column samples. Sediment samples will be used to evaluate the impact of bottom trawling on benthic communities (Queirós et al., 2006), while water column samples will be collected to examine the effects of sediment resuspension caused by trawling motion, which may lead to changes in water quality and soft-sediment infauna communities (Pilskaln et al., 1998).

The methodology section provides the protocols and procedures that would be applied to determine the potential impacts that bottom trawling, using the Fish Friendly Trawling Net for the removal of macro-litter items from riverbeds, could have on the riverine community. The sampling and analysis protocols have been developed by partners CIIMAR and CNR.

5.4.1. Riverbed sediments

This section outlines the protocols and parameters for analysing the riverbed sediment samples collected from the field.

Riverbed sediment sampling protocol

Riverbed sediments samples will be gathered with a Van Veen grab. The depth of the sampling point will be measured with an echo sounder. The collected sediments will be stored in two different containers for the analysis of benthic macroinvertebrate community composition and the organic matter and granulometry analysis. An additional container may also be used to gather microplastic samples, which would follow the protocols, described in D1.2. The benthic macroinvertebrate samples should be thoroughly rinsed *in situ* through a 1 mm mesh sieve to remove fine sediments.

1. **Organic matter and grain size analysis of sediment:**

The adapted Kristen and Anderson (1987) protocol should be followed to assess the amount of organic matter and grain site of the sediments. The sediment samples will be placed in a stove at 60 °C until completely dry. To ensure that all water is removed, they will be weighed on a five-decimal electronic balance every day until they have the same weight three times in a row. The samples will be then weighed and transferred to an aluminium crucible to be placed overnight in a muffle furnace at 450

°C. This temperature allows the removal of organic carbon without causing the hydroxylation of clay minerals (Nelson & Sommers, 1996), which occurs at around 550 °C (Sun et al. 2009) and could lead to an overestimation of organic carbon. After letting it cool, the samples will be weighed again. Additionally, the empty aluminium crucible will be also weighed to calculate the rate weight. Afterwards, the samples will be stored in clean containers and placed in a stove at 60 °C for subsequent particle size analysis. The amount of organic carbon is estimated through the loss-on-ignition percentage (LOI %) using the following Equation 22 (Dean 1974).

$$LOI\%_{OC} = 100 \cdot \frac{P_{dry} - P_{muffle}}{P_{dry} - P_{tare}} \quad (22)$$

Where P_{dry} represents the dry weight of the sample, P_{muffle} the weight of the sample after placing it into the muffle and P_{tare} the rate weight of the aluminium crucible. To estimate the percentage of Total Organic Matter (TOM), Equation 22 is corrected with the Van Bemmelen conversion factor "1.2" (Trask 1939), which assumes that on average 58 % of organic matter is organic carbon, as described in Equation 23

$$LOI\%_{OC} = 100 \cdot 1.724 \cdot \frac{P_{dry} - P_{muffle}}{P_{dry} - P_{tare}} \quad (23)$$

Pre-incinerated samples will be used to assess sediment particle size. Using a five-decimal electronic balance, both the full and empty container will be weighed to obtain the sample weight and the tare weight, respectively. To disaggregate the clay minerals, the sediment will be transferred to a beaker into which 200 mL of an aqueous dispersant solution will be added, consisting of 35.7 g/L sodium hexametaphosphate ($(NaPO_3)_6$) and 7.94 g/L anhydrous sodium carbonate (Na_2CO_3). In fact, through the formation of hydrogen and ionic bonds, sodium hexametaphosphate is adsorbed by the clay particles and prevents them from agglomerating, while anhydrous sodium carbonate increases the pH, which affects flocculation, as clays agglomerate under acidic conditions (Bhattacherjee et al. 2022). Each sample will be placed in an orbital shaker for 24 hours and the suspension will be wet filtered with a 63 µm sieve by wetting it with the dispersant solution to remove the fine clay/silt fraction, which will be discarded. The sediment fraction larger than 63 µm will be carefully recovered, placed back into the original container, and into an oven at 60 °C until completely dry. Once dried, the samples will be weight to determine the fraction greater than 63 µm. To evaluate the fraction larger than 63 µm, the sediment will be dry filtered on a sieving column consisting of sieves with different mesh sizes: 63, 100, 250, 500, 1000, 2000 µm. The empty sieves will be previously weighed for each sample to obtain the tare weight and shaken mechanically for approximately five minutes. Each fraction retained in the sieves (P_{bottom}, P63, P100, P250, P500, P1000, P2000) will then be weighted. The fine fraction in percentage was calculated by difference using Equation 24.

$$\%\,{}^{Clay}/_{Silt} = 100 \cdot \left(\frac{P_{dry} - P_{>63\mu m}}{P_{dry} - P_{tare}}\right) + P_{bottom} \quad (24)$$

where P_{dry} represents the dry weight of the entire sample, $P_{>63\mu m}$the weight of the fraction greater than 63 µm, and P_{tare} the tare weight of the container.

The following Equation 25 will then be used to calculate the percentage weight of fractions > 63µm instead:

$$\%\,fraction = 100 \cdot \frac{P_x - P_{tare}}{P_{tot}} \quad (25)$$

In the equation, P_x represents the weight of each fraction, P_{tare} the tare weight of the sieve and P_{tot} represents the total dry weight of the sample.

2. **Benthic macroinvertebrates community:**

To assess the benthic macroinvertebrates community, *in situ* sieved sediment samples will be preserved in formaldehyde 3.7 - 4% (buffered to pH = 7 and stabilized with methanol) with Rose Bengala sodium salt (12 mg/L). *Rose Bengala* is an anionic xanthene dye, a derivative of fluorescein, which is able to permeate into tissues, colouring the organisms pink or red in about 48 hours, greatly simplifying sorting operations. After the time required for dyeing, the samples will be thoroughly rinsed with water and will be placed in a tray to be carefully inspected to sort benthic macroinvertebrates. The organisms will be then preserved in 99.6% ethanol for subsequent identification. Benthic macroinvertebrates will be identified to species level, when possible, with a stereomicroscope and when necessary, through an optical microscope, following the dichotomous keys of Hayward and Ryland (2017). The quality of taxonomic identification will be assured by experienced colleagues and species will be validated using the World Register of Marine Species (WoRMS).

5.4.2. Water column

This section depicts the protocols and parameters that would be analysed form the water column samples, obtained from the field.

Water sampling protocols

Water samples will be collected at the same location sites of the sediment samples using Niskin or Van Dorn bottles to isolate water samples at specific depths. 5 L water sample should be enough from each site/depth selected to assess various parameters, such as chlorophyll a (Chl a), Total Suspended Solids (TSS), Fixed Suspended Solids (FSS), Volatile Suspended Solids (VSS), Coloured Dissolved Organic Matter (CDOC), light extinction coefficient (turbidity), nutrients, and metals. Transparency of the water column will be assessed with a Secchi disc, and temperature, pH, dissolved oxygen, and salinity (for transitional water regions) will be measured with a multiparametric probe (Table 55).

1. **Total, fixed and volatile suspended solids analysis**

TSS, FSS, and VSS will be measured according to Baird et al (2017). For each sub-replicate of water sample (3 per replicate), an aliquot of 500 mL will be filtered through a vacuum pump onto a glass fibre filter (GF/C 1.2 µm/pore and Ø= 47 mm). Then the filter will be dried in an oven at 60 °C until they achieve a constant weight. The TSS, will be calculated using the following Equation 26

$$TSS\ (mg/L) = 1000 \cdot \frac{P_{dry} - P_{tare}}{V} \qquad (26)$$

where P_{dry} is the weight of the filter with the sample (g), P_{tare} is the tare weight of the filter (g), and V is the volume of water sample filtered (L).

The filters will be then placed in a muffle furnace at 450 °C overnight and will be subsequently reweight. The content of FSS expressed in mg/L was calculated according to the Equation 27

$$FSS\ (mg/L) = 1000 \cdot \frac{P_{muffle} - P_{tare}}{V} \quad (27)$$

where P_{muffle} is the weight of the filter with the sample (g), P_{tare} is the tare weight of the filter (g), and V is the volume of water sample filtered (L). The VSS content, expressed in mg/L, will be determined according to Equation 28:

$$VSS\ (mg/L) = TSS - FSS \quad (28)$$

where TSS is the total suspended solids and FSS is the fixed suspended solids, both of them in mg/L.

2. Light extinction coefficient

In addition to the turbidity measured in the field, the light extinction coefficient will be calculated using a spectrophotometric method in accordance with the methodology described in Brower et al. (1997). An aliquot of unfiltered water sample from each replicate will be placed in a glass cuvette with an optical path of 1 cm and the absorbance will be measured at a wavelength of 450 nm, using a spectrophotometer. The absorbance coefficient (ε_{450}) of each sample will be then calculated, according to the Equation 29:

$$\varepsilon_{450} = \frac{2.30 \cdot ABS_{450}}{l} \quad (29)$$

where ABS_{450} is the absorbance read at 450 nm and l is the optical path of the glass cuvette in cm.

3. Dissolved organic carbon

Dissolved Organic Carbon will be determined indirectly through the colour of the water (CDOC – Coloured Dissolved Organic Carbon) according to the methodology established by Williamson et al. (1999). An aliquot of water samples from each replicate will be filtered through a glass fibre filter (GF/C 1.2 µm/pore and Ø = 47 mm) using a vacuum pump. Subsequently, the filtrate will be placed in a quartz cuvette with an optical path of 1 cm and the absorbance at a wavelength of 320 nm - the boundary between UV-B and UV-A radiation – will be measured in a spectrophotometer. For each sample, the absorption coefficient (ε_{320}) will be calculated following Equation 30:

$$\varepsilon_{320} = \frac{2.30 \cdot ABS_{320}}{l} \quad (30)$$

where ABS_{320} indicates the absorbance at 320 nm and l the optical path of the quartz cuvette in cm.

4. Nutrients and metals

Three aliquots of the water samples will be sent to a certified laboratory for the quantification of metals: cadmium (Cd), lead (Pb), copper (Cu), mercury (Hg) and nickel (Ni); and nutrients: nitrite ion (NO_2^-), nitrate ion (NO_3^-), ammonia/ammonium (NH_3/NH_4^+), phosphate ion ($PO4^{3-}$) and silica (SiO_2).

The concentration of NO_2^-, NO_3^-, NH_3/NH_4^+ and PO_4^{3-} in the water samples, expressed in µg/L, are determined using the Skalar Sanplus Segmented Flow Colorimetric Autoanalyzer using Skalar methods: M461-318 (EPA 353.2), M155-008R (EPA 350.1) and M503-555R (Standard Method 450-P I). The SiO_2 concentration are determined on the Palintest UV-Visible Spectrometer using the Phot 31 method. The analytical procedures used in the determinations were validated by doping some samples with known amounts of NO_2^-, NO_3^- and NH_3^+/NH_4^+, PO_4^{3-}, and SiO_2.

The concentration of metals in the water samples, expressed in ng/L or µg/L, are determined by Spectrometry Atomic Absorption with Stoichiometric Flame Atomization and Atomization Electrothermal. Analytical procedures used in the determination of metals in water samples are validated by pricking samples with known amounts of each metal.

5. Chlorophyll a concentration

Quantification of Chl a concentration, a proxy for phytoplankton biomass, will be performed according to the method described by Lorenzen (1967). For each sub-replicate of water sample (3 per replicate) an aliquot of 500 mL will be filtered through a vacuum pump onto a glass fibre filter (GF/C 1.2 µm/pore and Ø = 47 mm). Subsequently, the filters will be placed in 15 mL Falcon tubes with 5 mL of 90 % alkalinised acetone. The photosynthetic pigments will be extracted for 15 hours in the dark at 4 °C. After this extraction period, the samples will be centrifugated at 5 °C for 20 minutes at 3900 rpm. The absorbance of the samples will be measured in a spectrophotometer in glass cuvettes at two wavelengths: 665 nm and 750 nm (ABS_{665} and ABS_{750}). Immediately afterwards, the samples will be acidified with two drops of hydrochloric acid (HCl 0.1 M) and readings will be performed again at the same wavelengths (ABS_{a665} and ABS_{a750}). The Chl a concentration will be calculated using Equation 31:

$$Chl\ a\ (mgL^{-1}) = \frac{26.7 \cdot (E665_0 - E665_a) \cdot v}{V \cdot l} \tag{31}$$

in which: $E665_0 = ABS_{650} - ABS_{750}$; $E665_a = ABSa_{650} - ABSa_{750}$; v corresponds to the volume of acetone used for extraction (mL), V is the volume of water sample filtered (L) and l stands for the optical path of the cuvette (cm).

5.4.3. Monitoring of retained macro-litter items from riverbeds

This section outlines the separation and monitoring protocols used to assess and classify macro-litter items collected during bottom trawling with the Fish Friendly Trawling Net, as outlined in Section 4.1.3. These protocols for separating and monitoring retained riverbed macro-litter will follow the guidelines, described in Section 4.1.3.1 while also gathering datasets as described in Section 4.1.3.3. The frequency of monitoring riverbed macro-litter will align with the schedule set for floating riverine litter retention technologies, as depicted in Section 4.1.3.2. During the bottom trawling activities, the presence of accidentally collected organisms (by-catch) will be checked. If accidentally caught organisms are found, they will be quantified per taxa and mortality will be monitored as well, before their release back into the environment (Broadhurst et al., 2006).

5.4.4. Connecting of riverbed macro-litter items with societal sectors, according to International Labour Organisation (ILO)

The retained riverbed macro-litter items collected during bottom trawling with the Fish Friendly Trawling Net will be analysed following the guidelines established for floating riverine macro-litter items in Section 4.1.3. Macro-litter items will be classified according to the Joint List of Litter Categories for Marine Macro Litter Monitoring (J-list), developed by the JRC, as outlined in Section 4.1.3.1. Following classification, the J-code list categories will be linked to specific societal sectors, as defined by ILO. This procedure would align with the procedures used for the floating riverine macro-litter items in Section 4.1.4.

5.5. Evaluation of Fish Friendly Trawling Net

This section outlines the deployment of the Fish Friendly Trawling Net, for the collection and removal of litter from riverbeds. As part of the INSPIRE project, Fish Friendly Trawling Net will be deployed in the Port of Ostend.

The assessment will follow a four-step procedure:

1. Identifying litter accumulation hotspot locations

Multi-beam sonar and underwater drones, through the process, as depicted in D2.1, will be used to obtained litter accumulation hotspots on the riverbed. Table 57 showcases representative equipment that may be used during the litter mapping of the riverbed.

Table 57: Technical specifications of equipment used for riverbed litter mapping.

	Type	Image	Manufacturer	Specifications
Multi-beam sonar	HELIX 12 CHIP MEGA SI GPS G2N		Humminbird	• Depth imaging: 121 m • Power input: 10.8 -20 VDC • Sonar frequencies: 50/83/200/455/800 kHz
	EM2040 MKII		Kongsberg	• Soner frequency: 200-400 kHz • Depth: 6000 m
Underwater drone	DTG3 ROV		Deep Trekker	• Resolution: 1920 x 1080 • Framerate: 30 FPS • Depth rating: 200 m • System voltage: 19.2 V DC • Weight: 8.5 kg • Operating temperature: -10 °C to 50 °C

The identified potential litter hotspot locations will then be validated using an underwater drone.

The multi-beam sonar will be installed on a small boat that will collect data along transect in order to obtain the full coverage of the riverbed in the area selected to test the technology. This method has already shown to be effective in turbid and shallow environments, such as Venice Lagoon in Italy (Madricardo et al., 2019). The sensor emits pulses of sound that bounce off the bottom and return as echoes, allowing for the creation of a top-down view of the riverbed, allowing for precise identification of the accumulation areas. The data will be then processed to obtain high resolution digital terrain models of the riverbed to be used in a GIS to identify the presence of anthropogenic objects and marine litter hotspots. Using the multi-beam bathymetry map as a reference, dedicated in situ campaigns with the underwater drone will be carried out to verify the nature of the multibeam targets to identify the potential location for the trawling activity. This approach, using underwater drones, will be tested, as its use is heavily influenced by the turbidity. If feasible, the underwater drone will provide visual confirmation of these areas, supporting the results, obtained from the multi-beam sonar. The results will be summarized in a GIS map to be used for the environmental assessment and successive cleaning operations. Repeated surveys pre- and post- cleaning operations will document the effective removal of the litter from the seafloor.

