Scalable full-cycle marine litter remediation in the Mediterranean: Robotic and participatory solutions

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D8.*1 Full check-list characterization of litter to address sorting/treatment possibilities*

WP8 – *Full-Cycle Framework*

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1 R = Document, report, DEM = Demonstrator, OTHER = Software, technical diagram, etc., DMP = Data Management Plan

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Definitions

- **Beneficiary:** A legal entity that is signatory of the EC Grant Agreement no. 101093822.
- **Consortium:** The SeaClear2.0 Consortium, comprising the list of beneficiaries below.
- **Consortium Agreement:** Agreement concluded amongst the SeaClear2.0 beneficiaries for the implementation of the Grant Agreement.
- **Grant Agreement:** The agreement signed between the beneficiaries and the EC for the undertaking of the SeaClear2.0 project (Grant Agreement no. 101093822).

Beneficiaries of the SeaClear2.0 Consortium are referred to herein according to the following abbreviations:

- **TU Delft**: TECHNISCHE UNIVERSITEIT DELFT
- **DUNEA**: REGIONALNA AGENCIJA DUNEA
- **Fraunhofer**: FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV
- **HPA**: HAMBURG PORT AUTHORITY
- **ISOTECH**: ISOTECH LTD
- **MDanchor**: M. DANCHOR LTD
- **Subsea Tech**: SUBSEA TECH SAS
- **TECHNOSUB**: TÉCNICAS Y OBRAS SUBACUÁTICAS, SLU
- **TUM**: TECHNISCHE UNIVERSITÄT MÜNCHEN
- **UNIDU**: SVEUČILIŠTE U DUBROVNIKU
- **UTC**: UNIVERSITATEA TEHNICA CLUJ-NAPOCA
- **VEO**: VEOLIA PROPRETE
- **VLPF**: VENICE LAGOON PLASTIC FREE

Abbreviations

- **EC**: European Commission
- **GA**: Grant Agreement
- **WP**: Work Package
- **ADEME :** Agence de la transition écologique
- **MODECOM :** Méthode de Caractérisation des Ordures Ménagères
- **MITECO:** Ministerio para la Transición Ecológica y el reto demográfico
- **LAGA:** Bund/Länder-Arbeitsgemeinschaft Abfall
- **ML**: Marine Litter
- **MSW:** Municipal Solid Waste
- **PPE:** Personal Protective Equipment
- **CPE**: Collective Protective Equipment
- **UXO**: UneXploded Ordnance
- **ALDFG**: Abandoned, Lost, and Discarded Fishing Gear

- **ELV**: End-of-Live Vehicle
- **WEEE:** Waste from Electrical and Electronic Equipment
- **PVC**: PolyVinyl Chloride
- **PE**: PolyEthylene
- **HDPE**: High Density PolyEthylene
- **LDPE**: Low Density PolyEthylene
- **VCR:** VideoCassette Recorder
- **LED:** Light-Emitting Diode
- **NIR:** Near Infrared Spectroscopy
- **PET**: PolyEthylene Terephthalate
- **PP**: PolyPropylene
- **PS**: PolyStyrene
- **FT-IR**: Fourier Transform Infrared Spectroscopy

Executive Summary

This report is part of the SeaClear 2.0 project work package eight (WP8) entitled “Full-Cycle Framework”, WP8 aims at finding scalable and efficient solutions to create a full-cycle framework, which integrates elements related to collection of marine litter (ML), sorting, and repurposing solutions. As such, the WP8 encompasses the implementation of effective marine litter collecting strategies and the development of innovative waste valorisation methods including mechanical recycling, chemical recycling and energy conversion processes.

This report is the deliverable associated with the task 8.4 of the WP8. It’s a framework for the characterization of collected marine litter. A waste classification system is made using sorting grids that satisfies the facilitation of future treatment and potential recovery; indeed, they were chosen with a repurposing solution in mind. This report also underlines the manpower, the tools needed and emphasizes on litter that shouldn’t be picked as a safety hazard or an environmental hazard. Information regarding plastic degradation and how to measure it is also provided. Lastly, sampling protocol sheets are provided at the end of the report.

1. Introduction

1.1. Overall objective

The SeaClear 2.0 project aims at creating an autonomous waste management system for marine litters. Autonomous robots are used for the detection and the collection of marine litter across two critical zones: the sea surface and the seafloor. The project is separated into different work packages, where WP8 focuses on the circular economy aspect of the project.

WP8 aims at developing and implementing a comprehensive waste management protocol. This includes establishing efficient collection choices for marine litter, developing advanced sorting methodologies and creating innovative waste valorisation pathways like mechanical recycling, chemical recycling and energy recovery.

To choose the best valorisation strategies, knowing the type of waste, their categories is needed. Therefore, a characterization of the waste is done, the challenges and the framework of the characterization are discussed in this report. This deliverable compiles actions made for that task (T8.4) and will give a general overview of marine litter characterization in the literature and use that information to create a standardized solution suited for the project. The characterization will have an identification step of marine litter origin which will facilitate data aggregation.

Furthermore, this paper will help with numerous tasks present in WP8. Firstly, characterizing the waste will help choose adequate repurposing solutions. Technical specification regarding repurposing solution will briefly be mentioned in this report and will be studied in depth in the associated deliverable of T8.5 using the categories and subcategories selected. Secondly, this document will be used as a template to find the composition of collected marine litter/waste (T8.3).

1.2. Waste characterization overview

Waste characterization means finding out which type of waste is discarded in your waste stream. Wastes can be categorized by types of materials (e.g. metal, glass, plastics), uses (e.g. bottle, tire) and activity of origin (industrial waste, municipal waste). Characterizing waste helps in planning how to reduce waste and set up a revalorisation process. Waste characterization can be done on municipal waste, industrial waste and even marine waste/marine litter. Characterization methods are typically used for municipal waste. Those methods are going to be modified and adapted for marine litter.

For municipal waste, the French Agency for Ecological Transition (ADEME) has for example the *"Méthode de Caractérisation des Ordures Ménagères"* (MODECOM) which is a standardized waste characterization methodology to determine municipal waste composition [1]. The method involves sampling and sorting waste into specific categories. Spain's *Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO)* has a similar method which is the *"Diseño de una caracterización normalizada de los residuos municipales"*. Germany provides guidance on sampling of waste in the LAGA PN 98 *"Guideline for procedures for physical, chemical and biological testing in connection with the recovery/disposal of waste"* *made* by the Joint Waste Commission of the Federal States (LAGA).

For marine litter characterization numerous methods exist and they can be divided into two fundamental categories. The first one is used for carrying out scientific investigation and the second one is used to facilitate waste management and waste treatment [2].

