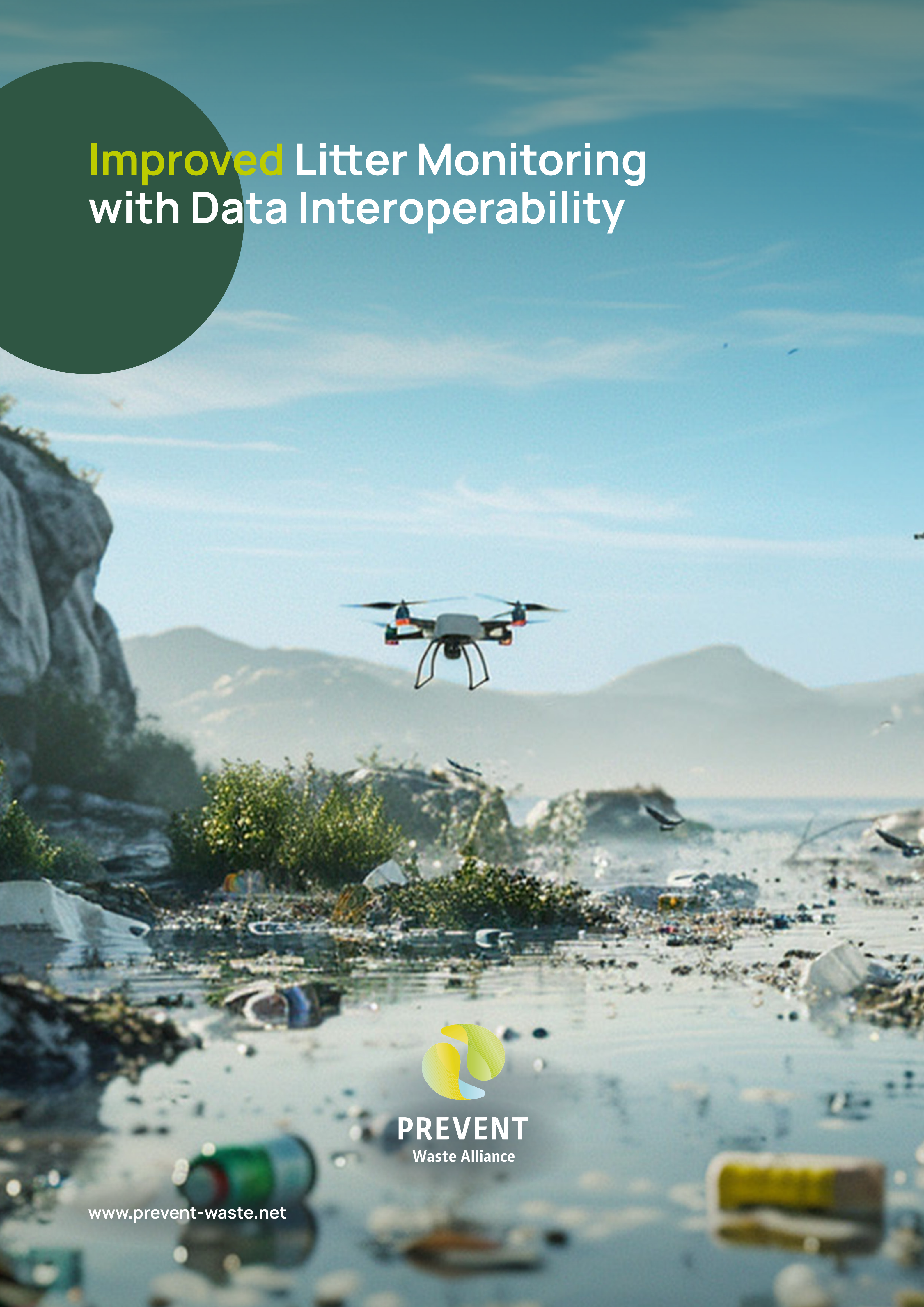
# Improved Litter Monitoring with Data Interoperability



PREVENT
Waste Alliance

www.prevent-waste.net

# Abstract

This discussion paper explores how data interoperability can improve litter monitoring.

Interoperability of litter monitoring data can improve information quality and increase data quantity. Better and more data are critical for litter monitoring, as waste-related information is currently scarce and difficult to obtain.

First, we introduce the current opportunities and challenges for data interoperability in litter monitoring.