The first trial tests will include the identification of accumulated litter hotspots using multi-beam sonar and underwater drones, through the process, as depicted in D2.1.

2. Environmental sampling and screening of litter accumulation hotspot locations

Once the potential location for trawling has been identified, the images captured by the underwater drones will be used, whenever possible, to gather information of the riverbed. This includes determining the type of riverbed (e.g., mud, rock) and potentially identifying plant aquatic species, if recorded.

An initial environmental screening is required to check for the presence of endangered or protected species (fauna and flora) within the selected location. This can be done by consulting local environmental reports or conducting a literature review of the investigated area. In the case of lack of previous data, an ecological screening will be conducted to acquire this information. If no endangered or protected species are identified, the location will be selected for bottom trawling to remove accumulated litter. However, if the screening reveals the presence of such species, that location will be excluded from the trawling process, and the screening will be repeated for another litter accumulation hotspot identified in Step 1.

Before the bottom trawling begins, sediment and water column samples from the location will be collected. Three replicate samples will be gathered, following the protocols outlined in Sections 5.4.1 and 5.4.2.

3. Conducting the bottom trawling

Following the environmental sampling and screening, and if the results reveal the suitability of the selected demo site, bottom trawling for accumulated litter can be conducted. Prior to trawling, the time and GPS location must be recorded. The trawling net is then deployed to the riverbed and slowly trawled using a boat, with boat speed closely being monitored and recorded. Trawling continues until the net is deemed full, as indicated by a signal from the crane on the boat and a noticeable change in boat speed. The time and GPS location at this point will also be noted.

The trawling net is then fully lifted out of the water, and the litter content is placed on the boat, where it is weighed. The collected items are sorted into natural non-litter items and anthropogenic litter, with the latter categorized according to the J-list classification, as outlined in Section 4.1.3.1. Furthermore, any by-catch, identified during the litter classification procedure, will be adequately documented.

4. Post deployment screening of location.

After trawling is completed, the boat will return to the area where the litter was removed to collect additional multi-beam data, sediment and water column samples, as defined in Section 5.4.1 and 5.4.2. Three replicates will be taken, right after the bottom trawling of the litter.

This sampling will be repeated 3-4 months after the litter has been removal. During this follow-up, three replicates of sediment and water column samples will be collected and analysed regarding the same defined parameters. Additionally, sonar and underwater drones will be deployed to the location for further observation and assessment of the riverbed.

5.5.1.1. Frequency

The collection of rivered litter items using Fish Friendly Trawling Net will be conducted at the Port of Ostend, in Belgium. Here only one trawl of the Fish Friendly Trawling Net will be conducted. Table 58 provides an overview of the activities at Port of Ostend, which includes the number of environmental samples that would need to be aquert as well the involvement of partners.

Table 58: Sampling overview for biological assessment.

	Sediment samples	Water column samples
Number of replicates	3	3
Sampling times	• Before trawling • Right after trawling • 3-4 months after trawling	• Before trawling • Right after trawling • 3-4 months after trawling
Total number of samples	9	9
Sample provision and sample preparation	FF and VLIZ	FF and VLIZ

The riverbed litter items, that would be collected during the deployment, would be separated, weight and analysed as described in Section 4.1.3.1. Only one litter assessment is foreseen and would be done in a collaborative approach by partner FF, VLIZ and other relevant partners.

5.6. Data collection sheet

Data from the collection of accumulated riverbed litter will be collected by partners in the following datasheet, based on methodologies and procedures presented in the preceding sections as shown in Table 59. The trawling will be conducted only once, while the sediment and water column three replicates would be gathered at three different times, as defined in Section 5.5. This datasheet will be digitized, allowing demo site data to be streamed to the INSPIRE repository in accordance with activities of dataset collection from demo sites in T4.4 – Impact evaluation dashboard, and with data storage requirements in T7.3 – Data Management.

Table 59: Data collection sheet for Fish Friendly Litter-Removal Trawling net.

	Parameter	Units
Deployment of Fish Friendly Litter-Removal Trawling Net	Location	/
	River name	/
	Date and time	YYYY:MM:DD
	Trawling start	HH:MM
	Trawling end	HH:MM
	Start coordinates	/
	End coordinates	/
	Trawling distance	m
	Trawling boat speed	m/s
	Wet mass of collected litter	kg
	Number of litter Items from J-List	/

Water column samples	Sample date	YYYY:MM:DD
	Sample ID	/
	Location coordinates	/
	Volume of sample	L
	Transparency	m
	Temperature	°C
	pH	/
	Dissolved oxygen	% sat
	Salinity	ppt
	Total, fixed and volatile suspended solids	/
	Light extinction coefficient	$cm^{-1}(mol/L)^{-1}$
	Nutrients, metal and micro organic contamiant content	/
	Chlorophyll a concetration	µg/L
	Coloured dissolved organic matter	/
Sediment samples	Sample date	YYYY:MM:DD
	Sample ID	/
	Location coordinates	/
	Organic matter	/
	Grain size	/
	Benthic macroinvertebrates	/
	Metals and micro-organic contaminants	/

5.7. Conclusion

This section outlines the evaluation of the Fish Friendly Trawling Net, designed to collect litter from riverbeds. The trawling may effectively reduce macro-litter and the risk of microplastic formation, thus mitigating harm to marine life. However, as trawling resembles bottom trawling in fishing, it risks damaging seafloor habitats and disrupting ecosystems. To address these concerns, the INSPIRE project recommends targeted deployment in high-litter, non-protected areas, following comprehensive baseline assessments of pollution and ecosystem characteristics.

For the evaluation, multi-beam sonar will be used to map the riverbed and identify litter hotspots, with underwater drones validating the sonar survey results. Bottom litter trawling will be conducted only in areas where thorough biological assessments have been completed prior to deployment. To accurately assess the impact of trawling on the riverbed ecosystem, sediment and water column samples will be collected before and after the operation, with potential by-catch also being investigated. Following the deployment of the Fish Friendly Trawling Net, both multi-beam sonar and underwater drones will be used to assess the net’s effectiveness in removing litter. This comprehensive approach, which includes an evaluation of biological parameters, will provide insight into the net's litter-removal capabilities and its potential environmental impacts.

6. Microplastic retention technologies

At a global scale, rivers are estimated to export approximately 0.5 million tonnes of plastic to the ocean each year, where a significant proportion of waste streams are dominated by microplastics (MPs) (Strokal et al., 2023). Rivers are a direct pathway for the transport of land-based MP waste to seas and oceans, and while environmentally relevant MP concentrations as of now have not significantly affected riverine ecosystems (Catarino et al., 2021), action should still be taken out of precautionary principle, as river systems are affected by plastic pollution in general (van Emmerik & Schwarz, 2020). Over 80 % of MPs in riverine MP-dominated sub-basins originate directly from point sources, i.e. sewage systems (Strokal et al., 2023). Despite relatively high retention rates of MPs by municipal wastewater treatment plants (WWTPs) through accumulation in sewage sludge, large amounts of MPs are still being released to the environment, making WWTPs a major hotspot for direct discharge of MPs (Sol et al., 2020).

It is also important to address the introduction of MPs into wastewater streams before they reach treatment facilities, as it has been shown to be more effective to prevent the introduction of pollutants upstream at the source (Sturm et al., 2024). While it is preferrable that plastic litter never reaches water streams in the first place, it is easier to remove pollutants from water earlier rather than later in the flow process. Prior to discharge to WWTPs, the main MP hotspots in terms of wastewater point sources have been identified as particles released from car tyres, laundry, household dust, and personal care products (Strokal et al., 2023).

The INSPIRE project addresses these problem areas in a holistic manner by developing solutions for MP retention and elimination at various upstream points, including WWTPs, which are addressed directly using a cascade solution for retention and complete elimination of microparticles. This is in line with the revised EU Wastewater Directive (European Comission, 2022), which specifies the need for quaternary treatment to remove a broad spectrum of micropollutants from urban wastewater, among which MPs are also included. Retention of tyre and road wear particles (TRWPs) from run-off water prior to discharge to WWTP will also be addressed by a cascade filtration system. In addition, INSPIRE will develop a solution for another key aspect of aquatic pollution that has been shown to increase MP and trace metals contamination near ports (Tesán Onrubia et al., 2021): effluent from boat washing in marinas.

This deliverable provides an evaluation framework for INSPIRE solutions used for retention and elimination of MPs. The purpose of this document is to formulate a plan for obtaining data from implementations of these solutions, with an overview of the problem definition, a tailor-made evaluation plan to address specific issues, and a method for quantitative assessment of the technology operation in the field at INSPIRE demo sites.

In addition to evaluating the removal efficiency of INSPIRE MP retention technologies based on release-catch experiments, which are specified in detail in INSPIRE D2.1 – Plastic removal efficiency protocols, it is also important to understand the operation of technologies in the field. While plastic removal efficiency tests will provide insight into the removal capabilities of the technologies, field tests will specify the exact litter materials retained and assess whether the technologies operate in a way that makes them viable for field replication.

Specifically for the cascade solution at the Kamniška bistrica demo site, namely the Domžale-Kamnik WWTP in Slovenia, this document proposes a methodology to assess the abundance of MPs in the nanoplastic range using INSPIRE technologies. For the marina wastewater treatment solution in

Marina Douro, Portugal, this document provides a framework for the effectiveness of microplastic removal from marina wastewater. For the retention of tyre and road wear particles at the Fetesti WWTP at the Danube demo site in Romania, the methodology for assessing abundance of MPs in the nanoplastic range will be utilized and cross-checked with laboratory analysis of retained TRWPs.

6.1. Methodology

This section refers to the methodology used to assess the efficiency of plastic removal for INSPIRE MP retention systems. The procedures described here build upon established protocols and are designed to evaluate applications in the field.

A detailed description of protocols and testing procedures for plastic removal efficiency of all INSPIRE technologies, including MP retention technologies, is available in INSPIRE D2.1 – Plastic removal efficiency protocols. While plastic removal efficiency testing is based on controlled release-catch experiments, assessment of the technologies in D4.1 refers to the specific needs of the technologies on the field.

Section 6.1.1 provides an overview of INSPIRE MP retention technologies as individual solutions. The implementation of these technologies as viable operational solutions in combination with each other or with other treatment methods is described separately in sections related to specific demo cases.

Sections 6.1.2 and 6.1.3 describe the wastewater sampling and analysis methods associated with the INSPIRE MP retention technologies. A detailed sampling procedure and equipment list are based on protocols developed in INSPIRE D1.2 – Monitoring and analysis protocols. An addition to the protocol for analysis of MP samples is a methodology for the mathematical estimation of nanoplastic abundance, based on particle size distribution in samples and quantification of particles in smaller size ranges.

Finally, section 6.1.4 provides an overview of the sensor kit used to perform continuous monitoring of INSPIRE MP retention solutions, which will allow the integration of sensors into the solutions as specified in each of the evaluated demo cases.

The impact pathways specified by the case studies in this section relate to the relation between the technology, the use case, the activities of performance analysis and field sampling, and the expected outputs. Figure 43 shows a brief overview of the defined impact pathway, which is the purpose of this section in D4.1.

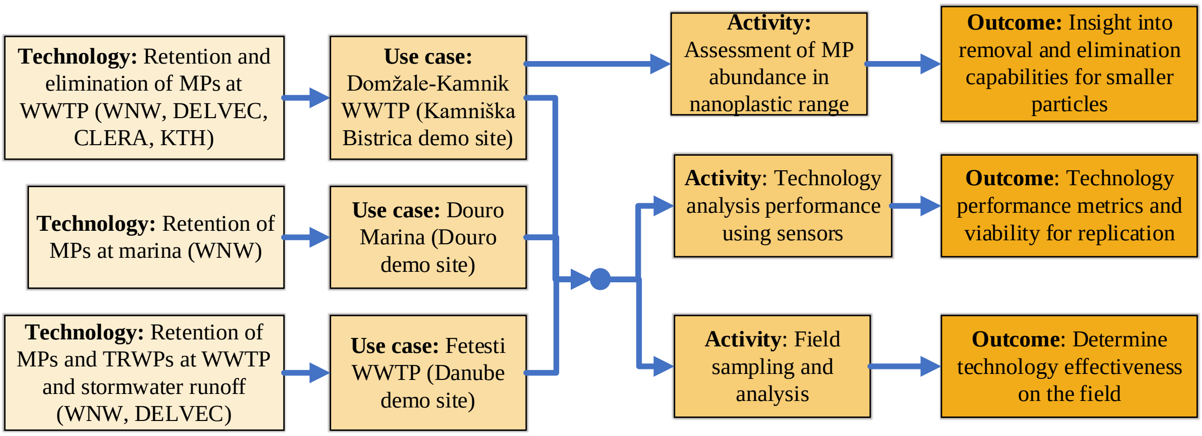


Figure 43: Impact pathway for the cases of collection of microplastic retention and elimination technologies.

6.1.1. INSPIRE microplastic retention technologies

In this booklet of D4.1, four INSPIRE MP retention technologies are evaluated: the Super-TW-Net filter developed by DELVEC, the special membrane filtration unit developed by CLERA, the EcoPlex Microplastic Remover developed by WnW, and the photocatalytic nanocoating device developed by KTH. These technologies will be deployed at three demo sites: Kamniška Bistrica (Slovenia), Douro estuary (Portugal), and Danube (Romania). An overview of these technologies, their related tasks, applications, and demo sites is provided in Table 60.

It should be noted that INSPIRE is also implementing and testing technologies related to removal of pellets, which are also considered MPs. The technology utilized for the retention of pellets is the CirCleaner, developed by partner NOR as part of T2.6 and implemented in the Londenhaven port in the Netherlands. The CirCleaner device is evaluated under section 4 of this document (Floating riverine retention technologies), as it its purpose is the removal of pellets directly from a port area. For this reason, it is evaluated alongside technologies which treat water directly in river streams as well as ports and docks.

Table 60: Overview of INSPIRE MP retention technologies.

No.	Technology	Provider	Related task(s)	Related application(s)	Related demo site(s)
1	EcoPlex Microplastic Remover	WnW	T2.3, T2.4, T2.5	WWTP, marina vessel washing water, stormwater runoff	Kamniška Bistrica, Douro, Danube
2	Special membrane filtration unit	CLERA	T2.3	WWTP	Kamniška Bistrica
3	Super-TW-Net filter	DELVEC	T2.3, T2.4	WWTP, stormwater runoff	Kamniška Bistrica, Danube
4	Photocatalytic nanocoating device	KTH	T2.3	WWTP	Kamniška Bistrica

The EcoPlex Microplastic Remover® (EcoPlex Device) developed by WnW consists of two MP filtering units working in series, retaining particles in size ranges between 10 and 100 µm. The device consists of hydraulic valves in appropriate places to allow the connection of the two filter units to be easily changed from serial to parallel. The filter units are mounted on skids for easy relocation. An electrical panel is installed in front of the filters for automatic operation, making the unit self-cleaning and fully automatic. Each filter unit contains a bottom layer of fine media and a top layer of coarse media. EcoPlex can also be remotely controlled by connecting a Programmable Logic Controller (PLC) to the electrical panel, including control of all peripheral equipment.

The special membrane filtration unit developed by CLERA is a chemicals-free water recycling system that enables removal of the finest particles down to a size range of 100 nm. Its innovative membrane allows a high-water permeation and flow while maintaining low pressure. An additional ozone generator disinfects the membranes and prevents fouling.

The Super-TW-Net filter developed by DELVEC is a device designed to collect nanometric particles, in particular tyre wear particles resulting from friction between car tyres and the road surface, in the size range between 10 and 100 nm. Its operation is based on functional paramagnetic nanoparticles immobilised on a suitable scaffold, which act as high-affinity adsorbents for the retained particles. The filter materials, consisting of hybrid Fe-based nanoparticles with high affinity for the carbon and sulphur contained in the weathered particles, are produced on an industrial scale using DELVEC's flame spray pyrolysis technology. The collected particles are recovered from the filter by backwashing, after which they can be collected for final disposal. In the INSPIRE case, these particles will be mineralized by the photocatalytic reactor (see Section 6.3.3 for details).