The former focuses on understanding the origin of waste, their sources and types. Migration phenomena and monitoring approach of marine litter are commonly done [3][4][5]. Samplings are regular and litters are monitored through diving campaigns, cleanup or underwater video [5]. *Carlos Dominguez-Carrio et al* characterized marine litter in different domains of the north west Mediterranean Sea using underwater video and studied marine litter distribution [2][3].
UNEP's global assessment of marine litter and plastic pollution underlines monitoring methods and standards [6]. Its main objective is the estimation of litter levels on beaches and in the oceans. EU's Guidance on the Monitoring of Marine Litter in European Seas shares the same objective [7]. Both guidance and articles were designed for monitoring litter and scientific purposes. They were not specifically designed to facilitate waste treatment and recovery. Waste grids are numerous and can contain a lot of subcategories that aren't affiliated with any revalorisation solution.

The latter type of marine litter characterization is used to choose the best revalorization solution. It can therefore change according to the country and the legislation; sampling frequencies are low and depend on collecting campaigns. It focuses on waste quantities and qualities. It sorts the collected waste by considering origins, valorisation strategy and feasibility. Not many articles regarding this type of characterisation were found in the literature. One study by *A. Mendoza et al* evaluated the possibility of incorporating marine litter from the coast into the management system of the non-selectively collected fraction of municipal solid waste (MSW) and showed promising results [10]. Similar things were conducted by *R. Tramoy et al* but on litter from a river near Marseille [10]. The necessity of a standardized method that can tackle valorisation strategies is needed [2]. Challenges noted by the articles were about metallic waste as they are corroded by the sea [2][10][11].

This report's objective is to establish a marine litter characterization for repurposing solutions and therefore uses guidelines from municipal waste characterization and marine litter monitoring data to offer a standardized solution.

2. Guide for Marine Litter Characterization

Items described in previous SeaClear 2.0 studies collected from sea surfaces and seafloor are mostly identical to those found in household waste [8]. This report is a guide for the characterization of collected marine litter / marine waste. This report is based on a guide published by ADEME following the associated French standard XP X30-484[1][11]. The characterization methods implement safety measures to ensure a smooth operation and protect workers. It sorts marine litter according to categories and subcategories associated with their major constituent material and/or uses. A list of examples is provided to help associate waste with targeted categories. Granulometric screening is also done and based on marine litter sizes described in "the Guidance on monitoring Marine Litter in European Seas" [7]. Sorting of large objects (>100 cm) is done using a mini excavator if quantities and masses are significant and manual sorting is recommended with smaller objects (<100 cm). The quartering method is executed if quantities and masses are substantial. A determination of the weight proportion of each waste category and subcategories is conducted during the characterization.

2.1. Safety and resources

Safety is a must during the waste characterization of marine litter obtained from sampling campaigns. Safety measures must be met during the project and after industrialisation of the concept, protecting workers is required and a crucial point. Safety concerns can be divided into two categories, operational safety and human safety.

2.1.1. Operational and human safety

Several points of vigilance must be acknowledged to ensure safety during each characterization campaign:

- The host site must provide a ground surface for proper operations.
- The use of a mini excavator is necessary for collecting objects of significant size and mass (fishing nets, steel bars, etc.) and requires a minimum surface area of 300 m².
- A safety inspection is mandatory before any collection campaign between the host and the operators.
- Establishing a safety sheet describing all safety instructions (wearing Personal Protective Equipment), route planning, safety instructions, barring the mini-excavator's operating radius when in use) is mandatory.
- Wearing personal protective equipment (PPE) is mandatory during the process.

Sampling, sorting, categorising marine litter involve numerous risks such as: vehicle (mini excavator) traffic, noise, cuts and punctures, crushing and pinching from massive objects and risks associated with manual handling of loads.

Working with PPE throughout the characterization is therefore mandatory:

- Cut resistant gloves (Class 4342)
- Safety glasses
- Work overalls and high-visibility vest
- Safety work shoes
- Hard hats & Safety Helmets (bump caps are forbidden)
- Hearing protection.

As marine litter shouldn’t contain fine particles, due to the humidity, wearing an FFP3 mask isn’t necessary but can be done as a safety measure.

Figure 1. Symbols of Mandatory PPE

The working area must be marked out to allow workers to operate in a dedicated and visible area. Collective protective equipment (CPE) such as traffic cones and/or marking posts are a requisite. Having a fire extinguisher at one's disposal in case of a fire outbreak is mandatory, self-ignition of a lithium battery can be a risk.

2.1.2. Human resources

The human resources to be deployed for the characterization are as follows:

- On-site coordinator responsible for managing and upholding the process.
- One mini-excavator operator who has the associated license (CACES R4B2 Category A or R372m Cat. 1 in France; equivalent in the country where the campaign will take place)
- Two to three additional operators for manual sorting.

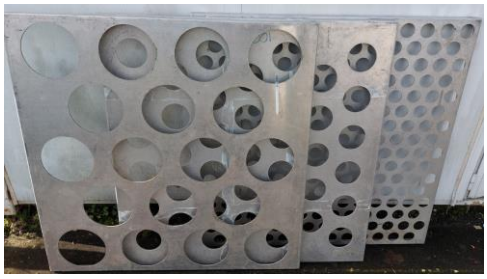
2.1.3. Material resources

Material needed to characterize collected waste are:

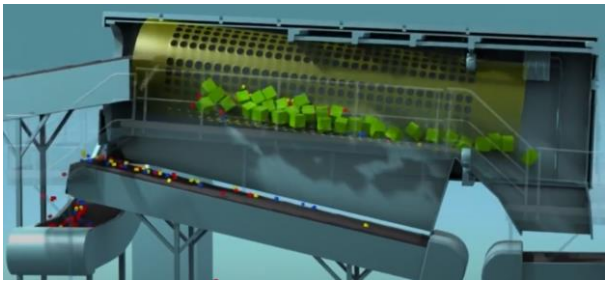
- Flat concrete or asphalt surface, ideally around 300m²
- 3.5t mini excavator, equipped with grippers capable of a 360° rotation
- Set of round-mesh screens that can rest on a pallet box (or 2 trestles)
- Containers for sorted fractions (plastic containers, wheeled bins with lids, pallet boxes, pallets, garbage bins, buckets, plastic bins)
- Weighing equipment up to 1500 kg with 0.2 kg precision, allowing for a sorting platform setup. The presence of a weighbridge would be preferable
- Two scales of 60 and 150 kg with 20 to 50 g precision for weighing small-volume waste categories and subcategories
- Pallet truck, utility cart
- Personal and Collective Protective Equipment (PPE & CPE)
- Fire extinguishers
- Fork, brooms, squeegees, shovels, cutters (with retractable blades), measuring tape, magnet
- Camera, mobile phone, measuring rule for taking photos of marine litter fractions

2.1.3.1. Selection of sieve set

The sieves used for manual waste sorting are equipped with round meshes to be representative of the separations obtained on Trommels (industrial equipment typically used as a first separation step in sorting facility).