Next, we present members of the PREVENT Waste Alliance with sophisticated digital solutions and discuss their interoperability potential. This theoretical foundation allows us to develop best practices to harmonize data, which we summarize as a Toolbox for practitioners.

Lastly, we provide recommendations for more engagement and collaboration. We identify the need for capacity building in data literacy and the need for support to build data partnerships between organizations.

Therefore, we contribute to the circular economy ecosystem by supporting the waste management sector to become more data-driven. Moreover, our Toolbox for practitioners provides actionable guidance to get started with data interoperability.

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# 1 Introduction

## 1.1 Background

Litter in the environment is an increasing problem, especially for marine and coastal ecosystems [2]. While the production and consumption of goods increases globally [8], waste management systems are challenged to cope with the increasing masses of waste [2]. Especially in regions with limited waste management services [11], these increasing masses of waste impose unprecedented challenges. Plastics are the most concerning fraction of marine litter, accounting for at least 85 percent of total marine waste [24]. As many waste management systems are used to capacity, and few systemic improvements are underway, litter quantities are likely to increase further in the coming years [6].
Improved measurement and monitoring of litter can support municipalities to better manage waste [7, 3]. Amidst the ongoing negotiations for a Global Plastic Treaty, the Intergovernmental Negotiating Committee (INC) assigns significant importance to measurement and monitoring [25]. With improved measurement and monitoring, litter impacts in life cycle assessments become clearer [28], and decision-makers from the private as well as public sectors can inform bespoke interventions [12]. Through interdisciplinary collaboration and effective communication, stakeholders can cope with the litter challenge more effectively [20]. In other words, better and more data are critical for litter monitoring [21, 23]. Unfortunately, waste-related information is currently scarce and difficult to obtain [26]. Despite a basic level of capacity built by governmental institutions [7, 3], public-private collaboration is key for enhanced litter monitoring [16]. This is mainly because the private sector employs innovative technologies with novel approaches to measuring, managing, and monitoring litter [1]. One promising approach to improved information quality and increased data quantity is data interoperability [17]. Data interoperability can enhance the economic value of communication technology by minimizing the cost of communication [13].

## 1.2 Goal of this Discussion Paper

Despite the potential of interoperability, collaboration in litter monitoring remains scarce [17]. This scarcity of interoperability initiatives can partially be explained by the lack of structured theoretical guidance. Consolidated information is not easily available for practitioners, which imposes a significant barrier to get started. We contribute to the circular economy ecosystem by supporting the waste management sector to become more data-driven.

Moreover, the absent success stories and case studies in data interoperability for litter monitoring temper the adoption of this collaboration type. Especially well-suited for practitioners, best practices and playbooks can provide a lot of value in a short reading time. We support practitioners with our actionable Toolbox and initial evidence of its transfer potential to practice.

## 1.3 Paper Structure

We structured this discussion paper into three sections:

First, we spotlight members of the PREVENT Waste Alliance with sophisticated digital solutions and discuss their interoperability potential.

Second, we develop best practices and case studies, which we present as a Toolbox for practitioners.