The photocatalytic nanocoating device developed by KTH has been designed to mineralize plastic particles into benign products using a novel Photo-Fenton process, where hydrogen peroxide (H_2O_2) and ferrous ions (Fe^{2+}) are used to deliver powerful oxidative properties by generating hydroxyl radicals (·OH) and converting microparticles into simple compounds (CO_2 and H_2O). The device will be installed as the final step in the treatment process, where the smallest particles will be pumped from the backwash tank to the photocatalytic nanocoating device.

Detailed descriptions of the evaluated technologies are available in deliverables D2.3 and D2.4.

6.1.2. Sampling with Ferrybox device in aquatic ecosystems

To sample water from effluents following treatment with INSPIRE technologies and in rivers at the demo sites, the Ferrybox device will be used for sampling of microlitter suspended in the water column. A detailed description of the Ferrybox device is available in INSPIRE D1.2 – Monitoring and analysis protocols.

Due to variations in accessibility between river locations and ecosystems, demo site leaders will adjust the procedure as necessary. For example, due to the narrow width of the river Kamniška Bistrica in Slovenia and the unavailability of a boat or other vessel for sampling, sampling according to the protocol will be carried out from suitable locations on riverbanks. In this case, equipment will be adjusted as necessary to ensure that hose tubes are long enough to reach the water column. Cleaning and storage of the equipment will be carried out in nearby laboratories.

6.1.2.1. Sampling equipment for testing in real environment

The following equipment will be provided by VLIZ for the Danube and Kamniška Bistrica demo sites:

- Ferrybox;
- Sieves: 25 µm, 50 µm, 200 µm, 500 µm, 1 mm;
- Hose connectors (3/4'' - 19 mm);
- Hoses inlet + outlet tubbing (19 mm);
- Kärcher SP 9.500 Dirt submersible pump;
- Stainless-steel funnel diameter 120 mm;
- Wash bottle.

The following equipment will be provided by the local partners:

- Generator or electricity connection (voltage 230-240 V, frequency 50 Hz);
- Rope (with sampling depth marked) and metal attachment segment;
- Metal container 10 L filled with (MilliQ) ultrapure water;
- Labels with sample codes, prepared before field work;
- Pre rinsed bottles and caps, including for blanks, for samples for VLIZ;

- Aluminium foil (roll or disks with diameter 80 mm);
- (Waterproof) notebook and pen;
- Paper towels;
- Boxes to transport materials and the sample bottles;
- Boots, gloves and water wear equipment if necessary.

6.1.2.2. Sampling protocol

Sampling follows the protocol for Ferrybox sampling described in INSPIRE D1.2 – Monitoring and analysis protocols. The following list of steps will be followed by the demo site partners when performing sampling with Ferrybox in the real environment:

Step 1: Field blank sample preparation and collection:

- Step 1.1: Rinse glass bottles with isopropanol and then with ultrapure water
- Step 1.2: Prepare labels on glass bottles
- Step 1.3: Place the inner housing on a table surface
- Step 1.4: Prepare the glass bottle (avoid keeping it open to not contain the sample from air)
- Step 1.5: Rinse the funnel with ultrapure water
- Step 1.6: Open the inner housing and rinse the larger mesh sieve from outside and inside, try to rinse out all visible particles (use around 1/3rd of the 1 L bottle)
- Step 1.7: Once rinsed, place the larger mesh sieve back on the tower and repeat the process with the smaller mesh sieve. Rinse every part of it in detail.
- Step 1.8: Place the sieves back in the inner housing in the correct order (1st: larger mesh for structure, 2nd: smaller mesh, 3rd: larger mesh)
- Step 1.9: Rinse the funnel into the glass bottle and close it with aluminium foil and the cap
- Step 1.10: Note the time of blank collection in the notebook.
- Note: The process is only done once. We are collecting one blank (in one bottle) for both sieves.

Step 2: Set-up on the field:

- Step 2.1: Ensure the sieve order is correct inside the Ferrybox
- Step 2.2: Close the Ferrybox holder screw until you feel a resistance
- Step 2.3: Assemble the Ferrybox along with the metal holder
- Step 2.4: Rinse the inlet tube with the river water (outlet does not need to be rinsed)
- Step 2.5: Prepare notebook (time, volume, flow, depth, sample #) and timer

Step 3: Water pumping through Ferrybox:

- Step 3.1: Press the RESET button on the Ferrybox to obtain 0 values
- Step 3.2: Connect the inlet tube to the pump (press the grey holder to remove it, attach tube, then re-apply the grey holder
- Step 3.3: Connect the outlet tube to flow back into the river
- Step 3.4: Plug the pump into the battery/generator
- Step 3.5: Attach the rope to the pump and tie it around a solid structure for safety
- Step 3.6: Hold the pump with the rope and the orange belt
- Step 3.7: Place the pump in the water (make sure the upper part is vertical)
- Step 3.8: Turn on the battery/generator power

- Step 3.9: Wait a few seconds for the water to flow through the tube, then start the 5-minute timer
- Step 3.10: Take note of the time and the fluctuating volume flow (usually 2 values)
- Step 3.11: After 5 minutes, turn off the pump
- Step 3.12: Before lifting the pump or removing the tubes, take note of the total volume.
- Step 3.13: Lift the pump out of the water, take note of the depth
- Step 3.14: Remove the tubes and the excess water inside them
- Note: If flowrate drops below 10 L/min, stop the operation, clean it, and restart. If the Ferrybox is leaking, stop the operation, reset it, and restart.

Step 4: Sample collection:

- Step 4.1: Unscrew the Ferrybox screw in a safe spot (to avoid losing it)
- Step 4.2: Lift the outer housing and wait for the water to flow out
- Step 4.3: Place the inner housing on a table surface
- Step 4.4: Prepare the glass bottle (avoid keeping it open to not contain the sample from air)
- Step 4.5: Rinse the funnel with ultrapure water
- Step 4.6: Open the inner housing and rinse the larger mesh sieve from outside and inside, try to rinse out all visible particles (use around 1/3rd of the 1 L bottle)
- Step 4.7: Once rinsed, place the larger mesh sieve back on the tower and repeat the process with the smaller mesh sieve. Rinse every part of it in detail. (use around 1/2 of the 1 L bottle)
- Step 4.8: Place the sieves back in the inner housing in the correct order (1st: larger mesh for structure, 2nd: smaller mesh, 3rd: larger mesh)
- Step 4.9: Rinse the funnel into the glass bottle and close it with aluminium foil and the cap
- Note: Repeat the process for 3 samples.

Step 5: Cleaning at laboratory:

- Step 5.1: Disassemble the Ferrybox and clean it with ultrapure water
- Step 5.2: Rinse the inlet and outlet tubes with tap water.

6.1.3. Analysis of water samples

This section describes the analysis of water samples collected with the Ferrybox device. It defines the output parameters for the analysis of MPs, NPs, and tyre and TRWP samples.

6.1.3.1. Analysis of microplastic particles

In the MP section of the Guidance on Monitoring of Marine Litter in European Seas (JRC - MSFD Technical Subgroup on Marine Litter, 2013), the JRC recommends quantifying MPs in the size range from 20 µm to 5 mm, and categorizing MPs according to their physical characteristics including size, shape and colour. It should be noted that while pellets are also in the MP range and officially considered as MPs, the technology designed for pellet retention is evaluated alongside the floating riverine litter retention technologies (section 4 of this document), which are implemented directly in river streams or ports and docks.

MP samples collected under INSPIRE activities will be analyzed by VLIZ according to standardized analysis protocols already in use. The methodology involves sieving of samples, digestion, density separation, centrifugation, and filtration, followed by analysis using two methods:

1) Nile red fluorescent dye-based staining and observation and
2) Micro-Fourier transform infrared (µFTIR) spectroscopy analysis, where the lower particle size limit for µFTIR analysis is 50 µm.

A detailed description of the analysis procedure is described in INSPIRE D1.2 – Sampling and analysis protocols. Sample analysis of microlitter in the water column will provide the parameters defined in Table 61.

Table 61: Parameters obtained from sample analysis of microlitter in the water column.

Parameter	Retrieval method	Unit
Sampling date	Sampling	YYYY/MM/DD
Total water volume	Sampling	L
Average volume flow	Sampling	L/min
Sampling time	Sampling	min
Water depth	Sampling	m
Sieve mesh size(s) used	Sampling	µm
MP concentration	Laboratory analysis	# of particles / m^3
MP mass per volume	Laboratory analysis	mg MPs / m^3
MP size distribution	Laboratory analysis	µm
Polymer type	Laboratory analysis	/

6.1.3.2. Analysis of nanoplastic particles

A key aspect of wastewater treatment addressed by INSPIRE MP retention technologies at the Domžale-Kamnik WWTP is the retention of particles in the size range down to 10 µm in size and further breakdown of micro- and nanoplastics (<1 µm) into simple compounds (CO_2 and H_2O) using KTH's photocatalytic reactor. However, due to the smallest available sieve mesh size for sampling at 25 µm and the limitations of analytical detection methods at small particle sizes, there is a need to assess the abundance of smaller particles using alternative methods such as mathematical estimation based on size frequency distributions as per Kaandorp et al. (Kaandorp et al., 2021).

Secondary nanoplastics (NPs) are formed by progressive long-term weathering of plastic material surfaces as a result of cascading fragmentation, first from primary plastic objects to MPs, and further from released MPs into even smaller pieces. The process occurs due to changes in surface properties as MPs form, including surface charge, roughness and crystallinity. These properties affect the adsorption of chemical contaminants and interactions with natural colloids, which has a significant effect on the cracking of weathered plastic surfaces to form secondary NPs (Maddison et al., 2023).

As the formation of NPs is a direct consequence of the presence of MPs, the abundance of NPs in aquatic systems can be estimated from the size distribution of detectable MP particles in a larger size range. As the particles break down into even smaller pieces, the size distribution of MPs resulting from fragmentation follows a power-law shape curve with a negative exponent (-α), the magnitude of which is determined by the degree of fragmentation (Kaandorp et al., 2021). Based on work done in previous studies, the size distribution of MPs follows a curve expressed by Equation 32:

$$y = bx^{-\alpha} \quad (32)$$

where y is the abundance of MPs expressed in number of particles, b is a coefficient used to fit the function based on y, x is the particle size in µm, and α is the exponent factor related to the degree of fragmentation.

Previous studies collecting data on the average fitted power law standard deviation exponent α have found that the mean exponent parameter varies between values of 1.6 ± 0.5 (Kooi & Koelmans, 2019) and 2.2 (Kooi et al., 2021) for all global MPs studied. The graph in Figure 44 shows an example of a logarithmic plot function of size distribution for MPs in the freshwater surface compartment. The solid line indicates the sizes for which the fitted power-law function is valid, while the dotted line shows the continuation of the slope beyond the minimum size.

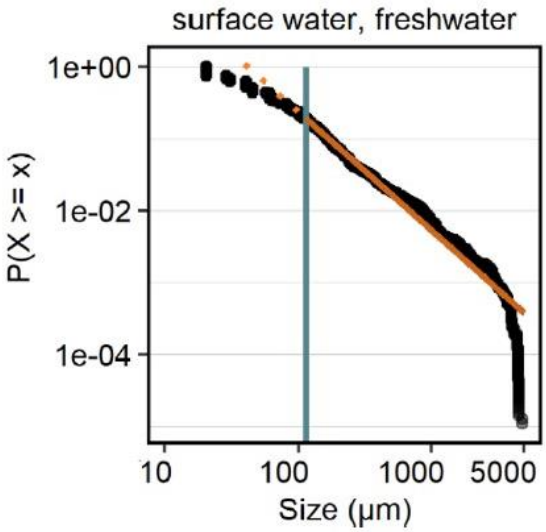


Figure 44: Example logarithmic plot of particle length distribution for MPs in the freshwater surface compartment (adapted from (Kooi et al., 2021)).

Such exponent values can be applied to case studies to estimate the abundance of MPs in different size classes. The procedure undertaken in INSPIRE will follow work from previous studies, where the values of particle abundances and particle lengths will be plotted to determine an exponential function and its associated α value. The exponent value will be applied and extrapolated to size ranges between 1 µm and 50 µm using the function to determine their abundance, or value y from Equation 32, as specified in Table 62.

Table 62: Parameters obtained during MP sample analysis and estimation of secondary NP particle abundance.

Parameter	Retrieval method	Unit
Sampling date	Sampling	YYYY-MM-DD
Particle abundance	Laboratory analysis	particles / L
Particle length	Laboratory analysis	particles / L in specific size class (in µm)
Polymer type	Laboratory analysis	/
α (exponent)	Calculations	/
y (abundance of MPs between 1 µm and 50 µm)	Calculations	/

The calculated estimated abundance of NPs in collected samples will be correlated with the calculated efficiency of MP retention technologies, which will be based on laboratory catch-release or release-catch experiments. These experiments will utilize tagged materials with previously determined size ranges, mass numbers, and polymer types, which will be added to spiked water to be fed into the technologies. A detailed plan for determining the efficiency of MP retention technologies in the laboratory based on controlled particle release-catch experiments is available in INSPIRE D2.1 – Plastic removal efficiency protocols. The final estimates of NPs released to the environment will be calculated using the estimated abundance of NPs at a given sampling point and the calculated retention efficiency of specific technologies.

It is important to note that such a size distribution analysis requires a greater number of size ranges when sampling with different mesh size sieves in order to develop an accurate size distribution curve. For this reason, water at the WWTP effluent will be specifically sampled with a greater number of sieve mesh sizes, which will enable the counting of retained particles by sieves with mesh sizes of 25, 50, 100, 200, 500, and 1000 µm. This will provide a more accurate size distribution of particles in the WWTP effluent will enable calculation of NP abundance in the water treated by INSPIRE retention technologies.

6.1.3.3. Analysis of tyre wear particles

Analysis of tyre and TRWPs in INSPIRE will be performed according to protocols implemented by FRE. The analysis will be based on mass detection using chemical markers to quantify TRWPs. Prior to analysis, samples will be separated by density, sieved, and digested. Instrumental analysis will be performed by inductively coupled plasma mass spectrometry. A detailed description of the analysis procedure is provided in INSPIRE D1.2 – Sampling and analysis protocols.

6.1.4. INSPIRE Sensor kit for microplastic retention technologies

In order to monitor data related to INSPIRE MP retention technologies and associated water flows, a set of sensor technology will be used for real-time data acquisition. The devices specified in the sensor kit are applicable to all INSPIRE MP retention technologies and can provide measurements of physical properties while transmitting data into the INSPIRE repository (T4.4).

A distinction is made between two types of sensors:

a) sensors on devices to measure performance (energy, noise, vibration) and
b) sensors on pipes to measure water data (flow, pressure, temperature, turbidity).

Table 63 presents a complete overview of sensor types and specific products that could be used to measure specific parameters. Based on the analysed measurement ranges, power consumption, and available price ranges, a selection of the most appropriate sensors for partner INFOR is possible. It should be noted that the table lists a selection of representative sensors which will be used for dynamic data collection as part of INSPIRE T4.4: Impact evaluation dashboard.

Specific set-ups for the integration of sensors onto the INSPIRE MP retention technologies can be found in Sections 6.2.5, 6.3.5, and 6.4.5 of this document, relating to the demo cases in Domžale-Kamnik WWTP in Slovenia, Marina Douro in Portugal, and Fetesti WWTP in Romania, respectively.

It should be noted that the microphone used as a noise meter will only be used once for each device at demo sites, as outlined in specific sections dealing with sensor integration. Since noise is not a parameter that is subject to significant changes, the same device will be used for all demo site measurements.

Table 63: Overview of sensors used for MP retention technologies.

Sensor type	No.	Type	Image	Manufacturer (website) & Mode	Measurable range (sensitivity)	Power consumption
Energy meter	1	Shelly 3 EM Pro		Shelly (shelly.com)	380 V ±10%, 50/60Hz Max 120A	< 1 W
	2	Shelly Pro 4PM		Shelly (shelly.com)	110 – 240 V 4 Channels Max 40A each	< 4 W
Flow or pressure meter	1	Clamp-On Flow Sensor FD-H series		KEYENCE (keyence.eu)	Maximum flow: 30 L/min	20–30 VDC
	2	Ultrasonic Clamp-On SONOFLOW CO.55		SONOTEC (sonotec.eu)	110 – 240 L/min	12-30 VDC
	3	Digital flow and pressure sensor		ADAJUSA (adajusa.com)	0.9 – 8 bar 0 – 100 L/min	12-24 Vdc ±10%

Table 63: Overview of sensors used for MP retention technologies (continued).