(a) screens for manual sorting



(b) diagram of industrial Trommel

Figure 2. Examples of screen for manual sorting (a) & diagram of an industrial Trommel (image property of Veolia) (b)

The set of sieves used to characterize waste of smaller size (< 100 cm) and lower mass must be representative of marine litter sizes described in the Guidance on Marine Litter in European Seas [7].

Table I. Marine litter size described in the Guidance [7] - sieve mesh diameter - classification of Marine litter sizes obtained with the screening sequence

Marine litter size from Guidance	Mesh size of the sieve	ML granulometric size
F > 100cm - 100cm = 10000cm2 = 1m2	/	> 100 cm
E < 100cm- 100 cm = 10000 cm2 - 1m2	100 cm	50 - 100 cm
D < 50 cm -50 cm = 2500 cm2	50 cm	20 - 50 cm
C < 20 cm - 20 cm = 400 cm2	20 cm	10 - 20 cm
B < 10 cm - 10 cm = 100 cm2	10 cm	5- 10 cm
A < 5cm - 5 cm = 25 cm2	5 cm	< 5 cm

2.2. Characterization method

During the sampling campaign, the characterization method will be adapted according to the number and size of items collected at sea.

The use of mechanical equipment such as an excavator aims to reduce sorting operations on the ground by workers to a strict minimum.

This characterization consists of determining the weight proportion of material according to their categories and subcategories. For this purpose, special attention is paid to weighing (marine litter collected, materials brought back to port, sorted categories and subcategories, resulting particle size fractions).

2.2.1. Handling of concerning marine litter

Some litter types/categories must be vigilantly monitored and handled when identifying or characterizing according to the cause tree described below (figure 3):

- ➢ Identification using observation robots:
  - ❖ UneXploded Ordnance (UXO) identification --> Immediately notify maritime authorities and law enforcement
  - ❖ Identifiable human anatomical parts --> Immediately notify maritime authorities and law enforcement
  - ❖ Identification of inert waste --> Do not collect if marine life is detected (surrounding flora and fauna)

- ➢ Unintentional collection and detection during characterization method
  - ❖ Firearm--> Immediately stop the characterization. Notify maritime authorities and law enforcement
  - ❖ Identifiable human anatomical parts --> Immediately stop the characterization. Notify maritime authorities and law enforcement
  - ❖ Asbestos --> Immediately stop the characterization phase. Contact port authorities to implement protection measures and isolate the risk with specific PPE. Call specialized companies if needed.
  - ❖ Full barrel of oil or petroleum --> Contact maritime authorities to know the procedures to isolate potential pollution risks

- ➢ Deliberate collection - characterization of specific waste
  - ❖ End-of-life vehicles (ELV) equipped with lithium batteries --> manual handling must be performed with care to avoid any mechanical shock to the battery that could cause heating, self-ignition, or even explosion

2.2.2. Marine litter classification principle

The sorting grid classifies marine litter into categories and subcategories based on their main constituent material (plastic, rubber, metal, glass, textile,) and/or according to their use (ELV, household packaging plastics, other plastics). Marine litters items which are composed of numerous materials can be separated when a recovery channel or an emerging channel exists for the dominant material. They should be treated as an “all” during the sorting sequence (i.e. plastic bottles composed of numerous types of plastics)

One category encompasses marine litters that can’t be sorted or recognized. This category is often necessary for small waste obtained as residual at the end of the screening and characterization sequence. For several waste categories, the "other" subcategory classifies waste that do not fit into other subcategories (generally associated with potential material recovery paths).

Many examples cited in this sorting grid are numbered and represent items listed in the 100 most found marine litter [8].

To help with characterization, many examples extracted from the deliverable 2.1 are cited in the sorting grid to help identify categories and subcategories of marine litter [8]. When an operator is

characterizing marine litter, they must ask themselves the following questions, self-explanatory categories weren't included in the set of questions. (i.e. glass category, metals category…) :

- Is it a fishing equipment then it is classified in the 1st category - Abandoned, Lost, and Discarded Fishing Gear (ALDFG)
- Is it an ELV containing several pieces of equipment made of different materials, it is classified in the 2nd category - ELV
    - subcategory 2.1 when the ELV contains its battery
    - subcategory 2.2 when the ELV is collected without its battery
- Is it an item used for food packaging, categories exist, and several subcategories as well.
    - If it is made of plastic; it is classified in the 3rd category - Plastic
        - subcategory 3.1 Bottles & flasks (household packaging)
        - subcategory 3.2 Cups & trays (household packaging)
        - subcategory 3.3 Plastic bag (household packaging)
    - If it is made of composite materials; it is classified in the 8th category - Composite Packaging with inseparable materials
        - subcategory 8.1 Food & liquid packaging (composite packaging of milk, carton of juice,)
        - subcategory 8.2 Other composite packaging (other complexed packaging)
- Does it contain hazardous materials, if it does it is classified in the 9th category-Dangerous waste. Six subcategories have been defined including:
    - subcategory 9.1 WEEE incorporating all waste from electrical and electronic equipment subcategory
    - subcategory 9.2 Specific diffuse waste with contaminated packaging and/or packaging containing hazardous waste (ammonia, caustic soda, solvent, paint, resin,)
    - subcategory 9.4 Batteries and accumulators (single unit)
- If the collected marine litter is a textile item made with any materials (clothing & laundry..) and isn't used for sanitary purposes then it is classified in the 10th category - Textile.
    - subcategory 10.1 clothing and laundry items
    - subcategory 10.2 shoes
    - subcategory 10.3 fashion accessories, like bags or belts made with any materials.
- If the collected ML is a sanitary textile, then it is classified in the 11th category - Sanitary textile.
- If the collected ML's dominant material is wood then it is classified in the 12th category - Wood, two subcategories exist.
    - subcategory 12.1 wooden packaging like crates or pallets
    - subcategory 12.2 other wooden items that aren't used for packaging.
- If the collected ML's dominant materials are made of paper & cardboard, then it is classified in the 13th category - Paper & cardboard.
- If an operator hasn't been able to answer previous questions and cannot assign the marine litter to any of the 13 categories (category 1 - ALDFG to category 13 - Paper & Cardboard) then it is classified as a ML in the 14th category – Other.