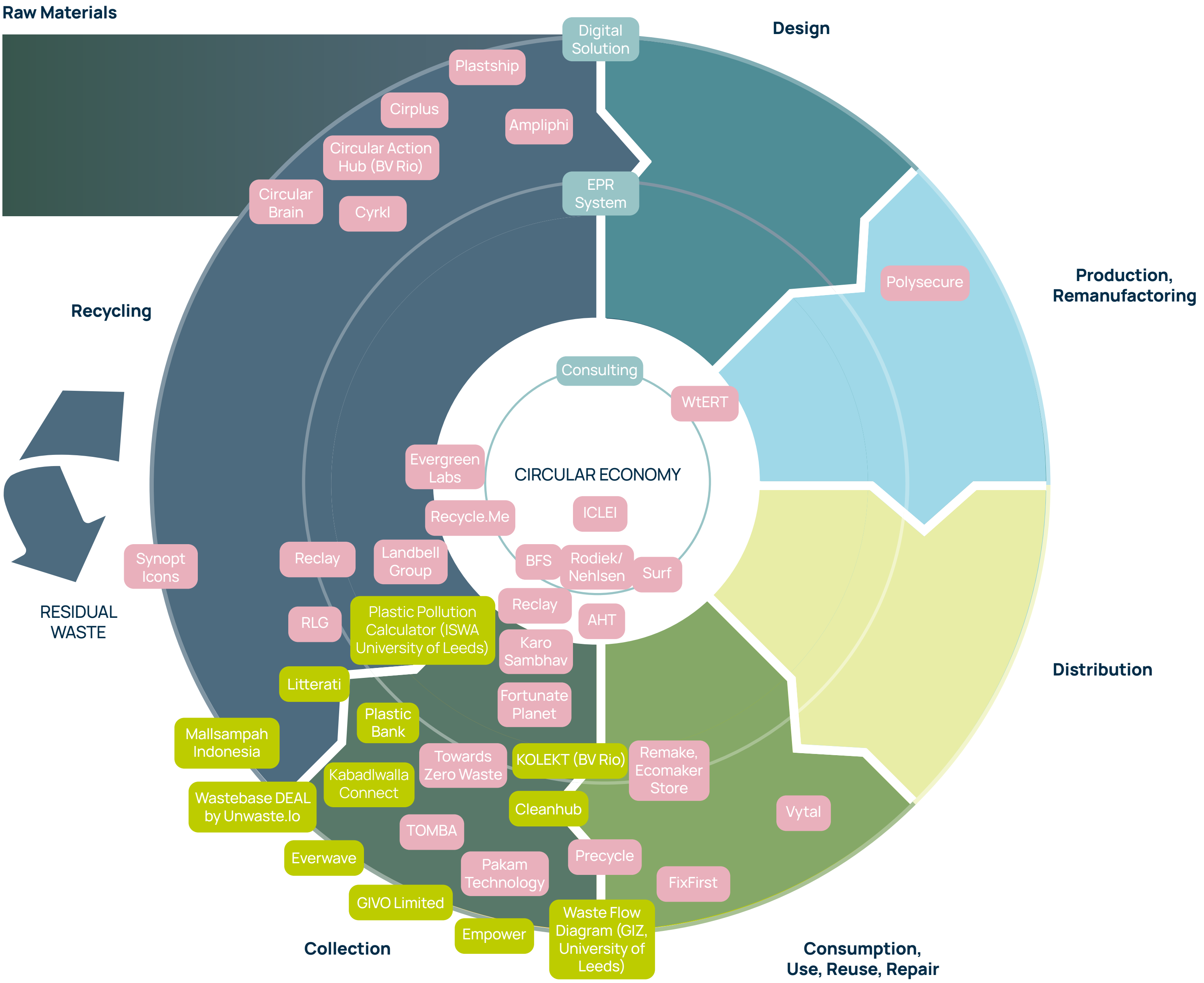
Third, we discuss recommendations for further engagement and collaboration in the field of data interoperability for litter monitoring. Here, we also share opportunities for PREVENT members to participate in a pilot project related to data interoperability.

# 2 PREVENT Member Spotlight

## 2.1 Overview of PREVENT Digital Leaders

With more than 500 members from different sectors and regions, the PREVENT Waste Alliance can play a key role in connecting circular economy actors and enabling data cooperation. However, such data cooperations only work when circular economy actors understand their role and their interconnections in the value chain [17]. If for example, a product manufacturer collects product life cycle data and shares it with a digital waste management provider, this provider can predict the components in the municipal waste mix. Such a prediction could have economic benefits in the form of improved resource allocation, and circle back to the product manufacturer, who can then align their product design with extended producer responsibilities [16].

To further highlight the PREVENT members' roles and the interconnections of their digital solutions, Figure 1 provides an overview of the digital circular solutions developed by PREVENT members along the product life cycle. Those solutions that focus on litter monitoring are highlighted in green. We have structured additional information about these solutions in Table 1 (also available via interactive online mapping table).




Digital Solution developed by PREVENT member

Digital Solution developed by PREVENT member with a focus on (marine) litter monitoring

Figure 1: Mapping of the PREVENT member's roles and the interconnections of their litter monitoring solutions [17]