Noise meter	1	Decibel meter		Tadeto (amazon.com)	30 – 130 dB	1.5 V 2*AAA batteries
	2	LATNEX SM-130DB Sound Level Meter		LATNEX (latnex.com)	35 – 130 dB	9 V battery
	3	SKF Stethoscope TKST 11		SKF (skf.com)	30 Hz – 15 kHz	2 × AA battery
Vibration sensor	1	MPU9250		WITMOTION (witmotion-sensor.com)	•Acceleration (±6g), •Gyroscope (±2000°/s), •Magnet Field (±4900µT).	5-36V
	2	BWT61CL		WITMOTION (witmotion-sensor.com)	•Acceleration (±16g), •Gyroscope (±2000°/s).	3.3-5 V

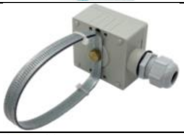
	3	Recovib.Tiny		Micromega (micromega-dynamics.com)	Vibration modal analysis	DC to 250Hz useful bandwidth
Temperature sensor	1	Clamp-On Temperature Sensor		Titan Products (titanproducts. com)	-40 – 70 ℃ ±0.2℃	24V AC/DC
	2	TN2511		IFM Electronic (ifm.com)	-50 – 150 ℃	18-32 V DC
	3	Zada Tech temperature sensor		Zada Tech (turbozentrum.de)	0 – 150 ℃	/
Turbidity sensor	1	BH-485-TU		BOQU instruments (boquinstruments. com)	0.001 – 0.1 NTU	DC 24 V (19-36 V)
	2	YSI ProDSS Turbidity Sensor		Fondriest (fondriest.com)	0—4000 NTU	20-hour battery
	3	TST-10 Turbidity sensor		Amphenol (farnell.com)	0—4000 NTU	5 VDC

Table 63: Overview of sensors used for MP retention technologies (continued).

Water flow and pressure	1	Water pressure sensor Model Fafeicysx3k7 whmru-03		Fafeicy	0~12 bar	
	2	Water Flow Sensor Model Zerodis8xpy0 ms2uh		Zerodis	2-45 L / min	
pH Sensor	1	PH sensor model Eujgoovgpn5z u0rq1600		Eujgoov	pH 0-14	

TDS (Total Dissolved Solids)	1	CQRobot TDS Meter Sensor Model CQRSENTDS01		CQRobot	ppm	Wide Voltage Input: 3.3V to 5.5V
ORP	1	Nobotech OPR Sensor		Nobotech	-1999 mV ~ + 1999 mV	

6.2. Evaluation of INSPIRE cascade solution at the Domžale-Kamnik WWTP and on river Kamniška Bistrica

The technologies developed in INSPIRE T2.3: Retention, collection and elimination of MPs from WWTPs are used as a cascade solution at the Domžale-Kamnik WWTP in Domžale, Slovenia on the river Kamniška Bistrica.

6.2.1. Problem definition

In response to the ever-increasing pressures on freshwater resources, the EU has adopted a number of frameworks aimed at restoring and maintaining the status of rivers, lakes and groundwater, and preventing adverse environmental impacts from urban wastewater discharges in Europe. The two main directives related to these goals are the Water Framework Directive and the Urban Wastewater Treatment Directive. To date, these regulations have not imposed any restrictions on MPs and have left the responsibility for removal to the treatment companies themselves.

The revised EU Urban Wastewater Treatment Directive (2022/0345) (European Commission, 2022) introduced the obligation to upgrade WWTP facilities and apply additional treatment for urban wastewater in order to eliminate the broadest possible spectrum of contaminants of emerging concern, which applies to all urban WWTPs treating a load of 100 000 population equivalents or more by 2035 at the latest. The range of contaminants also includes MPs and Per- and polyfluoroalkyl substances (PFAS).

This revised directive is expected to have a significant impact on the operation of municipal WWTPs, which are currently designed to remove contaminants from wastewater but do not adequately remove micropollutants and MPs, posing a threat to aquatic ecosystems. As WWTPs will require additional 4th stage treatment, the implementation of advanced MP retention technologies will enable facilities to be ahead of the curve in treating smaller particles after the tertiary treatment effluent. To address this issue, INSPIRE plans to install a cascade solution for the elimination of MPs from the effluent of the Domžale-Kamnik tertiary WWTP in Slovenia.

6.2.2. Description of testing location

The Domžale-Kamnik WWTP is shown on the map in Figure 45. As the fourth largest WWTP in Slovenia, it serves six municipalities and treats residential, commercial, and stormwater wastewater. With a capacity of 149,000 population equivalents, the plant can process up to 9 million m^3 of wastewater per year.

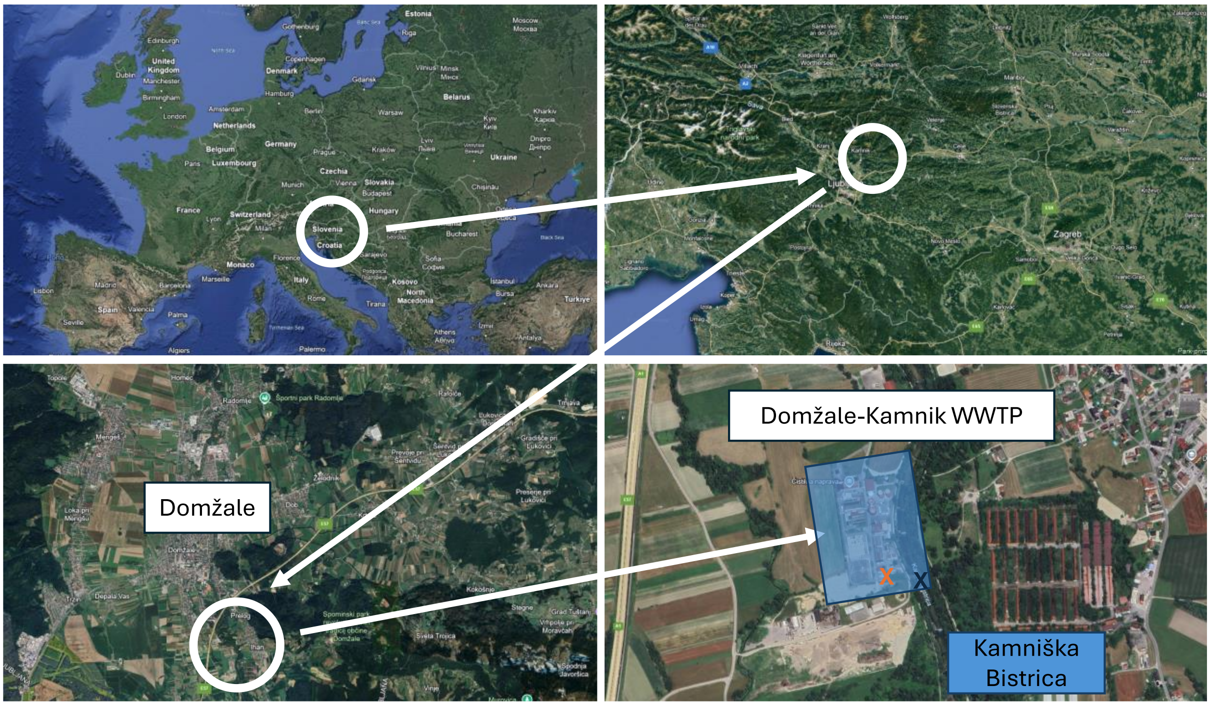


Figure 45: Location of the demo site in Slovenia (top left: map of the EU, top right: map of Slovenia, bottom left: Domžale municipality within Slovenia, bottom right: satellite image of the Domžale-Kamnik WWTP near the river Kamniška Bistrica).

The treatment process at the Domžale-Kamnik WWTP consists of three stages. First, coarse solids and large contaminants are removed from wastewater by mechanical treatment. This is followed by an aerobic biological stage in a sequencing batch reactor (SBR), which removes carbon, nitrogen, and phosphorus compounds. In the final stage, produced sludge is aerobically converted into biogas. The treatment processes and their components are shown in Figure 46.

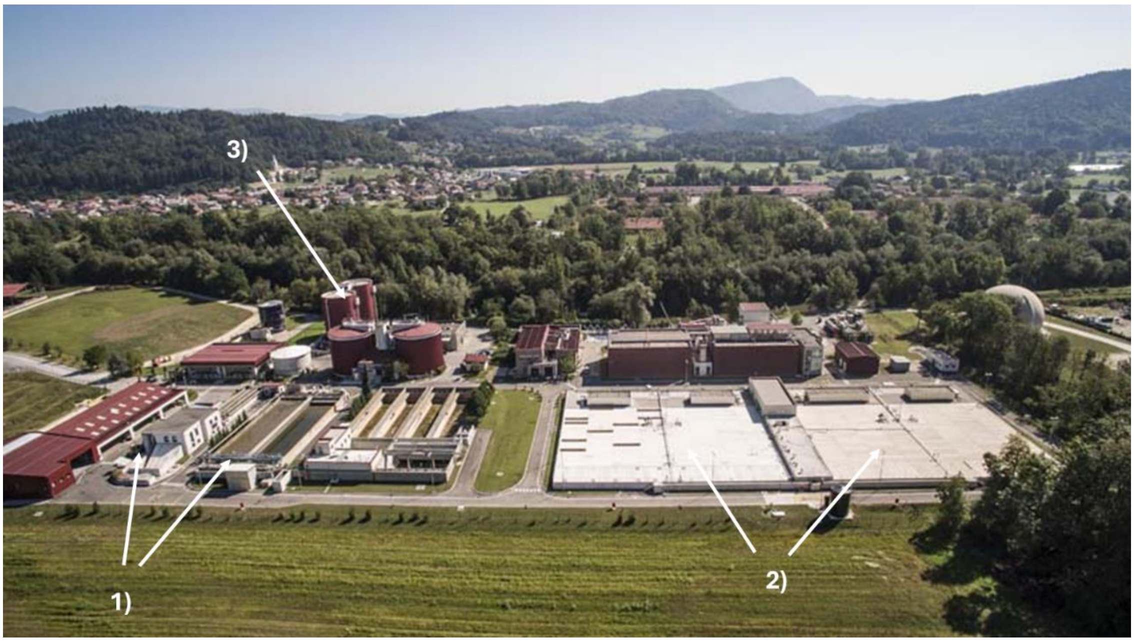


Figure 46: Wastewater treatment steps at the WWTP: (1) mechanical, (2) aerobic and (3) anaerobic treatment (photo source: WWTP website (d.o.o., 2023)).

The river Kamniška Bistrica is a 33 km long river originating from the Kamnik-Savinja Alps. It crosses gorges and ravines and flows through the urban areas of Kamnik and Domžale before merging with the river Sava as a left tributary. The river is home to many species of flora and fauna. The Domžale-Kamnik WWTP is located on the left bank of the river. The wastewater discharge, marked with a blue X in Figure 45, is located at the southern part of the WWTP complex and is directly connected to the river, as seen from Figure 47. The plant operates as a fully automated system, ensuring continuous monitoring and automatic measurement of specific water parameters at each stage of the treatment process.

Figure 47: WWTP Domžale-Kamnik water outlet into the Kamniška Bistrica River (photo source: company website (d.o.o., 2023)).

The quality of the treated water is strictly controlled. Parameters such as chemical oxygen demand (COD), biological oxygen demand (BOD), total nitrogen and phosphorus content are always kept below the legally prescribed limits for WWTP effluent before being discharged into the river.

6.2.3. Implementation of INSPIRE technologies

The INSPIRE MP removal solution will be tested with a specific layout, consisting of 3 different retention and one elimination technology, set up sequentially or in parallel, as shown in the flowsheet in Figure 48. The following technologies will be connected at the demo site:

1) EcoPlex Microplastic Remover developed by WnW (T2.3, T2.4, T2.5);
2) Special membrane filtration unit developed by CLERA (T2.3);
3) Super-TW-Net filter developed by DELVEC (T2.3, T2.4);
4) Photocatalytic nanocoating device developed by KTH (T2.3).

The technologies will be arranged in such a way to optimise operational efficiency and MP removal, with larger particles being removed at the beginning of the cascade system. The deployment, layout and operation of the solution is defined in INSPIRE WP2, task T2.3.

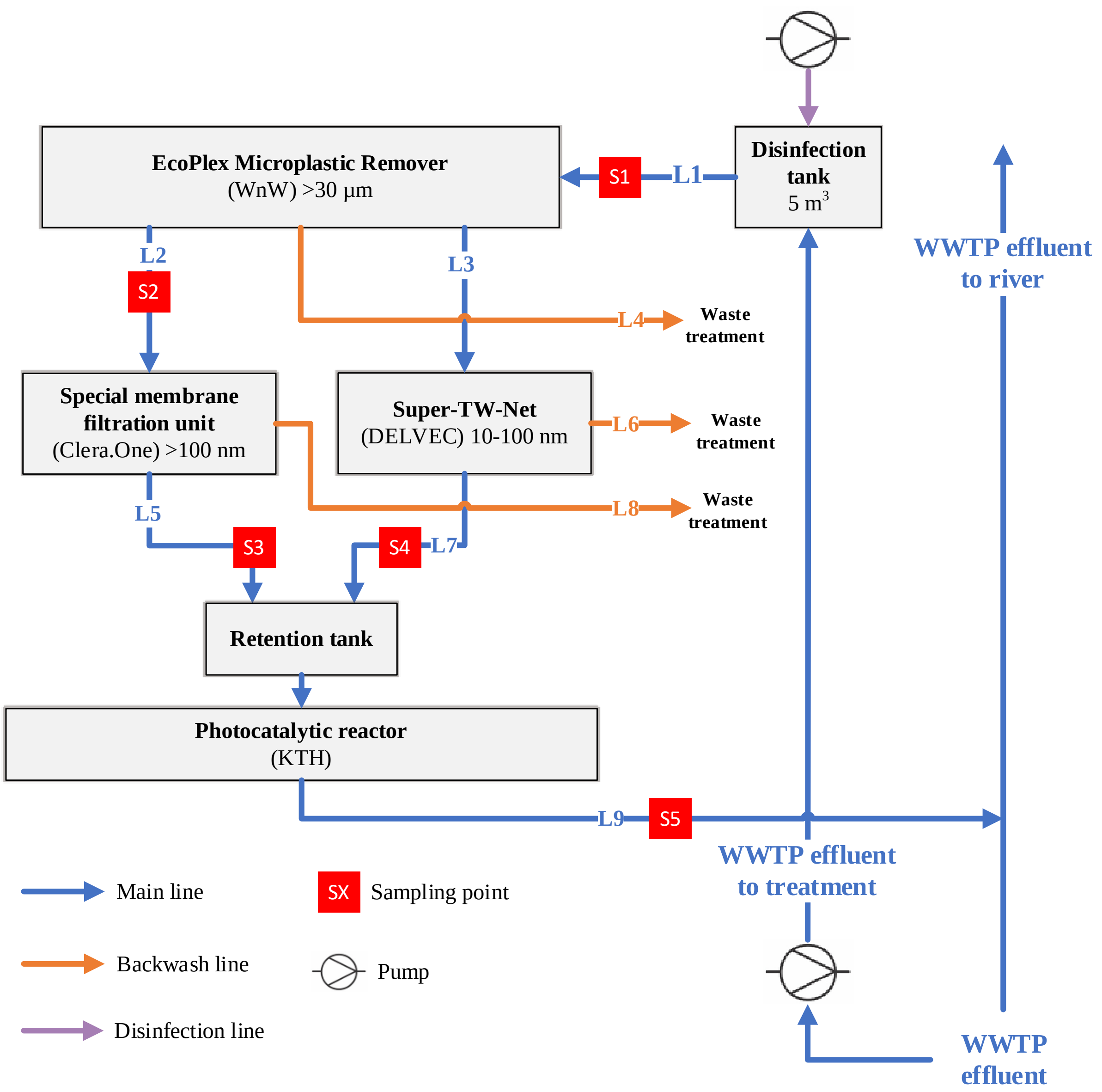


Figure 48: Schematic representation of the cascade solution with inflows and outflows.