Table II. Sorting grid with examples extracted from the deliverable 2.1 of the SeaClear project [8].

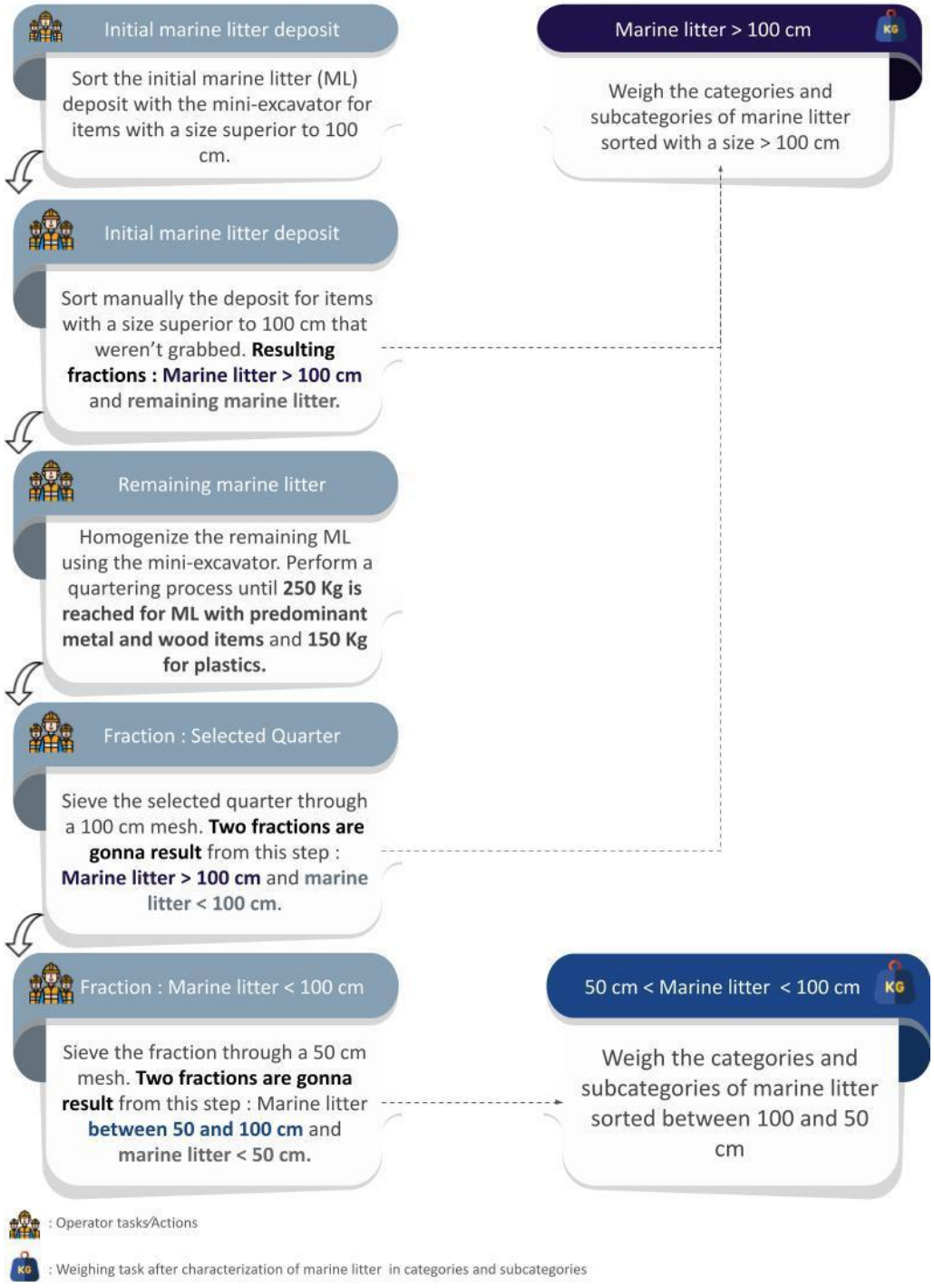
Category	N°	Subcategory	Examples (ref from seaclear D2.1)
1. ALDFG			Mussel/oyster nets - pergolas w/o shells (18) , fishing net < 1m2 (20), fishing net >1m2 (21), fished line (22), tangled nets (23), longline, Fishing related (weights, sinkers, lures, hooks) (69), **floats for fishing nets (25), fish buoys, fish Boxes**
2. ELV	2.1	ELV with Battery	e-scooter, e-bicycle, e-motorcycle
	2.2	ELV w/o battery	kick scooter, bicycle, motorcycle, multi-material vehicle parts (tires with rims, various wheels (53), car door with glass), **Car parts (28)**
3. Plastic	3.1	Bottles & flasks (household packaging)	Bottle&flasks made with PET, HDPE, PP (3): Still or sparkling water bottles, carbonated soft drink bottles, fruit juice bottles, vinegar bottles, cleaning product bottles, empty oil bottles (for cooking), milk bottles (3) (4), body and care bottles & flasks (Household cleaning products, laundry products bottles, shampoo/soap bottles) (8) (9)
	3.2	Cups & trays (household packaging)	Cups&Trays made with PE,PP, PET mono or multi-layer, PS, PVC : Plastic food trays (7), empty dairy product (yogurt) and butter/margarine cups , ice cream boxes (7), plastic cups and lids (only for food packaging) (13) , cutlery and trays (15), cover packaging (17) , blister packaging (moulded plastic packaging, e.g., packaging for batteries, toothbrushes, pens, light bulbs...), plastic coffee/tea capsules
	3.3	Plastic bag (household packaging)	Shopping bags or on-site packaging bags (any plastic film bag not dedicated to packaging a specific product) (1) (part of 2): supermarket bags (soft bags, shopping bags), plastic bags from shops and stores, fruit and vegetable bags, LDPE or biodegradable bags, plastic wrap from water bottle packs,
	3.4	Other rigid plastic	Foam sponge (32), Styrofoam packaging (42), straws (16), medical/pharmaceuticals container/tubes (w/o product), (39) Various rigid plastic items and fractions >50 cm, < 50 cm & < 20 cm (13) (14) : - Styrofoam packaging (42), Styrofoam fast food trays (7) - Pipes, hard hats/helmets (29), traffic cones (31), cables ties (35), toilet seat, PVC windows/door frames w/o glass - Containers, boxes, flower boxes, toothbrushes, tubes, pitchers, cups, household utensils (68) and toys (operating without electrical plug, battery or accumulator),sunglass, pens, straws (16), cotton swabs, deodorant stick, mascara brushes - Garden/outdoor furniture (e.g. sunbeds (41)); household storage boxes/containers (12), plastic buckets (5) (7), fish boxes (24) - Canoe, kayak, paddle/roar, snorkel masks, buoys (26),
	3.5	Other plastic film	Various plastic items and fractions >50 cm, < 50 cm & < 20 cm (13) (14) : - Other household packaging : small plastic bags (e.g. Frozen food bags) (2), food pet packaging (dry food), transparent squeezable fruit pouch, stretch film, fruit & vegetable mesh bags/nets, - Inflatable floats , inflatable paddle, buoys (26) and beach toys, beach balls (e.g. football, volleyball) - Tarp. Tarpaulin, sheets, sheet industrial packaging / plastic sheeting (27] - Watering hoses, geotextile sheets, agricultural films, fertilizer bags, compost bags
4. Rubber			Rubber only: bicycle tyres (48), car tyres (49), large industrial tyres (50), tractor tyres (51), rubber belts (52), other rubber pieces < 50 cm (54), other rubber pieces > 50 cm (55), balls (46)