Table 1: Comparative analysis of technological solutions developed by PREVENT members. An updated and complete version of the mapping with a focus on (marine) litter monitoring can always be found here:https://airtable.com/app8mg6NFvm12yrZG/shrHOFPqTR8OaNYFB



| | Cleanhub | Empower | everwave | Kabadiwalla Connect | KOLEKT (BV Rio) |
|---|---|---|---|---|---|
| Website | www.cleanhub.io | www.empower.eco | www.everwave.de/en | www.kabadiwallaconnect.in | www.kolekt.app |
| Functions | Digital trading of secondary plastic from collection to the final recovery or recycling endpoint | Offer plastic credits, connects plastic recyclers with international buyers and manufacturers and the development of a crypto native token for incentives | Offer Plastic Credits through worldwide cleanup projects with garbage collection boats and waste pickers. Supported by remote sensing of waste, building waste management infrastructure and awareness raising (Detect, Collect, Recycle, Inspire) | Collects data on the contribution of the informal sector on municipal waste systems to improve ISWM (informal infrastructure and material tracking) | Offer and sell. Request and buy. View on map. Bid on offers. Earn points & withdraw cash. Map enabled search and location, to finding buyers and sellers |
| Main problem(s) addressed | Funding gap<br>Sustainability requirements and frameworks | Market challenges for secondary materials<br>Sustainability requirements and frameworks | Market challenges for secondary materials<br>Sustainability requirements and frameworks | Insufficient waste management<br>Social Inclusion | Capacity/awareness gap<br>Collaboration gap |
| Main solution(s) provided | Financing<br>Monitoring & Traceability<br>Litter Monitoring | Connecting stakeholders<br>Litter Monitoring | Connecting stakeholders<br>Litter Monitoring | Monitoring & Traceability<br>Improving waste management services Litter Monitoring | Connecting stakeholders<br>Litter Monitoring |
| Target Group | Households<br>Companies & Brands | Waste pickers and collectors<br>Recyclers | Waste pickers and collectors<br>Recyclers | Waste pickers and collectors<br>Communities | Households<br>Waste pickers and collectors<br>Recyclers |
| Technologies | Track and trace app | Cloud storage and blockchain | Cloud storage and blockchain | Extensive survey on informal sector, ICT and IoT based technology | Android & iOS App |
| Up- or downstream solution? | Downstream | Downstream | Downstream | Downstream | Downstream |

Table 1: Comparative analysis of technological solutions developed by PREVENT members.
An updated and complete version of the mapping with a focus on (marine) litter monitoring can always be found here: https://airtable.com/app8mg6NFvm12yrZG/shrHOFPqTR8OaNYFB



| Litterati | Mall Sampah Indonesia | unwaste.io (Wastebase) | Plastic Pollution Calculator (ISWA, University of Leeds) | Waste Flow Diagram (by GIZ, University of Leeds, Eawag-Sandec & Wasteaware) |
|---|---|---|---|---|
| Website<br>www.litterati.org | Website<br>www.mallsampah.com | Website<br>www.unwaste.io | Website<br>www.plasticpollution.leeds.ac.uk/home/toolkits/calculator | Website<br>www.wfd.rwm.global |
| Functions<br>Assess litter impact & monitor the effectiveness of waste interventions. | Functions<br>Network of local waste collectors. Pick up and drop off waste to recycling centers. Recycle infrastructure support. Recycling campaigns. Digital exchange currency. | Functions<br>Wastebase data platform connects a global network of individuals and organisations working towards a circular economy for plastic. It demonstrates where plastic products end up in the environment and helps to understand full life cycle of products. | Functions<br>Thorough solid waste management system analysis, and combining this with local socioeconomic, geographical and meteorological factors, it quantifies the specifics of plastic pollution sources and pathways at an unrivalled resolution. | Functions<br>Analysis and visualisation of waste streams and plastic leakages in municipal waste management systems, identification of inefficiencies and opportunities for improvement & planning of countermeasures. |
| Main problem(s) addressed<br>Data & information gap | Main problem(s) addressed<br>Collaboration gap<br>Insufficient waste management | Main problem(s) addressed<br>Market challenges for secondary materials<br>Sustainability requirements and frameworks | Main problem(s) addressed<br>Insufficient waste management<br>Data & information gap | Main problem(s) addressed<br>Environmental pollution<br>Insufficient waste management<br>Data & information gap |
| Main solution(s) provided<br>Monitoring & Traceability<br>Litter Monitoring | Main solution(s) provided<br>Connecting stakeholders<br>Financing Litter Monitoring | Main solution(s) provided<br>Connecting stakeholders<br>Litter Monitoring | Main solution(s) provided<br>Litter Monitoring<br>Monitoring & Traceability | Main solution(s) provided<br>Litter Monitoring<br>Monitoring & Traceability |
| Target Group<br>Governments<br>Companies & Brands | Target Group<br>Households<br>Companies & Brands<br>Governments<br>Waste pickers and collectors<br>Recyclers | Target Group<br>Waste pickers and collectors<br>Recyclers | Target Group<br>Companies & Brands<br>Governments<br>Municipalities & Utilities | Target Group<br>Policy-makers<br>Municipalities & Utilities<br>Development organizations<br>Education and research institutions |
| Technologies<br>AI, Open data, geospatial dashboard | Technologies<br>App, SaaS for Governments | Technologies<br>Cloud storage and blockchain | Technologies<br>Mass Flow Analysis, GIS | Technologies<br>Data collection and analysis tools, geographic information systems (GIS), and diagrammatic visualization software. |
| Up- or downstream solution?<br>Downstream | Up- or downstream solution?<br>Downstream | Up- or downstream solution?<br>Downstream | Up- or downstream solution?<br>Downstream | Up- or downstream solution?<br>Downstream |