The WWTP effluent will be divided into two streams: One will be directed towards the cascade solution, while the other will be directed into the river as treated water from the WWTP. The water flowing to the cascade solution will first be disinfected with perchlorates to reduce the presence of microorganisms and prevent biofouling that could affect the operation of the cascade system. Larger MPs will be captured at the beginning of the process with WnW's EcoPlex unit. This consists of two consecutive filtering units with a fine media at the bottom and a coarse media at the top, which retains particles larger than 30 µm. The main flow from the EcoPlex system will be split into two streams, each of which will be directed to one of the remaining MP retention technologies: DELVEC's Super-TW-Net and CLERA's special membrane filtration unit. The Super-TW-Net system removes particles between 10 and 100 nm using functional paramagnetic nanoparticles immobilised on a scaffold that acts as a high-affinity adsorbent. CLERA's system utilizes a membrane unit with a pore size of 100 nm and includes an ozone generator to disinfect the membrane to prevent fouling. After these treatments in either system, water will be directed to a small retention tank which will lead to the final stage of the cascade solution. In this stage, KTH's photocatalytic reactor will mineralise micro- and nanoplastics into simple compounds (CO_2 and H_2O) using the Photo-Fenton process. After a sufficient retention time in the photocatalytic reactor, the treated water will be returned to the wastewater WWTP outlet and then discharged into the Kamniška Bistrica river through the regular waste stream. A graphical outline of the solution is presented in Figure 49.

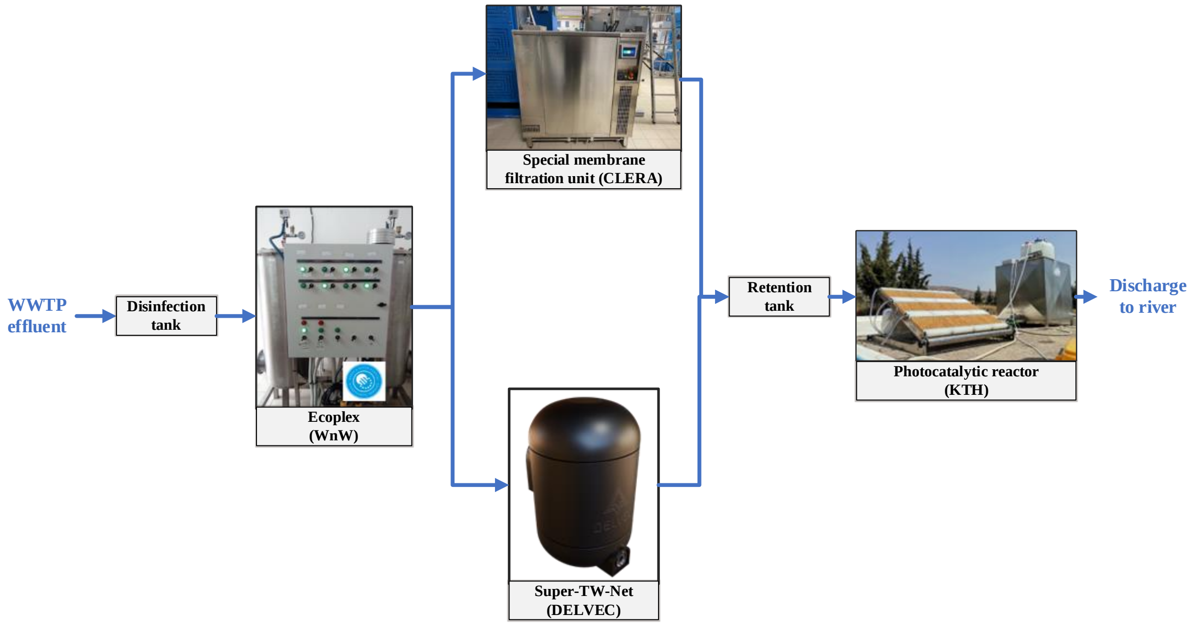


Figure 49: MP cascade solution implemented in the Domžale-Kamnik WWTP.

Figure 50 shows the proposed location of the MP retention and elimination system within the WWTP. The system will be installed in the southern part of the plant near the WWTP effluent, as indicated by the orange X in Figure 45. This location is easily accessible and secured by a fence and provides sufficient space to accommodate all the necessary technologies and ancillary components such as tanks. This location also provides access to an electrical outlet to ensure reliable operation of the cascade solution. An area of 20 m^2 was defined based on the size requirements of the technologies.

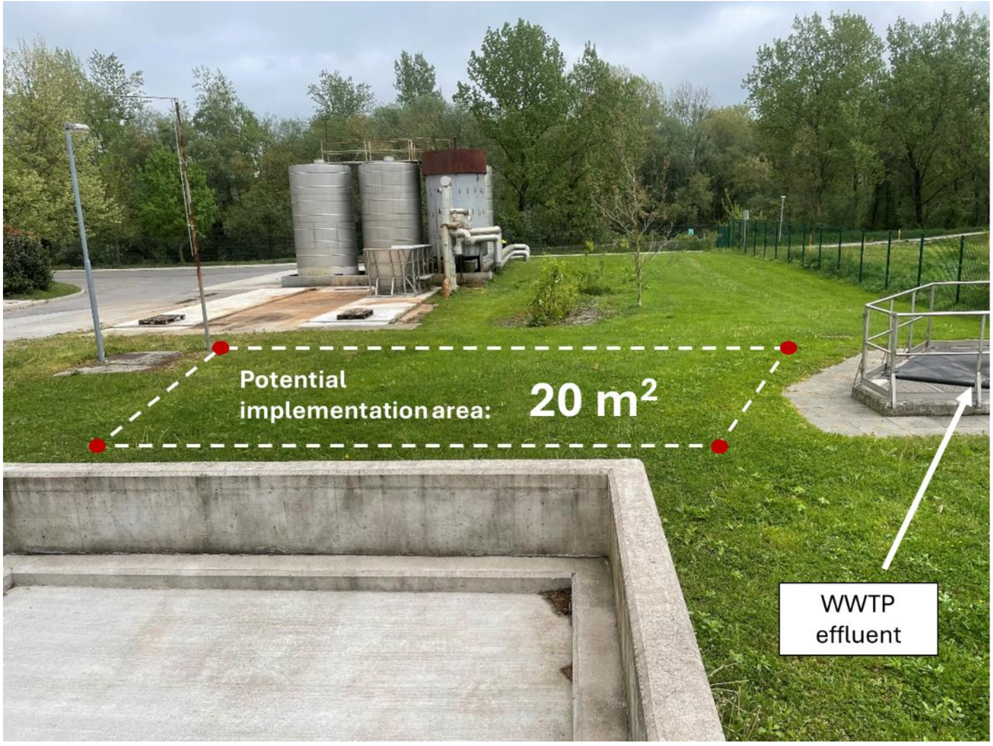


Figure 50: Solution implementation area within the WWTP.

6.2.4. Site-specific sampling plan

The site-specific sampling plan refers to sampling both in the river Kamniška Bistrica and in influent and effluent of the MP cascade solution. As river sampling is part of INSPIRE WP1 activities, this document primarily focuses on sampling and analysis procedures for the implemented technology.

The sampling points have been determined in a way that allows for sampling of water prior to and after each device to determine its retention efficiency. Each technology has one water inlet and two outlets (except the KTH photocatalytic system), as shown in Figure 48: the main line (blue line), which contains all the particles passing through the technology, and the backwash line (orange line), which contains all the particles retained by the technology. MP sampling points are located after each of the four technologies. An additional sampling point is located before the first retention technology to determine the baseline level of MP contamination of the treated water from the WWTP before it enters the cascade system. A total of 5 sampling points were identified and labelled with the initial letter S in Figure 48.

Due to limitations in sampling and analysis procedures for particle smaller than 25 µm, only water from sampling points S1 and S2 will be physically sampled on site, as they are are in the MP range, while sampling points S3, S4 and S5 are in both micro and nano ranges. All sampling points, except for S3 and S4, are located along the main water lines of the designated technologies. As the main lines of the DELVEC and CLERA devices act as an inlet flow for the photocatalytic reactor, these lines were selected as sampling points. In this way, the photocatalytic reactor will treat all MPs not retained by preceding technologies. Using the mathematical estimation procedure described in Section 6.1.3.2 of this document, MP and NP abundances at these three points will be calculated to provide information on particles present in the water inlet of the photocatalytic reactor. Based on the characteristics of sampling points, two sampling procedures will be used and followed, as shown in Table 64. UM, as the demo site leader, will be responsible for providing and preparing the samples before sending them to VLIZ, who will be responsible for sample analysis.

Table 64: Sampling and analysis procedure at the Kamniška Bistrica demo site.

Sampling point	Partner responsible for sampling	Sieve mesh sizes used	Sampling methodology	Partner responsible for analysis	Analysis methodology	Sampling frequency
S1	UM	25 µm + 50 µm + 200 µm	Protocols from D1.2	VLIZ	Protocols from D1.2	Weekly during operation
S2	UM	25 µm + 50 µm + 200 µm	Protocols from D1.2	VLIZ	Protocols from D1.2	
S3	/	/	No direct sampling	UM, VLIZ	Estimations described in section 2.2.2 of this document	/
S4	/	/		UM, VLIZ		/
S5	/	/		UM, VLIZ		/
River	UM	200 µm + 1 mm	Protocols from D1.2	VLIZ	Protocols from D1.2	4 times per year

6.2.5. Integration of sensors

To collect real-time monitoring data during operation of the system, 6 types of sensors selected from the sensor kit (described in Section 6.1.4 of this document) will be installed. Table 65 provides an overview of sensor types, their purpose and placement within the cascade solution system.

Table 65: Sensors installed on the Domžale-Kamnik WWTP cascade solution system.

Sensor type	Purpose	Sensor placement	Quantity of units
Flow and/or pressure	Monitoring potential clogging prior to water treatment with EcoPlex, water recycling system, and Super-TW-Net	Water pipe	2
Turbidity	Water quality	Water pipe	3
Temperature	Effluent water temperature	Water pipe	1
Noise	Monitor potential excessive noise	Device	2
Accelerometer	Monitor potential excessive vibrations and movements	Device	2
Power meter	Record power consumption	Device	2

A detailed schematic view of the installed sensors is presented in Figure 51. Sensors for flow and/or pressure have been selected to provide continuous data on potential clogging of filtration equipment. For this reason, sensors will be installed on flows L1, L2, and L3, as these lines are the only ones leading to devices that could potentially become clogged. Turbidity measurements will be carried out on all main lines, as shown in the figure. Temperature will only be monitored at the final discharge line, L9. Noise, vibration, and power meters will be installed on the devices themselves: each sensor will be placed on the EcoPlex Microplastic Remover by WnW, the water recycling system by CLERA, the Super-TW-Net by DELVEC, and the photocatalytic reactor by KTH.

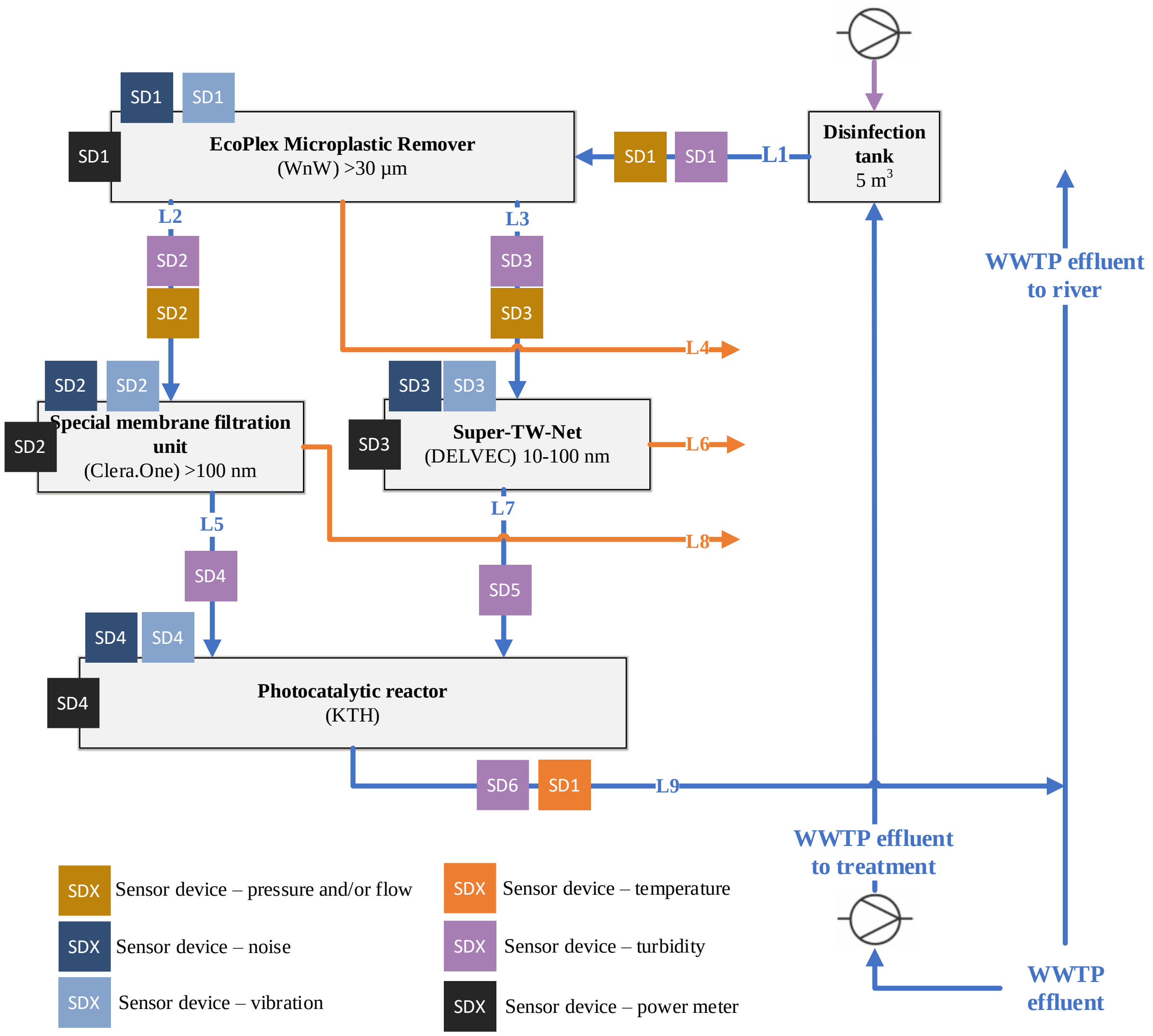


Figure 51: Integration of sensors at the Domžale-Kamnik WWTP demo site.

6.2.6. Demo site data collection sheet

Data from the Kamniška Bistrica demo site will be collected by partners in the following datasheets, based on methodologies and procedures presented in the preceding sections and shown in Table 66. This datasheet will be digitized, allowing demo site data to be streamed to the INSPIRE repository in accordance with activities of dataset collection from demo sites in T4.4 – Impact evaluation dashboard, and with data storage requirements in T7.3 – Data Management.

Table 66: Data collection sheet for technologies at the Kamniška Bistrica demo site.

Parameter	Measurement frequency	Sampling location(s)	Unit
Sampling date	Weekly during technology operation	S1, S2	YYYY/MM/DD
Total water volume		S1, S2	L
Average volume flow		S1, S2	L/min
Sampling time		S1, S2	min
Water depth		S1, S2	m
Sieve mesh size(s) used		S1, S2	µm
MP concentration		S1, S2	# of particles / m^3
MP mass per volume		S1, S2	mg MPs / m^3
MP size distribution		S1, S2	µm
Polymer type		S1, S2	/
α (exponent)		S1, S2	/
y (abundance of MPs between 1 µm and 50 µm)		S3, S4, S5	# of particles / m^3
Flow and/or pressure	Weekly	Based on scheme in Figure 51	L/min
Turbidity	Weekly		NTU
Temperature	Weekly		Ċ
Noise	Once		m/s^2
Vibration	Once		dB
Power	Weekly		W

6.3. Evaluation of INSPIRE filtration system at Marina Douro

The INSPIRE solution described in this section relates to T2.5: Use of special filtration to eliminate MPs in marinas and shipyards. It should be noted that the first version of this deliverable included additional information on the legislative background related to wastewater re-use in marinas, water purification procedures, and on periodic water quality tests. Following the review process and the decision to focus exclusively on microplastic removal from marina wastewater, this information was excluded from this document in order to clarify that the evaluation also considers only the MP removal process.