Category	N°	Subcategory	Examples (ref from seaclear D2.1)
5. Metal	5.1	Ferrous metal packaging	Beverage cans (beer, cola, etc.) (64), ferrous metal aerosol cans that have not contained toxic chemicals (e.g., misting spray, whipped cream spray, deodorant, shaving foam...) (63), pet food cans, food cans (vegetables, fruits, meat, fish), tin can (63), coke tins (63)
	5.2	Other ferrous metals	Container and barrels that have not contained toxic chemical (e.g. oil, petroleum) (73),middle size container < 50cm (70), disposable BBQ's (66), large metallic objects (various) (77), other metal pieces < 50cm (78), other metal piece> 50cm (79), tools, C-clamps, household utensils, umbrella, wire/wire mesh/nabbed wire (72), drum and & buckets (gas cylinders excluded) (71)
	5.3	Non-ferrous packaging	Beverage cans (beer, cola, etc.) (64), food cans (64), trays, coffee capsules (e.g. Nespresso brand), aluminium aerosol cans that have not contained toxic chemicals (63), foil wrappers (65)
	5.4	Other non-ferrous metals	Profiles, cutlery, kitchen utensils, water bottle, moulded objects (faucets, pans, ..), pipes, yogurt pot lids, foil wrappers (65)
6. Glass	6,1	Clear glass packaging	Clear glasses, bottles, flakes and jars (80) (81): jams, ketchup, mayonnaise, vinegar, small onions, pickles, pâté, baby food jars, fruit juice, lemonade, fragrance, wines and spirit, spices, coffee, powdered tea
	6.2	Coloured glass packaging	Coloured glasses, bottles, flakes and jars (80) (81): beer, cider, wine, mineral water, fragrance & cosmetic jars
	6.3	Other glasses	Flat glass, large glass objects > 50cm (87), glass buoys (85), tableware (plates, cups) (83), glass or crystal drinking glasses, small pieces of glasses (w/o ceramic) > 2,5 cm (86), standard light bulbs (82]
7. Inert material	7.1	Fireproof packaging	Clays items: jar, trays, yogurt pots
	7.2	Other fireproof items	Inert Materials: rubble, stone, potteries, ceramics, tiles, earthenware or porcelain (86), clay bricks, clay flowerpots, plaster, stone objects, fuses
8. Composite	8.1	Food and liquid packaging	food complexed packaging (i.e. Tetra Pack brand): milk, juice, soups, sauces, cream) (92) (part of 90)
	8.2	Other composite packaging	Complexed packaging (PE with aluminium), potato chip bags (part of 90), coffee packaging, butter/meat/fish, food pet packaging (humid food), non-transparent squeezable fruit pouch
9. Dangerous waste	9.1	WEEE (household appliances)	All or part of an appliance that operated with an electrical plug, battery, or rechargeable battery. Appliances (refrigerators, washers, ...) (67) Small appliance : Hair dryer, iron press, radio, telephone (incl. parts) (33), electric razor, printed circuit board, calculator, mouse, coffee maker, computer, watch, VCR, electric toy, camera, plug with transformer, extension cords, power strips, cables (75). Plastic construction (switch, electrical outlet) (part of 34)
	9.2	Specific diffuse waste	Contaminated packaging and/or packaging containing hazardous waste: Household cleaning products (6) : drain cleaners, ammonia, caustic soda, strippers, textile dye DIY and decoration products: solvent, strong acids, white spirit, toluene, trichloroethylene, ink, varnish, nail polish, glues, paint, resins Vehicle maintenance products : antifreeze, engine oil bottles (10) (11) Gardening products, plant protection products and biocides (insecticides, anti-moss, fungicides, fertilizers) and pool products (chlorine, disinfectants)

Category	N°	Subcategory	Examples (ref from seaclear D2.1)
	9.3	Fluorescent tubes and energy-saving lamp	Neon tubes, energy-saving lamps, LED lamps
	9.4	Batteries and accumulators	Car battery (alone) (74), household battery (button cell, alkaline batteries, saline batteries, rechargeable batteries) (76), mobile phone batteries, power tool batteries
	9.5	Medical waste	Rubber gloves (45), Sharp medical waste (syringes), bandages, medications (product with its packaging) (39)
	9.6	Other special waste	Other hazardous waste: asbestos, explosive waste (firecrackers, fireworks), fire extinguisher, distress flare, gas bottles (71), oil barrel
10. Textile	10.1	Clothing and Laundry	Textiles natural and synthetic fibres (excluding bags and shoes): clothing (56), rags made of natural fibres (cotton, wool, linen...) and synthetic textiles (stockings, tights, fabrics), clothing rugs and towels (58) carpets and furnishings (60), other textiles pieces > 50cm (62), dishcloths, fabric handkerchiefs, towels, balls of wool, yarn, string, rope (61), synthetic ropes ((19), curtains, blankets, reusable baby diapers, headwear, rainwear, furs
	10.2	Shoes	Shoes (regardless of material) (57): sneakers, trainers, leather shoes, shoes/sandals (30), boots, rubber boots (47), flip-flop (40)
	10.3	Fashion accessory	Handbag, travel bag, backpack (59), suitcase, belt
11 Sanitary textiles			Diapers (excluding washable diapers) (38), sanitary napkins, cotton pads, wet wipes (36),
12. Wood	12.1	Wooden packaging	Crates (97), various boxes (fish boxes) (98), small crates, pallets, fruit trays
	12.2	Other wood	Corks (95), Various processed wooden items > 50 cm (100), Processed timber (96), ice-cream stick, chip forks, chopsticks, toothpicks (99)
13. Paper & carboard			Paper / carboard (88), carboard (boxes and fragments) (89), newspapers & magazines (91), other paper items <20cm (93), other paper items < 50 cm (94), cardboard packaging (cups, food trays (7), food wrappers (parts of 90)
14. Other			Part of items that can't be identified, small & tiny items, organic waste

2.2.3. Protocol of characterization

During sampling phases of marine litter (ML), if possible, for space on the tender store the largest and most massive objects (fishing nets, metal bars, etc.) separately from other marine litter. The protocol of characterization is as follows (Figure 3). The protocol isn't exhaustive and shows a framework and should be modified according to the mass of ML extracted (i.e. quartering process).