## 2.2 Interoperability Potential within PREVENT

Within the working groups of PREVENT, members have frequently identified opportunities to make communication more effective by connecting to the medium (e.g., Member 1 connects their database with Member 2 to achieve mutual benefits). However, many intentions have not been realized due to an inherent misalignment of messaging strategies [13, 14]. This has led the project team to wonder how technology should be designed to make communication more effective by not connecting only the medium, but also the attributes of the message itself [22].

We explored the interoperability potential of the shortlisted PREVENT members for litter monitoring.
For data to be interoperable data shall:

- use a formal, accessible, shared, and broadly applicable language for knowledge representation;
- use vocabularies that allow FAIR principles [27] - ensuring that data is findable, accessible, interoperable, and reusable; and
- include qualified references to other data.

As demonstrated in Figure 1 and Table 1, the characteristics of the PREVENT member solutions vary considerably. This variation imposes challenges on interoperability but also underpins the rationale behind more collaboration. To consolidate the data gathered from PREVENT members, we applied the model presented in Figure 2.

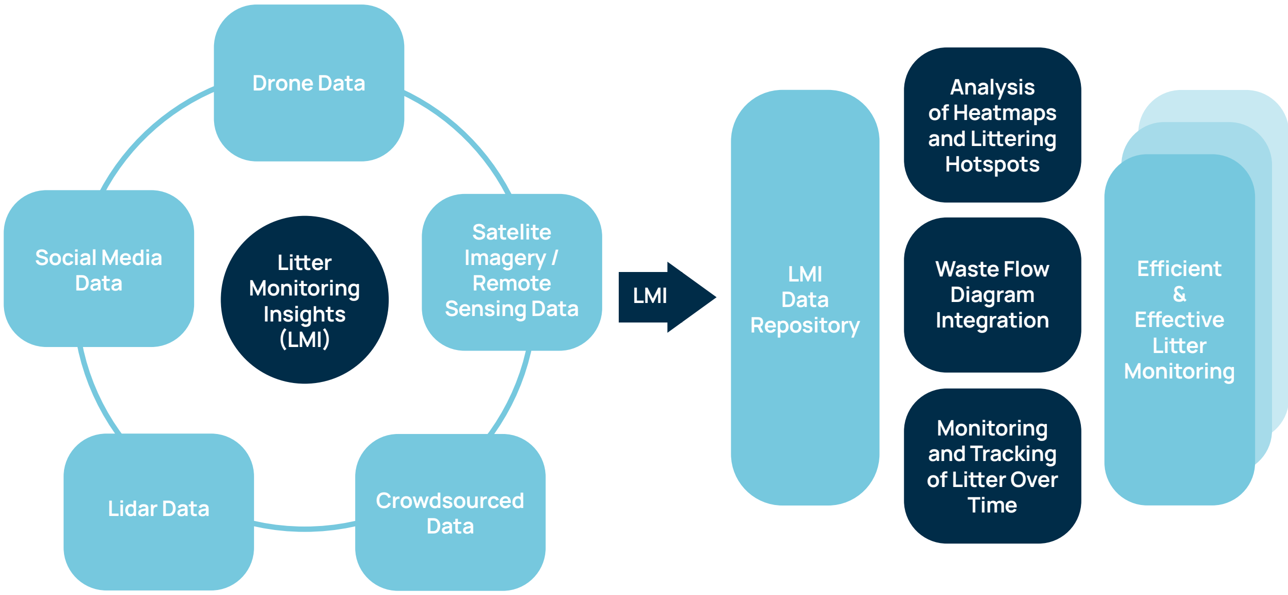



Figure 2: Model used to harness litter monitoring insights for the private and public sectors

Our initial analysis confirms the enormous potential of data interoperability between PREVENT members. Despite the heterogeneous nature of the member's solutions, data can be abstracted to a format that enables interoperability.