6.3.1. Problem definition

During the time that ships and boats are stationed in the water, various types of organisms accumulate on the hull of the ship, either through by bacterial growth or attachment, also known as biofouling. Biofouling is a concern for the structural stability and operation of the vessel, as it can damage the hull if organisms are allowed to reproduce, as well as increasing the weight of the vessel, which in turn increases hydrodynamic friction, leading to significantly higher fuel consumption with increases up to 40 % (Vietti, 2009). In addition, the transport of invasive species beyond their normal habitats can cause changes in aquatic ecosystems (GEF-UNDP-IMO GloFouling Partnerships Project, 2022).

Biofouling organisms include microalgae, macroalgae, barnacles, tubeworms, and bivalves. A brief overview of key organism groups in marine biofouling communities and the main problems they cause is provided in Table 67.

Table 67: Key organism groups in marine biofouling communities (adapted from (Vuong et al., 2023)).

Biofouling organism group	Examples of notable species	Problems caused by biofouling groups
Biofilms	Bacteria	Biofilms provide an adhering layer for other biofouling organisms
	Fungi	
	Microalgae	
Biocalcifying microorganisms	Bacterial groups such as Cyanobacteria	Precipitation of calcium carbonate leading to biofouling issues
	Sulfate-reducing bacteria	
	Denitrifying bacteria	
Morphogenesis agents	Marine invertebrates	Bacterial species induce the growth of larvae and algal spores
	Algae	
Biofilm-based viruses	Double-stranded DNA viruses	Viruses increase biofilm formation capabilities
Macro-fouling organisms	Molluscs	Compromised surface structures and increased weight of vessels
	Barnacles	
	Hard and soft corals	
	Marine sponges	

In addition, biofouling organisms have different attachments strengths and consequently require varying levels of force to remove them. Previous research on attachment strength of biofouling organisms has found that forces up to 3.3 MPa are needed to remove barnacles (hard fouling organisms) from hard epoxy-based paints (Granhag & Oliveira, 2021). However, such forces are highly dependent on the combination of organism and paint type.

Anti-fouling paint coatings are applied to the ship hull to prevent biofouling and to deter marine organisms from attaching to the surface and causing damage to the ship. Some types of anti-fouling paints can gradually release biocides from a porous film on the surface, which inhibit the growth of subaquatic organisms. Once all biocides have been released, a new coat of anti-fouling paint must be applied, which is usually done seasonally. In this sense, seasonal maintenance of boats in marinas is carried out as a routine cleaning operation to remove the old anti-fouling paint from boats before a new coat is applied. This cleaning is usually performed once per year to remove biological growth and paints, and it is done by power or pressure washing over the bottom of the boat while it is lifted out of the water.

6.3.1.1. Anti-fouling paint substances

The composition of substances used for anti-fouling paints has changed over the last few decades as certain common biocidal substances have been found to be harmful to the environment. One of the most effective biocides, tributyltin (TBT), was banned worldwide in 2008 (Gipperth, 2009), after studies showed that TBT persisted in water, entering the food chain and harming the environment (International Maritime Organization, 2023). Since then, most commonly used anti-fouling paints have been copper-based (Shi et al., 2019). However, other studies have also shown that the presence of copper oxides in the water and underlying sediments has led to a decrease of water quality because of discharging copper-based anti-fouling paints (California Coastal Commission's Water Quality Program, 2019), and copper oxide is classified as highly toxic to aquatic life with long lasting effects.

While there are no global restrictions on the use of copper in anti-fouling paints, some countries have already imposed national restrictions to such substances, including Sweden and Denmark, where requirements limit the discharge of copper into seawater for leisure boats (LIFE Fit for REACH, 2020). As of 2018, Denmark has imposed strict legislation on the use of any anti-fouling paint on leisure boats if the anti-fouling paint contains biocides which release substances that are classified with hazard statements related to toxicity to aquatic life (The Danish Environmental Protection Agency, 2018). An overview of EU countries that have imposed bans on anti-fouling paints and specifically copper-based substances is provided in Table 68.

Table 68: Notable national restrictions on copper-based anti-fouling paints.

Country	Restrictions on anti-fouling paints	Source
Denmark	Anti-fouling paint is prohibited if: • It contains irgarol (cybutryne) on boats shorter than 25 m; • It is applied on leisure boats weighting less than 200 kg which sail mainly in salt water; • It is applied on leisure boats weighing over 200 kg that sail mainly in salt water and where release of copper to the aquatic environment exceeds 200 µg Cu/cm^2 after the first 14 days. Anti-fouling paint on leisure boats is banned if it contains biocides which release substances classified with the following hazard statements: • R53: May cause long-term adverse effects in the aquatic environment, or • Classification, Labelling and Packaging (CLP) hazard statements H400, H410, H411, H412 or H413.	The Danish Environmental Protection Agency (The Danish Environmental Protection Agency, 2018)
Sweden	Anti-fouling paint products need to be authorized by the Swedish Chemicals Agency before they are sold and used. A large part of the north-eastern coast of Sweden, as well as its inland waters, do not permit any anti-fouling paints. Other coastal areas only approve of specific biocide-containing paint products which limit the amount of active copper substances to 13 % by weight.	Swedish Chemicals Agency (Swedish Chemicals Agency, 2023)
Finland	Anti-fouling paint products need to be authorized by the Finnish Safety and Chemicals Agency before they are sold and used. The use of anti-fouling products is only approved in marine areas and is prohibited in freshwater areas and inland waters.	Finnish Safety and Chemicals Agency (Tukes) (Finnish Safety and Chemicals Agency (Tukes), 2023)
Netherlands	Any copper-based anti-fouling paints on leisure boats has been banned since 2004.	The Hydrex Group (The Hydrex Group, 2011)

The majority of anti-fouling paints are currently based on copper or cuprous oxide (CuO) as the active biocidal substance which repels organisms. They work by keeping the biocidal product in suspension, which then reacts with oxygen in the air to produce cuprous ions that deter living organisms and most organic weed growth. The performance of anti-fouling paints is highly dependent on the quantity of biocide, the material which holds the paint together, and the proportion of these materials. Anti-fouling paints can be broadly divided into two types, as described in Table 69:

a) Hard anti-fouling paints, and
b) Soft anti-fouling paints.

Table 69: Anti-fouling paint types and their properties.

Anti-fouling paint type	Solubility of resin in water (GEF-UNDP-IMO GloFouling Partnerships Project, 2022)	Main binding component (Almeida et al., 2007)	Biocide binding and release mechanism (GEF-UNDP-IMO GloFouling Partnerships Project, 2022)	Suitable vessels
Hard anti-fouling paint	Insoluble	Acrylic resins, vinyl resins or chlorinated rubber polymers	Biocide is suspended in solid coating. Hard anti-fouling paints release biocide from the insoluble paint film which does not wear away during service.	Racing yachts and small cruisers which are regularly polished
Soft anti-fouling paint	Soluble	Acrylic polymer such as methyl meta-acrylate	Biocides are chemically bound to the vessel paint. Surfaces of self-polishing paint films erode slowly as the biocide is released when the vessel is in the water.	Suitable for all vessels except racing vessels

Hard paints leach out slowly over time in contact with seawater and are durable enough not to damage the coating. The paint film remains intact once the biocides have been released and exhausted. Old layers of paint must be removed by scraping or blasting. This type of antifouling paint uses high molecular mass binders, such as acrylics, vinyls or chlorinated rubber, all of which are insoluble in seawater. Due to their good mechanical strength characteristics, they can contain high levels of toxicants, the particles of which can be in direct contact with each other thus gradually released. Soft or self-polishing paints are softer, more soluble and designed to erode quickly, leaving a fresh layer of biocide on the surface. As biocide release rate is constant throughout the specified lifetime and the paint is consumed more quickly, several coats may need to be applied.

Both hard and soft antifouling paints share similar material compositions, with biocidal substances contained within being the main potentially toxic substances that can affect the environment (Turner, 2010). While the most commonly used biocides used today are copper (I) oxide and zinc oxide, common reinforcing secondary biocides used to as boosters to enhance anti-fouling paint properties are zinc and copper pyrithione, irgarol, chlorothalonil, ziram, zineb, dichlofluanid, and diuron.

A study that compiled data from government agencies and paint manufacturers' safety data sheets showed that 25 active ingredients have been used as biocides in 2021 (Paz-Villarraga et al., 2022). A dataset of 1013 antifouling paint products, produced by 64 different manufacturers, was compiled, showing that copper oxide, copper pyrithione, zinc pyrithione, zineb, dichlorooctylisothiazolinone (DCOIT) and cuprous thiocyanate were the most common biocides in these formulations. A bottleneck in the ban on harmful substances from these paints is also apparent, as the study found that some substances still contained TBT, which has been banned worldwide for over 10 years. The most common biocides and their average mass fractions in anti-fouling paints are shown in Table 70.

Table 70: Most commonly used biocides in anti-fouling paints, percentage of antifouling paints containing biocides, and relative mass fraction of biocides in antifouling paints (Paz-Villarraga et al., 2022).

Biocide type	Percentage of antifouling paints containing biocide [%]	Average mass fraction in antifouling paint [%]
Cuprous oxide	76.1	35.9 ± 12.8
Copper pyrithione	28.8	2.9 ± 1.6
Zinc pyrithione	16.7	4.0 ± 5.3
Zineb	11.5	5.4 ± 2.0
Dichlorooctylisothiazolinone (DCOIT)	9.3	1.9 ± 1.9
Cuprous thiocyanate	8.8	18.1 ± 8.0

6.3.2. Description of testing location

The Douro River is one of the largest rivers of the Iberian Peninsula. It flows into the Atlantic Ocean through a highly dynamic funnel-shaped narrow estuary (21.6 km long; 9.8 km^2 in area) surrounded in the estuary area by two cities: Porto and Vila Nova de Gaia (Iglesias et al., 2019). The freshwater flow, as well as the estuarine dynamics, are controlled by the Crestuma-Lever dam, used for hydroelectric production. Due to the dam functioning, water discharge takes place in pulses, with an important effect on water velocity and its vertical stratification, turbidity, aquatic biota, oxygen, nutrients, contaminants and suspended solids concentrations (Azevedo et al., 2010).

Due to the hydrodynamic patterns of this estuary, regions of stagnant waters with higher residence times can be generated (Iglesias et al., 2019), which prolongs the permanence and sedimentation of contaminants inside the estuarine area. Higher residence times are likely to increase damages to local communities caused by contamination events, also considering that industrial effluents and domestic sewage without treatment could be still discharged into the Douro estuary (Costa-Dias et al., 2018; Mucha et al., 2004). A clear signature of anthropogenic trace metal contamination has been detected in sediments, with consequences for estuarine communities and salt marsh vegetation (Almeida et al., 2006; Mucha et al., 2004). Hydrocarbons contamination in coastal areas, including the Douro estuary, has also been reported (Gravato et al., 2010; Guimaraes et al., 2009), including the presence of toluene in Douro estuary sediments (Gouveia et al., 2018). A more recent study has revealed the presence of hazardous and noxious substances (HNS) (toluene, ethylbenzene, m-xylene, p-xylene and o-xylene), as well aspolycyclic aromatic hydrocarbons (PAHs) (naphthalene, acenaphthylene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, crysene, benz(b)fluoranthene, benz(k)fluoranthene, benz(a)pyrene, indene(1,2,3-cd)pyrene, dibenz(ah)anthracene and benz(ghi)perylene) and trace metals (Zn, Pb, Ni, Cd, Hg and Cu) in the Douro estuarine water and sediment samples (Iglesias et al., 2019). Some of the contaminants detected have the potential to affect local and remote wildlife, and others the potential of being accumulated in organisms, with consequences for the entire trophic chain. However, it must be stressed that the concentrations of the analysed contaminants were below the respective established legal limits, indicating that this estuary is not severely contaminated. Among these contaminants, MPs accumulate in the river from several anthropogenic sources, including urban, industrial and maritime activities, which also includes vessel maintenance and boats paint washing. All four forms of MPs, commonly described in the literature (fibres, films, pellets and fragments), were found in the Douro estuary. The most common form were fibres followed by pellets and fragments (Rodrigues et al., 2019; Steyer-Molinari, 2023). It was also observed a possible loss of colour in some of the collected MPs, suggesting that these polymers had been available in the environment for some time and lost their colour due to environmental factors (e.g. temperature, salinity, etc.) (Rodrigues et al., 2019; Steyer-Molinari, 2023).

In addition, the huge increase in tourism in the Porto district (from 199.2 to 874.2 guests in tourist accommodation per 100 inhabitants between 2001 and 2017), accompanied by a growth in the birth rate (from 8.2 to 9.2 births per 1000 inhabitants between 2009 and 2018) and a rise in electric energy consumption (from 2445.3 to 5576.9 kWh/inhabitant between 2001 and 2017), may further deteriorate physical and biogeochemical estuarine conditions due to domestic and industrial contamination, and hydropower production pressure, associated with changes in nutrient, dissolved oxygen and suspended solids concentrations, turbidity, water level and currents velocity (Iglesias et al., 2020; Iglesias et al., 2021; Rodrigues et al., 2019).

The Douro estuary is densely urbanized, containing several WWTPs which discharge into its waters, and highly modified by human activities such as construction, high-traffic roadways and bridges, navigation and transport, and tourism and leisure activities including marinas. The area is of historic and socioeconomic importance, being dedicated a UNESCO World Heritage Site in 1996 (UNESCO ID: 755), which corroborates the need to uphold good local environmental conditions (Cruz et al., 2023). This is reinforced by the necessity of preservation of the Douro Estuary Local Nature Reserve, located on the south bank of the mouth of this river, near the fishing village of Afurada, encompassing Cabedelo and the bay of São Paio, where there is a salt marsh.

The demo site location is shown in Figure 52.

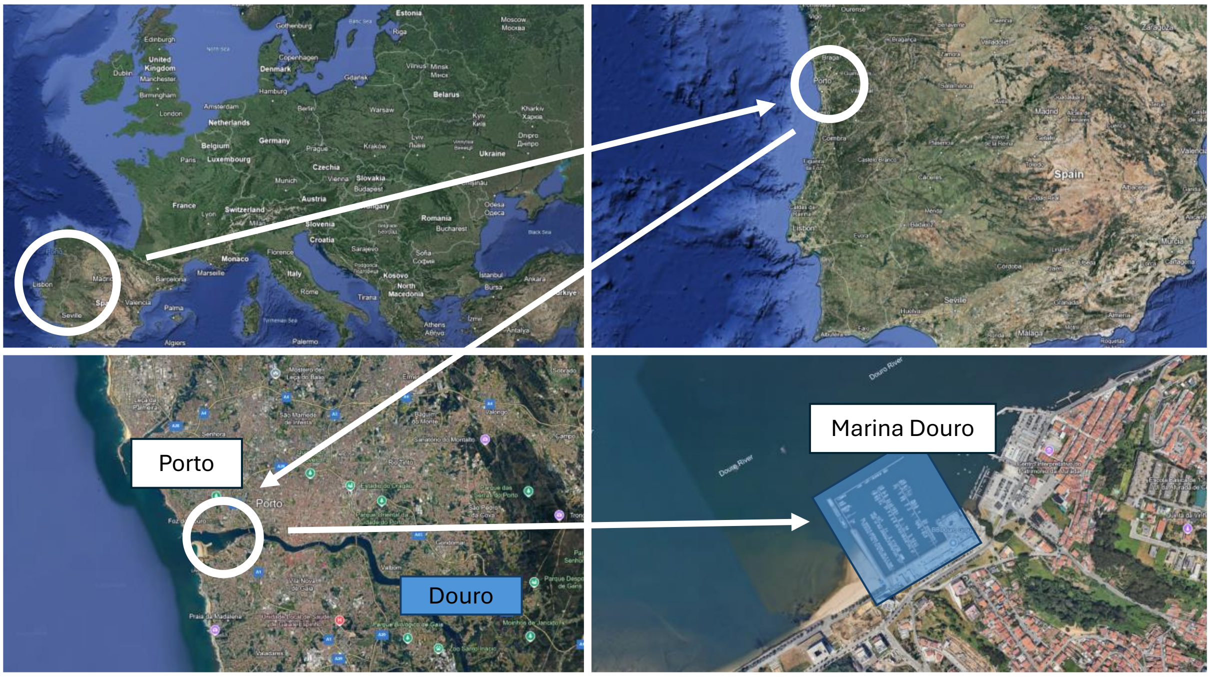


Figure 52: Location of the demo site in Portugal (top left: map of the EU, top right: map of Portugal, bottom left: Porto municipality within Portugal, bottom right: detailed satellite image of Marina Douro).