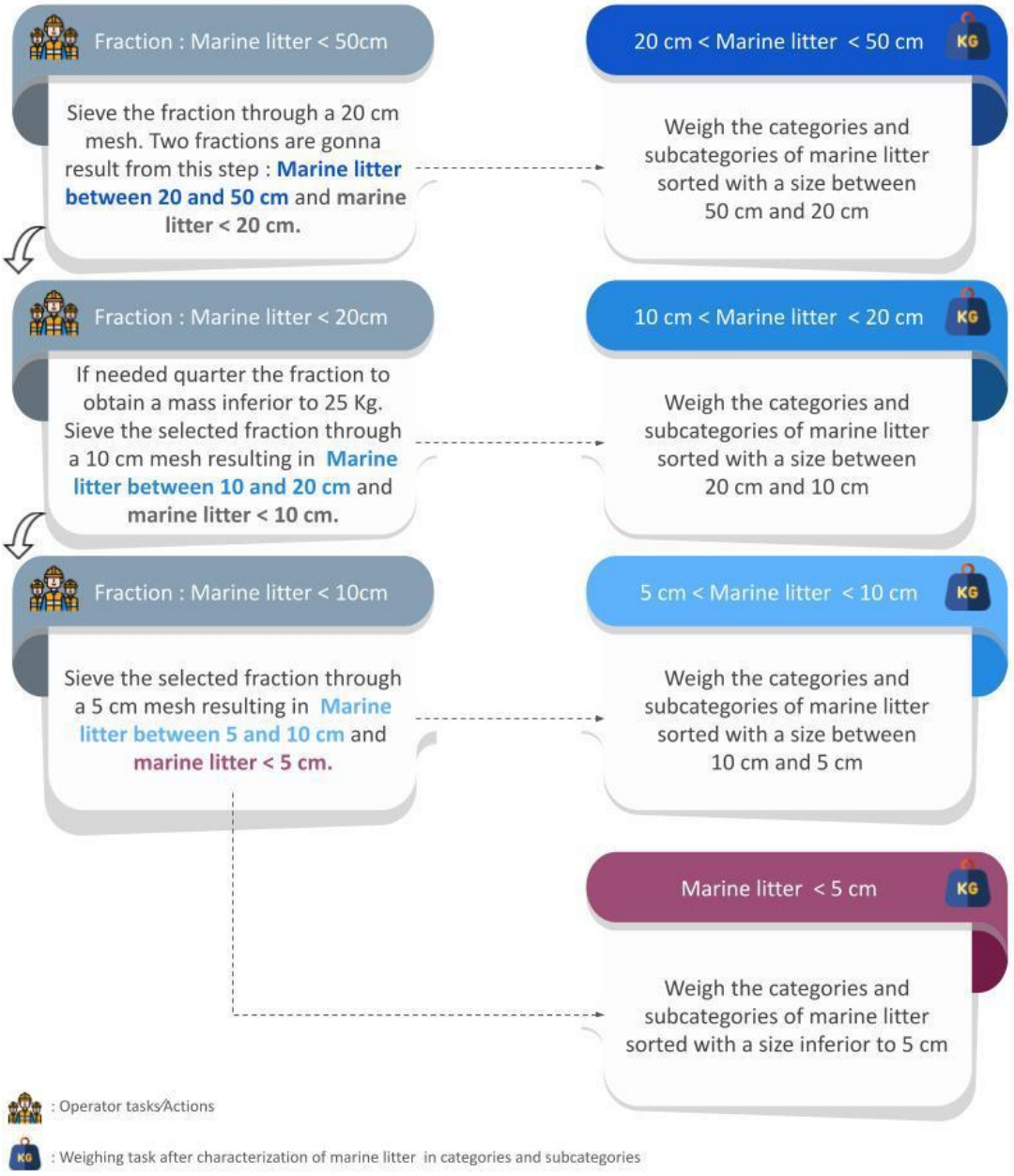


Figure 3. Characterization protocol diagram

Once at the storage and characterization site:

1. Weigh all samples (in one or several times) to determine initial mass
2. Identify and weigh receiving containers (tare) of sorted products for each category and subcategories
3. Spread the sample contents on the ground
4. Sort and weigh the fraction of large and massive objects (> 100cm by visual assessment)

    a. Given the heterogeneity and unit weight of these elements, it is imperative to sort them completely

   b. Sort by category and subcategory using mini-excavator and weigh each fraction on the 1500 kg scale
   c. Perform manual sorting if needed and weigh elements not grabbable by mini excavator. (Out-of-service vehicles like e-scooters and e-bicycles fall under this scope)
   d. For the abandoned, lost, and discarded fishing gear (ALDFG) category, remove marine fauna and flora. Weigh it to determine fauna proportion
   e. Take pictures of ML categories and subcategories

5. Sum the weight of all elements > 100 cm to determine weight proportion and the mass of remaining marine litter < 100 cm on the ground.
6. If needed, reduce the fraction smaller than 100 cm to obtain a mass of 250 kg when metal and wood are the major components. Reduce it to 150 kg if plastics are almost exclusively present. To do this, perform quartering using the mini excavator until reaching the target mass, limited to two successive operations.

   a. Homogenize all items on the ground as much as possible. For this step, use the conical pile method, which involves shovelling from the bottom of the pile and depositing it on top of the pile while forming a cone. This operation must be repeated all around the pile, 4 to 5 times depending on the size of the pile.
   b. Once the mixture is homogenized, it will be spread out to form a flat patty.
   c. Divide the pile into four quarters
   d. Choose a quarter at random and weigh it and take a picture
   e. Repeat this quartering step if needed to obtain the desired target mass

7. Using mini excavator to place the quartering fraction to be sorted on the 100 cm (1000 mm) mesh sieve

   a. Sieve the entire fraction
   b. Sort residual marine litter larger than 100 cm by category and subcategory, then weigh each of these fractions and take pictures

8. Using a mini excavator to place the fraction < 100 cm on the 50 cm (500 mm) mesh sieve.

   a. Sieve the entire fraction
   b. Sort residual marine litter larger than 50 cm by category and subcategory, then weigh each of these fractions and take pictures

9. Repeat the operation with the fraction to be sorted on the 20 cm (200 mm) mesh sieve.

   a. Sieve the entire fraction.
   b. Sort residual marine litter larger than 20 cm (200 mm) by category and subcategory, then weigh each of these fractions and take pictures.
   c. Weigh the residual fraction smaller than 20 cm (200 mm) and take a picture

10. If necessary, reduce the fraction < 20 cm (200 mm) by quartering to obtain a maximum mass of 25 kg.
11. Sort the entire quartered fraction on the 10 cm (100 mm) sieve and then the 5 cm (50 mm) sieve, following the previously described procedure

12. Complete the characterization grid of various weighing of categories and sub-categories of materials, considering the proportionality rules applied when performing quartering steps.