However, interoperability is currently only possible with manual intervention. These manual interventions are required to contextualize raw data and harmonize semantics. As PREVENT members collaborate towards further contextualization of their raw data and apply a collaborative schema, these manual interventions could be reduced in the future. Reducing manual interventions will directly benefit the business case for data interoperability.

## 2.3 Case study: Classification of Marine Litter

The classification of (marine) litter provides a robust foundation for harmonious communication. The more actors align with a certain classification framework, the more relevant this framework gets [10]. Various classification frameworks for one research field provide advantages and disadvantages [15]. On the one hand, framework diversity integrates several views and classification approaches. On the other hand, framework diversity creates confusion and obstacles to data interoperability.

**Step 1: Classificatory Framework**
For our case study, we analyzed and compared six classification frameworks for (marine) litter. The objectives were to identify a) minimum common classifications for harmonization, b) possible reference typologies functioning as guide in harmonization and c) possible corresponding pairs between the typologies, which would enable the 'translation' of datasets from one framework into another framework.

The objects (e.g., bottles, lids, wrappers) and materials (e.g., plastic, metal, glass) of each framework were listed in tables and matched with possible corresponding pairs. Objects were matched from high level of detail to lower level of detail (e.g., lid, subcategory: Beverage bottle caps → Other small dense items (< 20 cm)). We summarized examples for properties and objects within the six frameworks in Table 2 and for material categories in Table 3. These six frameworks were: 1) Waste Flow Diagram by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, University of Leeds, Swiss Federal Institute of Aquatic Science and Technology (Eawag) and RWA-Wasteaware; 2) ISWA Plastic Pollution Calculator (PPC) by University of Leeds; 3) APLASTIC-Q by German Research Center for Artificial Intelligence (DFKI) based on the classification of a World Bank project; 4) (Marine) Debris Tracker by Dr. Jenna Jambeck and Dr. Kyle Johnson supported by NOAA Marine Debris Program; 5) Litterati App by Litterati/Jeff Kirschner; 6) and GPML data harmonization matrix (DHM) by GPML Community of Practice.

All frameworks used different systems of classification with varying levels of typology details. GPML DHM showed the highest level of detail and Waste Flow Diagram the lowest level, focusing only on the classification of materials (see Table 2 and 3). The systems of classification, though working well on their own, were partially non-stringent, complicating direct references between the frameworks. For example, objects were merged with materials, material types, applications and/or sizes (see Table 2):

- bottles ↔ plastic bottles ↔ PET-bottles
- bottles ↔ Other Plastic Bottles ↔ PPCP bottle ↔ Personal Care Products
- Other small dense items (< 20 cm) ↔ cup lids, caps and small plastics ↔ Plastic Caps or Lids

Direct references were generally only possible when specific objects were named (e.g., bottles, cups, wrappers) in more than one framework. Otherwise, a 'translation' could only be made from a framework with a higher level of detail to a framework with a lower level of detail:

- Packaging and Containers, subcategory: Sweet and snack wrappers → Plastic Food Wrappers → plastic wrappers under 10 cm → Other Plastic Film → Plastics

Meaning that, for example, the classification 'plastic wrappers under 10 cm' in one framework (higher detail level) corresponds to 'Other Plastic Film' in another framework (lower detail level). Vice versa 'Other Plastic Film' does not directly correspond to 'plastic wrappers under 10 cm', because it could also be classified as 'plastic wrappers over 10 cm'. To decide whether it is a plastic wrapper under or over 10 cm, the classification is not sufficient. Additional information is needed, e.g., a picture of the actual item.

Finding corresponding pairs on the material level was more straightforward. Most frameworks applied the same classifications and levels of detail (e.g., plastic, glass, metal, other). However, not all material classifications were used in all frameworks (e.g., paper, rubber, textile/cloth), object groups were listed as materials (e.g., boat parts, fishing gear, electronics) and subcategories of materials were listed in parallel (e.g., plastic, polystyrene, cellulose acetate) (see Table 3).