The Douro Marina, located on the south bank of the Douro River (Figure 53), is the largest recreational boating infrastructure in the northern region of Portugal, with 300 boat mooring slots, combining sport, leisure, tourism, support for research and nature in an innovative set of services and activities. Relevant authorities and organizations external to INSPIRE are the Douro Marina (local marina), the Port Authority (Administração dos Portos do Douro, Leixões e Viana) and the Douro Capitancy (Capitania do Douro).

Figure 53: Marina Douro demo site (source: Marina Douro website (Marina Douro, 2023)).

6.3.3. Implementation of INSPIRE technologies

Wastewater from the vessel washing process contains larger flakes of bottom paints, which is why the treatment system starts by capturing residual heavy solids left on the washing pad and diverting them into an above-ground settling tank. The solution implemented by INSPIRE at the Douro marina includes removal of MPs as well as paints and dissolved ions through a cascading treatment system. After pre-treatment, chemical solutions with flocculants or coagulants will be applied to precipitate dissolved ions (like aluminium sulfate, ferric sulfate, ferric chloride, sodium aluminate or polyaluminium chloride) for easier removal.

The overflow water from the settling tank will be filtered by the EcoPlex Device, which removes particles and dissolved solids as well as all organic molecules larger than 30 µm. An overview of the marina wastewater treatment system is shown in Figure 54.

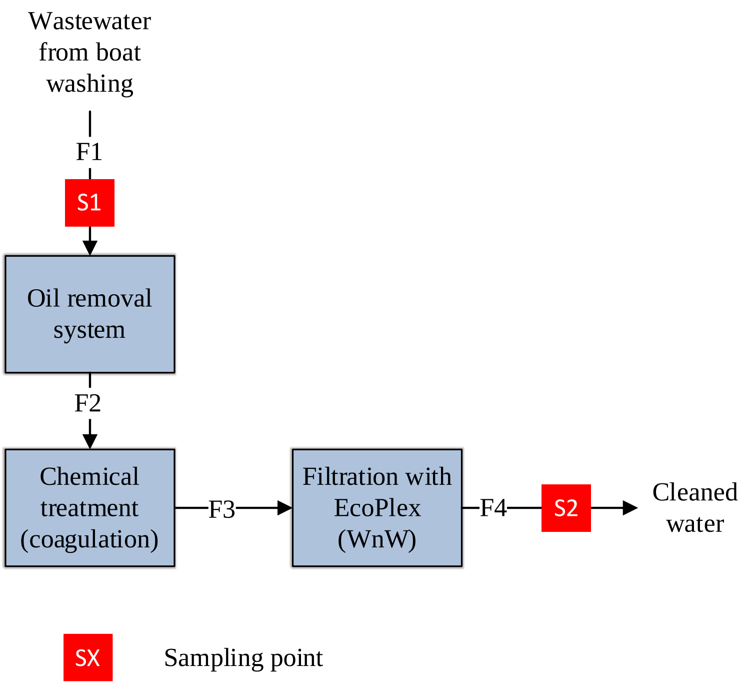


Figure 54: INSPIRE solution implementation at the Marina Douro demo site.

6.3.4. Site-specific sampling plan

The sampling plan has been determined based on the needs of analysis of MP retention efficiency. and water quality for reuse. Water will be sampled using the Ferrybox device at specified sampling points marked in red in Figure 54. It should be noted that wastewater at flow F2 is difficult to access, so the initial screening will be carried out for wastewater coming directly from the vessel washing process. The sampling plan is specified in Table 71.

Table 71: Sampling and screening plan for the Marina Douro demo site.

Sampling point	Partner responsible for sampling	Sampling methodology	Partner responsible for analysis	Analysis methodology
S1	CIIMAR	Protocols from D1.2	VLIZ	Protocols from D1.2
S2	CIIMAR	Protocols from D1.2	VLIZ	Protocols from D1.2

6.3.5. Integration of sensors

To collect real-time monitoring data during operation of the system, 6 types of sensors selected from the sensor kit (described in Section 6.1.4 of this document) will be installed. Table 72 provides an overview of sensor types, their purpose and placement within the cascade solution system.

Table 72: Sensors installed on the Marina Douro filtration system.

Sensor type	Purpose	Sensor placement	Quantity of units
Flow and/or pressure	Monitoring potential clogging prior to water treatment with EcoPlex	Water pipe	2
Turbidity	Water quality	Water pipe	2
Temperature	Effluent water temperature	Water pipe	1
Noise	Monitor potential excessive noise	Device	1
Accelerometer	Monitor potential excessive vibrations and movements	Device	1
Power meter	Record power consumption	Device	1

A detailed schematic view of the installed sensors is presented in Figure 55. Sensors for flow and/or pressure have been selected to receive continuous data on potential clogging of filtration devices. For this reason, sensors will be installed on flows leading to the EcoPlex device and the SWT device, which could potentially become clogged. Turbidity measurements will be conducted on all main lines, as shown in Figure 55. Temperature will only be monitored at the final effluent. Noise, vibration, and power meters will be installed on the devices themselves: each sensor will be placed on the EcoPlex Microplastic Remover by WnW, and the SWT device.

It should be noted that pressure sensor SD2 and power sensor SD2 are already installed on the SWT device and provide automatic data, which means that separate sensors for pressure and power will not be specifically purchased and installed for this device.

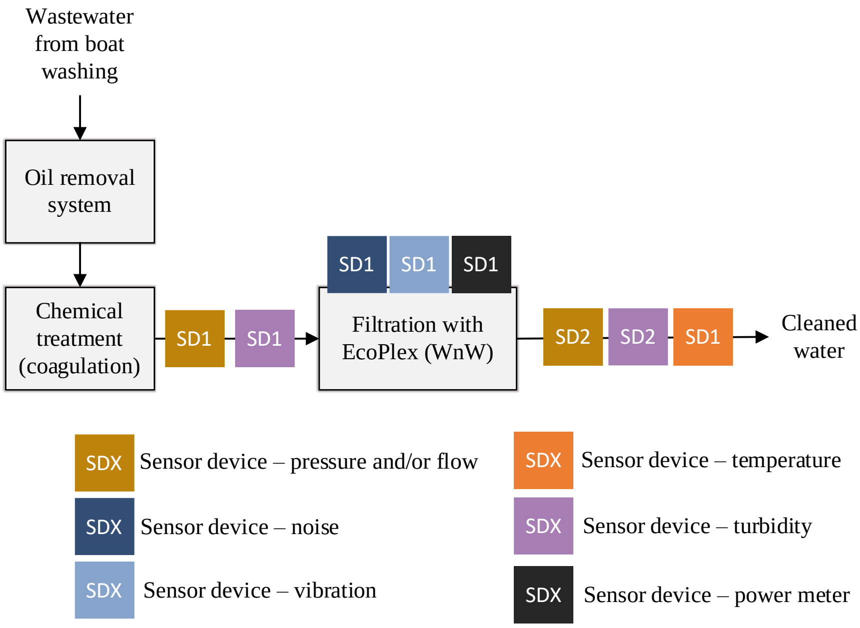


Figure 55: Integration of sensors at the Marina Douro demo site.

6.3.6. Demo site data collection sheet

Data from the Douro demo site will be collected by partners in the following datasheets, based on methodologies and procedures presented in the preceding sections and shown in Table 73. Additionally, optional metadata will be collected as defined in INSPIRE T1.1.2 Protocol for Micro litter evaluation. This datasheet will be digitized, allowing demo site data to be streamed to the INSPIRE repository in accordance with activities of dataset collection from demo sites in T4.4 – Impact evaluation dashboard, and with data storage requirements in T7.3 – Data Management.

Table 73: Data collection sheet for technologies at the Douro demo site.

Parameter	Measurement frequency	Sampling location(s)	Unit
Sampling date	Based on sampling frequency during technology operation	S1, S2	YYYY/MM/DD
Total water volume		S1, S2	L
Average volume flow		S1, S2	L/min
Sampling time		S1, S2	min
Water depth		S1, S2	m
Sieve mesh size(s) used		S1, S2	µm
MP concentration		S1, S2	# of particles / m^3
MP mass per volume		S1, S2	mg MPs / m^3
MP size distribution		S1, S2	µm
Polymer type		S1, S2	/
Flow and/or pressure	Weekly	Based on scheme in Figure 55	L/min
Turbidity	Weekly		NTU
Temperature	Weekly		℃
Noise	Once		m/s^2
Accelerometer	Weekly		dB
Power	Weekly		W

6.4. Evaluation of retention and collection of plastic litter in water and sewage runoff

The INSPIRE solution described in this section relates to T2.4: Retention and collection of plastic litter in water and sewage runoffs. The connected use case demo site is the river Danube, where technologies for MP retention will be installed to treat wastewater from (a) the Fetesti WWTP, and (b) the highway rainwater collection system.

6.4.1. Problem definition

TRWPs are a major source of microplastics entering the environment directly. Studies indicate that tyres release a significant amount of material, shedding 10–50% of their tread weight into the environment over their lifespan of approximately 40 000 to 50 000 km, which translates to roughly 0.8 kg per person per year globally (Parker-Jurd et al., 2021). These particles are emitted due to the friction between tyres and the road surface. Larger particles are carried into surface waters through road runoff, while smaller particles may also become airborne and be transported through the atmosphere. Factors such as vehicle weight, driving habits, tyre pressure, and tyre design all affect the rate of abrasion and, consequently, the amount of MPs released (J & J, 2017).

In Romania, most stormwater and runoff from roads is currently not treated before it enters the aquatic environment. As of 2024, the total length of Romanian highways is 1088 km, with over 300 km currently under construction (Statista, 2021). Stormwater from these highways is discharged directly into rivers without treatment.

In light of the contemporary challenges related to MP pollution, the Danube river and particularly the Borcea arm of the river offers unique opportunities for testing and implementing advanced technologies dedicated to capturing and removing these contaminants from the aquatic environment. This initiative underlines the INSPIRE project's commitment to developing innovative and sustainable solutions for the protection of water resources, thus contributing to the preservation of biodiversity and the promotion of the ecological health of European river basins.

6.4.2. Description of testing location

The Danube is the second-longest river in Europe with around 2850 km, flowing across Germany, Austria, Slovakia, Hungary, Croatia, Serbia, Bulgaria, Romania, Moldova, and Ukraine. The Danube river basin, which covers an area of 802 266 km^2, receives a significant contribution from its main tributaries on the right bank, including the Jiu, Olt, Argeș, Ialomita, Siret and Prut, each of which plays a crucial role in the hydrological dynamics of the river.

A key element of the river within the INSPIRE project is the Borcea arm, a distinct segment of the Danube that separates from the main course near Calarasi and joins the river near Giurgeni. This arm, with a length of about 100 km, crosses the Calarasi and Fetești areas. The river is connected to two use cases concerning MP retention in INSPIRE: (a) the Fetesti WWTP and (b) the Fetesti toll station, which will be the collection point for stormwater associated with the A2 highway.

6.4.2.1. Fetesti WWTP

Domestic wastewater, also known as grey water, along with stormwater (including rainwater and other surface runoff) from Fetesti city are collected and combined before reaching the Fetesti WWTP, as seen in Figure 56. The treated effluent from the Fetesti WWTP is then discharged into the Danube River. The Fetesti WWTP has an average flow rate of 6049 m^3/day and is designed for tertiary treatment of combined influent for 46,533 p.e., as well as of rainwater from the city of Fetesti (covering 100 km^2, with partial infrastructure).

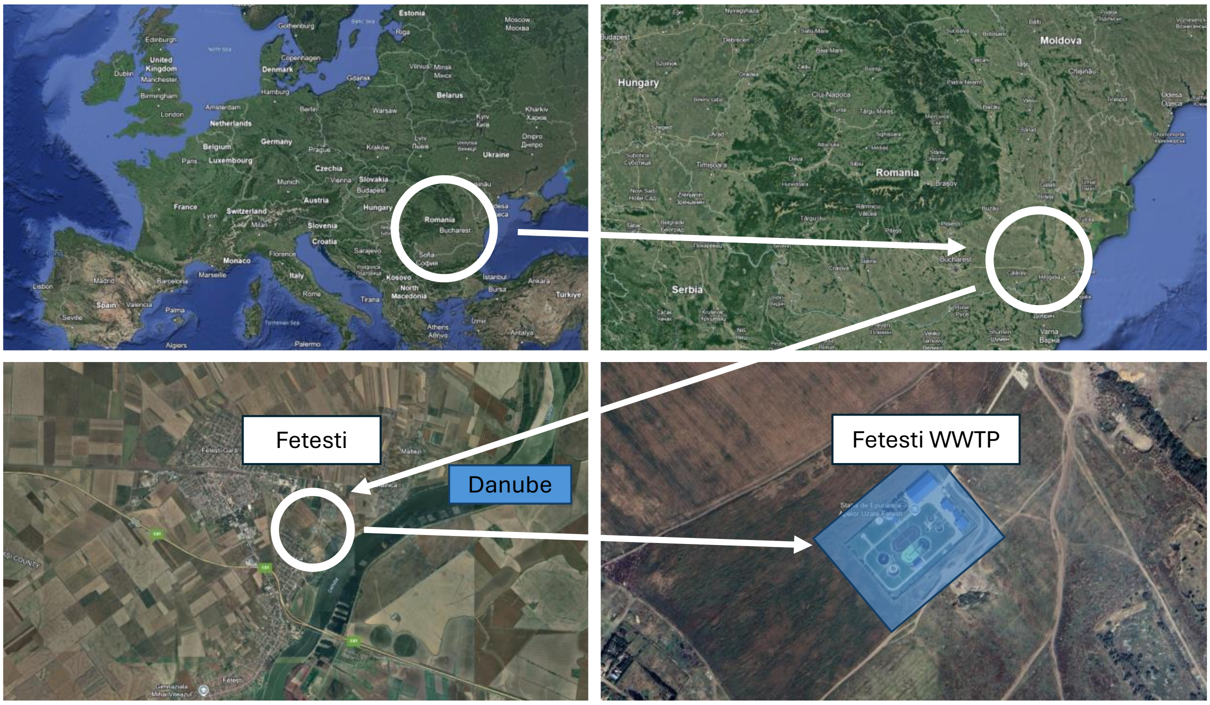


Figure 56: Location of the Fetesti WWTP demo site (top left: map of the EU, top right: map of Romania, bottom left: Fetesti municipality within Romania, bottom right: detailed satellite image of the Fetesti WWTP).

The treatment process at the WWTP includes mechanical treatment for removing suspended matter and solids, biological treatment involving dephosphorization, nitrification-denitrification, and the thickening and dehydration of sludge. Internet access is available at the site. There is a paved road providing access to and from the station. The sewage treatment plant is equipped with surveillance cameras and has a fixed security guard post. The WWTP's laboratory performs routine tests on influent wastewater, effluent, and drain discharges. The laboratory analyzes indicators such as pH, TSS, COD, BOD, ammonium, nitrites, nitrates, total nitrogen, total phosphorus, detergents, dissolved oxygen, filtered residue, and chlorides, as part of its technological monitoring. Figure 57 shows the Fetesti WWTP in Romania.