2.2.4. Characterization sheet

The first part of the characterization sheet includes fields for identifying the study site and its classification (whether it's a demonstration or pilot test site), along with specific details regarding marine litter origins, whether surface litter or seafloor litter (Table III-Appendix A). Indeed, marine litter degradation depends on their origin and should be considered. Additionally, it provides space for describing the site's characteristics such as the area, coverage, access methods, and available equipment. This standardized documentation approach is essential for maintaining consistency in marine litter analysis and enables proper scientific study of marine pollution across different locations.

Table III. Characterization sheet sampling template.

Sea Clear 2.0 use case - Characterization Sheet			
Site concerned by the study			
Site :			
Sampling Area :		**Depth (m)**	
Demonstration Site :		**Surface Litter :**	
Pilot Test :		**Seafloor Litter :**	
Intervention date (dd/mm/yyyy)			
Sampling date (dd/mm/yyyy) :			
Characterization date (dd/mm/yyyy) :			
Organisational method for the implementation of characterizations			

The weighted mass of each category and subcategory of marine litter is then reported, considering their size distribution and the proportionality rules. Table IV showcases an extract of the table; the full table can be seen in the Appendix B. All weighting results for each category and subcategories are recorded in the characterization sheet. At the end of the sorting campaign, the determined weight percentage of each category and subcategory make up the composition of the sample.

Table IV. Characterization sheet weighing template.

		Mass of the different size distribution (Kg)					
Category	**Subcategory**	**>100 cm**	**100-50 cm**	**50 - 20 cm**	**20 -10 cm**	**10-5 cm**	**< 5 cm**
1. ALDFG							
2. ELV	2.1 ELV with battery						
	2.2 ELV w/o battery						

		Mass of the different size distribution (Kg)					
Category	**Subcategory**	**>100 cm**	**100-50 cm**	**50 - 20 cm**	**20 -10 cm**	**10-5 cm**	**< 5 cm**
3.Plastic	3.1 Bottles & flasks (household packaging)						
	3.2 Cups & trays (household packaging)						
	3.3 Plastic bag (household packaging)						
	3.4 Other rigid plastic						
	3.5 Other plastic film						
.....							
12. Wood	Wooden packaging						
	Other Wood						
13. Paper & Carboard							
14. Other							

Additional and more specific characterizations can also be performed on plastic waste, such as polymer detection using a portable Near Infrared Spectroscopy (NIR) spectrometer. However, black plastic cannot be determined using that technology as the colours interfere with the analysis.

The nature of the polymer (PET, PE, PP, PS, ….) and the degradation state of plastics plays a predominant role in determining the subsequent recycling possibilities. On site and laboratory methods exist to determine degradation levels of waste materials, particularly for plastics as they undergo multiple degradation mechanisms. Ultraviolet (UV) radiation, saltwater exposure and mechanical stress from waves. A comprehensive analytical workflow for assessing plastic degradation is shown below (figure 4).

Prior steps must be done to prepare ML made of plastics for the laboratory study. Indeed, they must be cleaned, dried then shredded or grinded to create flakes. Afterwards, another drying step is made on the flakes to remove remaining moisture. They are then fed into an extruder with the appropriate temperature, shaped into pellets and then injected in a mould to obtain test specimens with a standardized size and shape for mechanical properties analysis. Those steps are time-consuming and necessitate a subsequent amount of plastics.

The analytical workflow starts with a visual assessment, made during the sorting phase. General appearance of the marine litter is looked at, colour changes on areas or on the entire object, presence of material crumbling, crazing. This step is crucial as yellowing, crazing, and surface erosion are common indicators of ocean exposure resulting in brittle plastics when it bends and can influence the choice of repurposing solutions.

Afterward, a Fourier transform infrared spectrometer (FT-IR) could be used to detect chemical changes caused by photo-oxidation and hydrolysis, which are prevalent in marine environments. Then, mechanical properties of the plastics could be determined since marine plastics typically show significant deterioration in tensile strength, elasticity and impact resistance due to prolonged water exposure and mechanical stress from wave action.

To further the study thermal aging is made on non-deteriorated plastics to help understand how the material's properties have been altered by environmental exposure and find for how long. Lastly, chemical analysis can be performed through gel permeation chromatography to quantify the extent of polymer chain breakdown - a common result of marine exposure where both UV radiation and hydrolysis can cause chain scission.