**Table 2:** Comparative analysis of six material typologies of (marine) litter used for our case study. Organizations are listed according to level of detail of the material and object classes from left to right.

| | Waste flow diagram [1] | Uni leeds ISWA plastic Pollution Calculator[2] | DFKI APLASTIC-Q (World bank classification)[3] | Marine debris tracker[4] | Litterati[5] | GPML UNEP/ DHI |
|---|---|---|---|---|---|---|
| **Founding/ Publication date** | 2020 | 2020 | 2020 | 2010 | 2015 | 2024 |
| **Scope** | Rapid assessment methodology for mapping flows of macro waste within a municipal solid waste system from generation to disposal. | Assessment quantifying specifics of plastic pollution sources and pathways within cities focusing on local characteristics (infrastructure, solid waste management practices, socio-economic context, geography, meteorology). | Remote sensing tool for detection and quantification of (plastic) litter in aquatic environments. | Open-data citizen-science tool for data collection of inland and marine debris. | Digital tool to geo-tag photos of litter focusing on litter mapping for cities. | Data harmonization matrix based on litter characteristics (spheres, objects, materials, compartments) to support unified data collection for integrated decision making. |
| **Sources** | Questionnaire | Questionnaire, literature, expert-reviewed leakage factors | UAV drones & airplanes | Mobile app | Mobile app | Various |
| **Typology detail level** | Low | Medium low | Medium | Medium | Medium high | High |
| **Example level 1** | 2 - Plastics | 10 – Other small dense items (< 20 cm) | 171 P – cup lids, caps and small plastics | Plastic caps or lids | Object: Bottlecap Material: Plastic Category: Drink | Lids subcategories: Beverage bottle caps/ Hinged caps |

[1] https://www.giz.de/expertise/html/62153.html
[2] https://plasticpollution.leeds.ac.uk/home/toolkits/calculator/
[3] https://iopscience.iop.org/article/10.1088/1748-9326/abbd01
[4] https://debristracker.org/
[5] https://www.litterati.org/

| | Waste flow diagram[1] | Uni leeds ISWA plastic Pollution Calculator[2] | DFKI APLASTIC-Q (World bank classification)[3] | Marine debris tracker[4] | Litterati[5] | GPML UNEP/ DHI |
|---|---|---|---|---|---|---|
| **Example level 2a** | 2 - Plastics | 04 - PET bottles | 131 P – bottles PET | Plastic bottle | Object: Bottle Material: Plastic Category: Drink | Bottles subcategory: Beverage bottles |
| **Example level 2b** | 2 - Plastics | 05 - Other plastic bottles | 151 P – PPCP bottle | Personal care products | Object: Bottle Material: Plastic Category: Personal hygiene | Bottles subcategory: Bottles for liquid toiletries |
| **Example level 3a** | 2 - Plastics | 03 - Other plastic film | 121 P – Wrappers under 10cm | Plastic film | Object: Piece Material: Plastic Category: Other | Film subcategories: Packaging film/ Cellotape/ Garden sheets/ Non-packaging film/Food packaging film/ Other films |
| **Example level 3** | 2 - Plastics | 03 - Other plastic film | 122 P – Wrappers over 10cm | Plastic film | Object: Piece Material: Plastic Category: Other | Film subcategories: Packaging film/ Cellotape/ Garden sheets/ Non-packaging film/Food packaging film/ Other films |
| **Example level 3c** | 2 - Plastics | 03 - Other plastic film | 121 P – Wrappers under 10cm | Plastic food wrappers | Object: Piece Material: Plastic Categories: Food/Other | Packaging and containers subcategories: Food wrappers/ Sweet and snack wrappers |
| **Example level 3d** | 2 - Plastics | 03 - Other plastic film | 122 P – Wrappers over 10cm | Plastic food wrappers | Object: Piece Material: Plastic Categories: Food/Other | Packaging and containers subcategories: Food wrappers/ Sweet and snack wrappers |

**Table 3:** Comparative analysis of six material typologies of (marine) litter used for our case study. Columns show the typologies by publishing entity and system. The 'Master' column summarizes the overarching material categories and forms the recommendation for harmonization. Rows list all categories with the corresponding pairs of the other typologies in. Material categories in light blue mark the reference category of the row in alphabetical order. P = Plastic; NP = Non-Plastic; NW = Non-Waste.