Figure 57: Fetesti WWTP (photograph by: Mariana Miranda).

6.4.2.2. Highway runoff stormwater collection

The A2 motorway, also referred to as The Sun's Highway, is a highway in Romania that connects the capitalty city of Bucharest to Constanta, the country's largest port. Starting with November 29, 2012, it can be circulated on its entire length of 202 km in both directions. It starts in the east of Bucharest, crosses the Romanian Plain up to Fetești, crosses the Borcea arm then the Danube at Cernavoda, after which it follows a route through Dobrogea Plateau to the eastern end, where it joins the Constanta ring road, A4.

The rainwater collected along the length of the highway is collected in retention basins equipped with hydrocarbon separators, which vary in capacity between 60 and 450 L. The plan for testing retention of particles in highway detention tank systems, where runoff water is collected prior to treatment, was originally in a different location in Romania, which planned to utilize a detention tank system on the A1 motorway. The detention tank contains runoff stormwater from the highway that is normally discharged directly into rivers without any pre-treatment at all. The technological set-up for runoff stormwater treatment is planned to be the same as in the WWTP case. However, due to a change in planning on the demo site, the technologies will only be installed at one location, which is the Fetesti WWTP. Collected water from stormwater runoff will be periodically connected to the system via an IBC tank to test its efficiency. In this way, the implementation will still achieve the original plan of using the same technologies in succession to treat runoff stormwater. Collection of the stormwater will be conducted at the toll station of the A2 motorway in Fetesti, which is located around 2 km south of the Fetesti WWTP. The location is shown on the map in Figure 58.

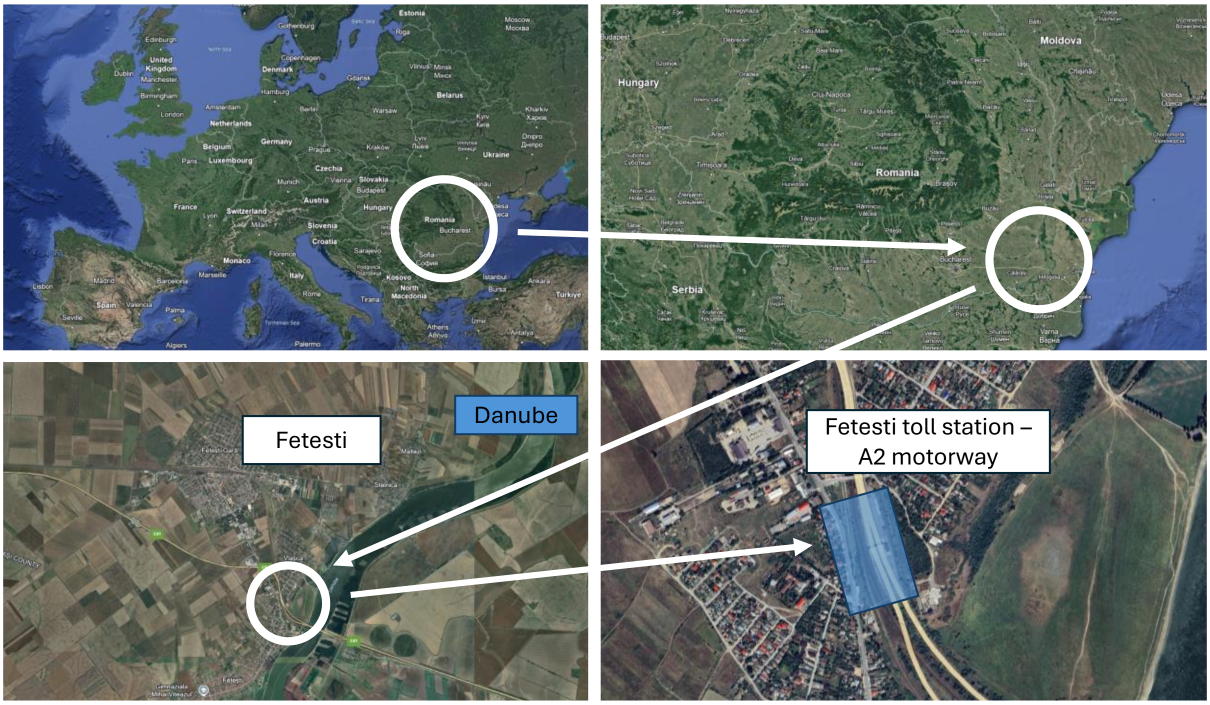


Figure 58: Location of the Fetesti toll station rainwater collection point (top left: map of the EU, top right: map of Romania, bottom left: Fetesti municipality within Romania, bottom right: detailed satellite image of the Fetesti toll station).

Water will be collected at the collection point within the infrastructure associated with the A2 motorway near the Fetesti toll station, shown in Figure 59. Testing of INSPIRE technologies for treatment on this water will provide information on the loading of rubber particles in stormwater, including information on the holding tank system and discharge pipes. The collected water will be transported to the WWTP to periodically test the technologies' efficiency in particle retention. It should be noted that collecting rainwater in this way does not focus on highway retention basins, as these are closed systems which do not communicate with the Danube river.

Figure 59: Fetesti toll station and rainwater collection point.

6.4.3. Implementation of INSPIRE technologies

For the Danube case, the goal is the retention and collection of plastic litter from grey water and/or stormwater at a) at the Fetesti WWTP, and b) at the toll station rainwater collection system. The EcoPlex Microplastic Remover and the Super-TW-Net filter devices will be installed at this demo site, aiming to retain MPs as well as TRWPs. The EcoPlex device is expected to remove MPs and tyre wear larger than 30 µm in size, while Super-TW-Net will selectively remove TRWPs due to the presence of sulphur in tyre material, as well as particles above 10-100 nm.

At the Fetesti WWTP, the technologies will be installed to treat the WWTP effluent, where the WWTP treats combined municipal grey water and stormwater. A disinfection tank will be installed to prevent fouling in a similar setup to the Kamniška Bistrica demo site (described in Section 6.2.3). The EcoPlex and Super-TW-Net devices will be implemented in succession and mounted with size-selection filters (SSFs). A scheme of the technologies is shown in Figure 60.

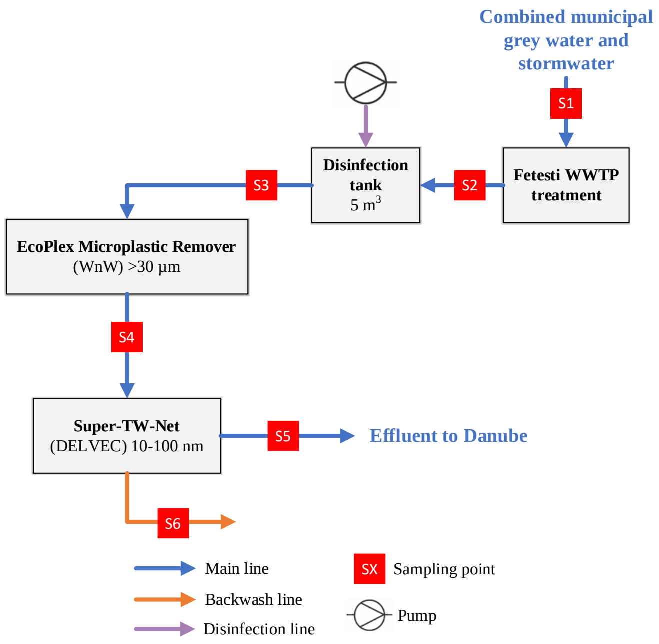


Figure 60: INSPIRE technology set-up at the Danube demo site.

The same sequence of technologies will be installed to treat rainwated from the A2 motorway, which will be collected and transferred to storage tanks. The retention technologies will be tested for efficiency in removing TRWPs as the SSFs on the Super-TW-Net system are designed to selectively attract TRWPs due to the presence of sulphur in tyres. Further detail about technology implementation plans is available in INSPIRE D2.1 – Plastic removal efficiency protocols.

6.4.4. Site-specific sampling plan

The sampling plan has been determined based on the needs of analysis of TRWPs retention efficiency. Water will be sampled at specified sampling points marked in red in Figure 60. Analysis of water for TRWPs will be conducted by FRE. The sampling plan is specified in Table 74. Detailed sampling plans for this demo site are available in INSPIRE D2.1 – Plastic removal efficiency protocols.

Table 74: Sampling and screening plan for the Danube demo site.

Sampling point	Partner responsible for sampling	Sampling methodology	Partner responsible for analysis	Analysis methodology
S1	ARA	Automated sampler at WWTP	FRE	Protocols for TRWPs from D2.1
S2	ARA	Automated sampler at WWTP	FRE	Protocols for TRWPs from D2.1
S3	ARA	Protocols from D2.1	FRE	Protocols for TRWPs from D2.1
S4	ARA	Protocols from D2.1	FRE	Protocols for TRWPs from D2.1
S5	ARA	Protocols from D2.1	FRE	Protocols for TRWPs from D2.1
S6	ARA	Protocols from D2.1	FRE	Protocols for TRWPs from D2.1
S3	ARA	Ferrybox (Protocols from D1.2)	VLIZ	Protocols from D1.2
S4	ARA	Ferrybox (Protocols from D1.2)	VLIZ	Protocols from D1.2

As the particles following retention by Super-TW-Net will be in the nano size range, DELVEC will also conduct preliminary in-house efficiency tests with samples prepared in the laboratory. These results can then be extrapolated to the field based on TRWP abundance and calculated retention efficiencies. Based on sample analysis and calculated retention efficiencies of the EcoPlex and Super-TW-Net devices, a comparison will also be possible between the methodologies applied in the Kamniška Bistrica case, where particle abundance at low size ranges will be calculated by mathematical estimation, and in the Danube case, where TRWP concentrations at different points will be provided by analysis of FRE.

Additionally, a comparison will be made between the demo sites of Kamniška Bistrica and Danube by sampling wastewater using the Ferrybox device. This will ensure comparison with the retention efficiency calculated by TRWP analysis, as both methods will calculate particle abundance in the nano size range. For the mathematical estimation of particles using size distribution analysis, Ferrybox sampling will be performed once at the WWTP effluent using a greater number of mesh size sieves in order to obtain a greater number of size ranges for accurate size distribution analysis (a detailed description is available in Section 6.1.3.2). Water at the WWTP effluent will be specifically sampled with mesh sizes of 25, 50, 100, 200, 500, and 1000 µm. This will be accomplished by storing a large volume of sample water from faucets in a container, from which a fraction will be pumped and filtered through the Ferrybox device for analysis of different MP size classes, while the other fraction following separate resuspension will be used by FRE in analysis of TRWP samples. Sampling and assessment of particles using the Ferrybox will provide a more accurate size distribution of particles in the WWTP effluent and will enable calculation of NP abundance in the water treated by INSPIRE retention technologies.

6.4.5. Integration of sensors

To collect real-time monitoring data during operation of the system, 2 types of sensors selected from the sensor kit (described in Section 6.1.4 of this document) will be installed. Table 75 provides an overview of sensor types, their purpose and placement within the cascade solution system. As the devices are also installed in succession at the Kamniška Bistrica demo site, integration of power, noise, and vibration meters will not be required at this demo site.

Table 75: Sensors installed on the Danube demo site.

Sensor type	Purpose	Sensor placement	Quantity of units
Flow and/or pressure	Monitoring potential clogging prior to water treatment with EcoPlex and SWT	Water pipe	2
Turbidity	Water quality	Water pipe	2

A detailed schematic view of the installed sensors is presented in Figure 61. Sensors for flow and/or pressure have been selected to receive continuous data on potential clogging of filtration devices. For this reason, sensors will be installed on flows leading to the EcoPlex and the Super-TW-Net devices, which could potentially become clogged. Turbidity measurements will be conducted the main flow lines, as shown in the figure.

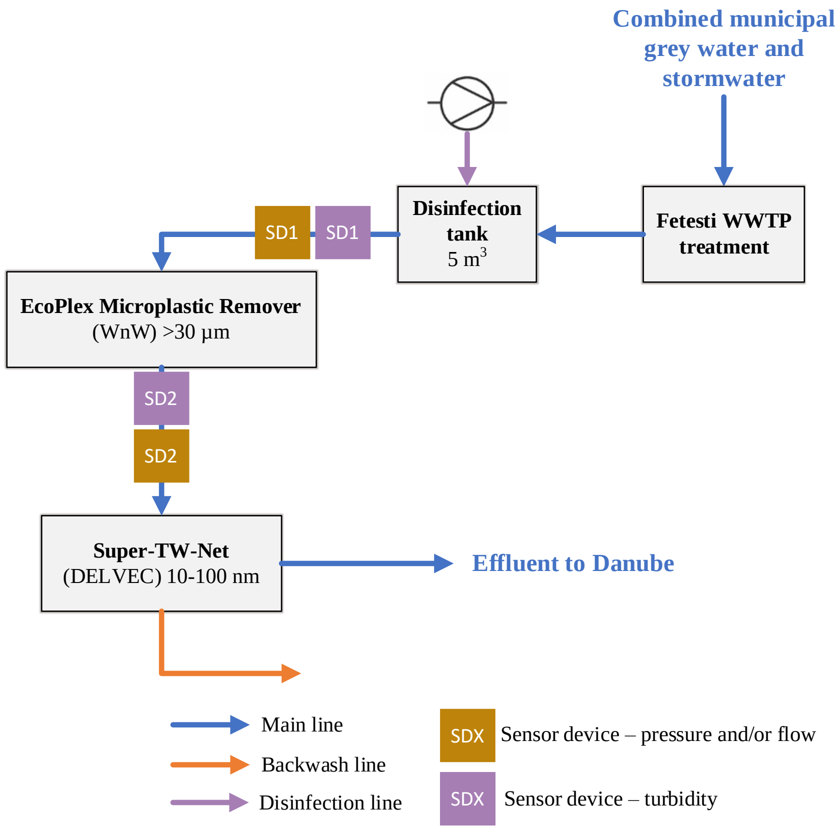


Figure 61: Sensor integration set-up at the Danube demo site.

6.4.6. Demo site data collection sheet

Data from the Danube demo site will be collected by partners in the following datasheet, based on methodologies and procedures presented in the preceding sections and shown in Table 76. This datasheet will be digitized, allowing demo site data to be streamed to the INSPIRE repository in accordance with activities of dataset collection from demo sites in T4.4 – Impact evaluation dashboard, and with data storage requirements in T7.3 – Data Management.

Table 76: Data collection sheet for technologies at the Danube demo site.

Parameter	Measurement frequency	Sampling location(s)	Unit
Sampling date	Based on sampling frequency during technology operation	S1-S6	YYYY/MM/DD
Total water volume		S1-S6	L
Sampling time		S1-S6	min
TRWP mass		S1-S6	mg / m^3
Flow and/or pressure	Weekly	Based on scheme in Figure 61	L/min
Turbidity	Weekly		NTU
Sampling date	Once	S3, S4	YYYY/MM/DD
Total water volume	Once	S3, S4	L
Average volume flow	Once	S3, S4	L/min
Sampling time	Once	S3, S4	min
Sieve mesh size(s) used	Once	S3, S4	µm
Particle concentration	Once	S3, S4	# of particles / m^3
Particle mass per volume	Once	S3, S4	mg MPs / m^3
Particle size distribution	Once	S3, S4	µm
α (exponent)	Once	S3, S4	/
y (abundance of particles between 1 µm and 50 µm)	Once	S3, S4	# of particles / m^3

6.5. Conclusion

Through the use of microplastic retention technologies, INSPIRE aims to demonstrate effective and scalable solutions to prevent MP discharge both at the hotspot of WWTPs and further upstream, before MPs can reach wastewater flows. This document provides a framework for extensive data collection on a case-by-case basis, where key parameters to be collected are based on wastewater source, expected pollutants, and technology specifications. Additionally, it provides a framework for estimating the abundance of particles in the nano size range, as the retention of these smaller particles is a key innovative aspect of INSPIRE technologies. The timeline of sampling and analysis activities specified in this document depends on scheduled technology implementation and testing activities taking place at the demo sites. Data collected from the demo sites is expected to provide valuable insights based on periodic sampling campaigns and additional estimations of MP retention on the field, which will be a key step in the verification of individual technologies and proposed combined solutions.

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