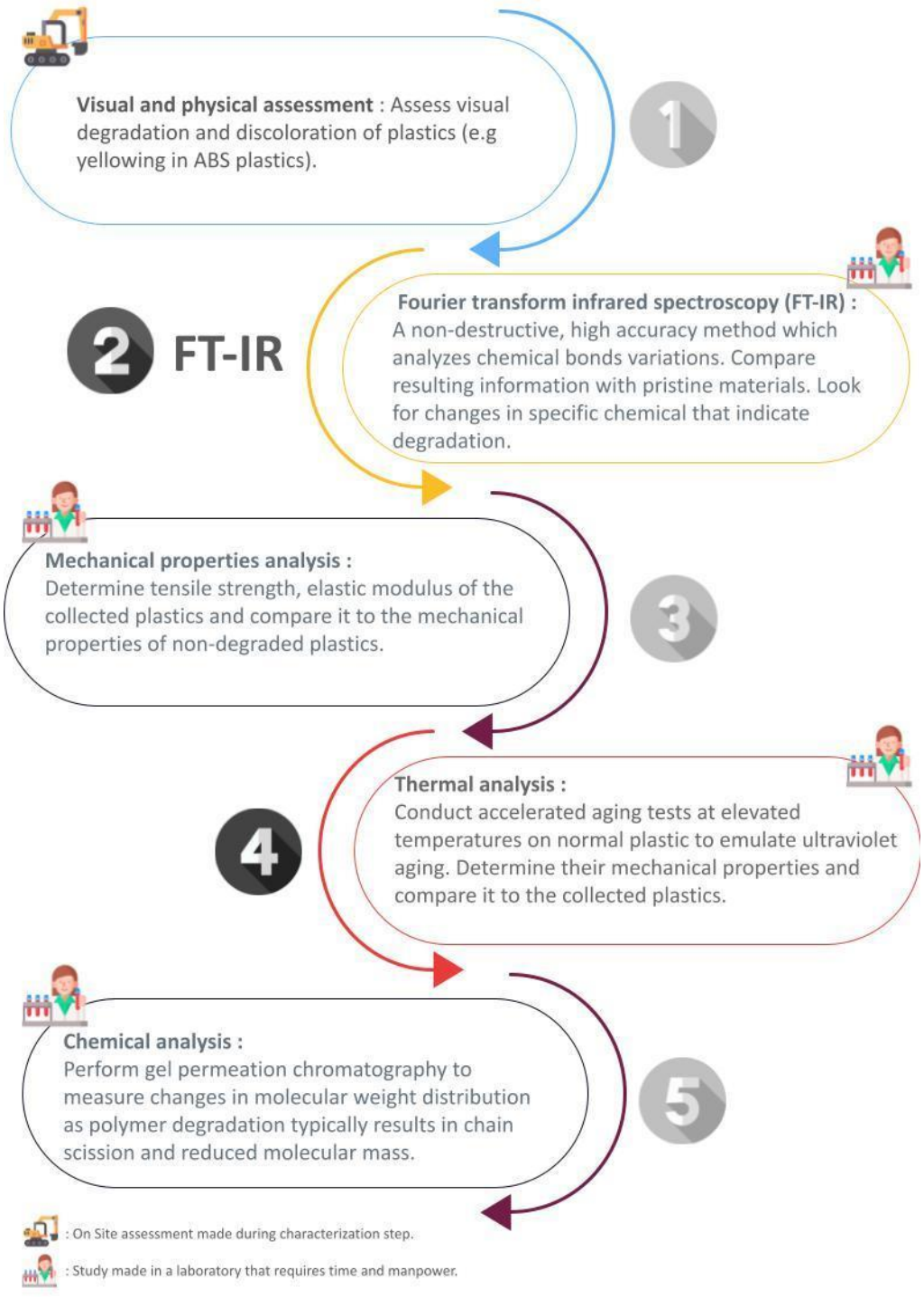


Figure 4. Laboratory study - Diagram of the assessment of plastic degradation.

A lack of collected waste does not permeate an assessment on real marine litter. However, degradation assessment of collected waste will be performed for T8.3 and added in the associated deliverable D8.6.

3. Conclusions

A comprehensive review of existing marine litter characterization methods showed that existing methods only monitor marine litter and can't fully satisfy the valorisation criteria. Few studies tackled the subject of marine litter characterization for repurposing purposes and highlighted that one of the main challenges involves marine litter made of metals and plastics, as the materials undergo corrosion and degradation due to the exposure to seawater.

This gap led to the development of a novel characterization method applicable to marine litter from the surface and the seafloor. The novel method was developed using existing municipal waste characterization methods and marine litter data. It considers waste origin and material composition, facilitating future processing and choosing of potential repurposing solutions. Nine material-based primary categories and thirty-five origin-based subcategories were designed to enhance marine litter traceability and end-of-life management.

Plastic waste can undergo degradation and further detailed analysis were proposed, including polymer identification through portable NIR spectroscopy (though this method is ineffective for black or dark-coloured plastics). Assessment of UV exposure and seawater exposure regarding the plastic's degradation. Both the polymer type and degradation level are crucial factors in determining recycling options for marine debris. These analytical aspects will be explored further in deliverable D8.6.

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Appendix A: Characterisation sheets: Sampling template

Sea Clear 2.0 use case - Characterization Sheet : Sampling Sheet				
Site concerned by the study				
Site :				
Sampling Area :		**Depth (m)**		
Demonstration Site :	(Y/N)	**Surface Litter :**	(Y/N)	
Pilot Test :	(Y/N)	**Seafloor Litter :**	(Y/N)	
Intervention date (dd/mm/yyyy)				
Sampling date (dd/mm/yyyy) :				
Characterization date (dd/mm/yyyy) :				
Organisational method for the implementation of characterizations				
Description of the characterization site (area, coverage, access methods, equipment availability, ...)				

Appendix B: Characterisation sheets: Sorting& Weighting template

Sea Clear 2.0 use case - Characterization Sheet

General Information

Initial sample weight (Kg)				
Presence of Marine Life		(Y/N)	**Weight of Marine Life (Kg)**	
			Weight (%)	

Description of marine life (types of organism, category and subcategory of affiliation)

Detailed results of characterization

		Mass of the different size distribution (Kg)					
Category	**Subcategory**	**>100 cm**	**100-50 cm**	**50 - 20 cm**	**20 -10 cm**	**10-5 cm**	**< 5 cm**
1. ALDFG							
2. ELV	2.1 ELV with battery						
	2.2 ELV w/o battery						
3.Plastic	3.1 Bottles & flasks (household packaging)						
	3.2 Cups & trays (household packaging)						
	3.3 Plastic bag (household packaging)						
	3.4 Other rigid plastic						
	3.5 Other plastic film						
4. Rubber							
5. Metal	5.1 Ferrous metal packaging						
	5.2 Other ferrous metals						
	5.3 Non-ferrous packaging						
	5.4 Other non-ferrous metals						
6. Glass	6.1 Clear glass packaging						
	6.2 Coloured glass packaging						
	6.3 Other glasses						
7. Inert Material	7.1 Fireproof packaging						
	7.2 Other fireproof items						
8. Composite	8,1 Food liquid packaging						

		Mass of the different size distribution (Kg)					
Category	**Subcategory**	**>100 cm**	**100-50 cm**	**50 - 20 cm**	**20 -10 cm**	**10-5 cm**	**< 5 cm**
	8.2 Other composite packaging						
9. Dangerous waste	9.1 WEEE (household appliances)						
	9.2 Specific diffuse waste						
	9.3 Fluorescent tubes and energy-saving lamp						
	9.4 Batteries and accumulators						
	9.5 Medical waste						
	9.6 Other special waste						
10. Textile	10.1 Clothing and laundry						
	10.2 Shoes						
	10.3 Fashion accessory						
11. Sanitary textiles							
12. Wood	Wooden packaging						
	Other Wood						
13. Paper & Carboard							
14. Other							