| Master | Waste flow diagram | Uni leeds ISWA plastic Pollution Calculator | DFKI APLASTIC-Q (World bank classification) | Marine debris tracker | Litterati | GPML UNEP/ DHI |
|---|---|---|---|---|---|---|
| **Glass** | Glass | n/a | NP - Glass | Glass | Glass | Glass |
| **Metal** | Metal | n/a | NP - Metal | Metal | Metal | Metal |
| | Metal | n/a | NP - Metal | Metal | Aluminum | Metal |
| **Paper/ card.** | Paper/card. | n/a | n/a | Paper & Lumber | Paper | Paper & Lumber |
| **Plastic** | Plastics | Plastics | Plastics | Plastics | Plastics | Plastics |
| | n/a | n/a | P - Fishing gear | Fishing gear | n/a | In objects category |
| | n/a | n/a | n/a | n/a | Cellulose acetat | In objects category |
| | n/a | n/a | n/a | n/a | Polystyrene | In objects category |
| **Rubber** | Other | n/a | NP - Rubber | Rubber | n/a | Rubber |
| **Textile/ Cloth** | Other | n/a | NP - Other | Cloth | Textile | Cloth |
| **Organic** | Organic | n/a | NW - Vegetation | n/a | n/a | Organic |
| **Other** | Other | n/a | NP - Other | Other items | None | n/a |
| | Other | n/a | NP - Other | Other items | None | Unknown |
| | Other | n/a | NP - Other | Other items | n/a | Electronics |
| | Other | n/a | NP - Other | Boat parts | n/a | See Objects |
| **Compart-ments** | n/a | n/a | NW - Wood | Paper & Lumber | n/a | Paper & Lumber |
| | n/a | n/a | NW - Sand | n/a | n/a | In compartments category |
| | n/a | n/a | NW - Vegetation | n/a | n/a | In compartments category |
| | n/a | n/a | NW - Water | n/a | n/a | In compartments category |

Referring to the objectives of the case study, the following conclusions and recommendations can be given:

a. **Minimum common classifications for harmonization:**

- Objects: Due to the wide variety of objects, the different levels of detail between the frameworks, and the non-stringent classification of merging objects with materials, material types, applications and/or sizes, it was not possible to identify sufficient minimum common classifications. To achieve harmonization of datasets it is highly recommended to follow a clear structure and stringent classification system based on clear parameters at a comparable level of detail. Mandatory parameters for a comparable level of detail should be at least material and object (e.g., plastic bottle, glass bottle, plastic lid, metal lid), which can be complemented by optional more specific parameters such as material type (e.g., plastic bottle PET, plastic bottle HDPE), application (e.g., plastic bottle PET drink, plastic bottle HDPE PPCP) and size (e.g., plastic wrapper < 10 cm; plastic wrapper > 10 cm). It is important to note that it can be very difficult to determine the optional parameters for each object, which complicates the interoperability of the data.
- Materials: Based on the comparison of the six frameworks the recommended minimum common classifications for harmonization are: Glass, metal, paper/cardboard, plastic, rubber, textile/cloth, organic, other. It is recommended to maintain the same level of detail, to add subcategories of materials only in combination with the main category (e.g., plastic - polystyrene) and to list object groups as main categories in objects (e.g., boat parts, fishing gear, electronics, bottles, wrappers, lids).

b. **Possible reference typologies functioning as guide in harmonization:**

- It has to be acknowledged that the structured classification of the vast and diverse amount of litter items and materials is a challenging task. In general, all frameworks offered practical classifications for their own use, with individual advantages and disadvantages. The Waste Flow Diagram applies the lowest level of granularity mainly to enable a rapid assessment method as a first approximation of plastic leakage into the environment. Regarding data interoperability ISWA PPC showed the most practical level of detail (medium low) among the reviewed frameworks and could be used as a reference typology, if existing data from different frameworks with a higher level of detail have to be compared on a common basis. The disadvantage of the ISWA PPC is that it only focuses on plastics and that it will limit data interoperability to its level of detail. For the future GPML DHM offers a clear structure and stringent system of classification based on clear characteristics at a high level of detail. It will also allow a high level of interoperability if comprehensively applied worldwide. The disadvantage is the comparably higher amount of effort to classify each object. Here digital tools, as applied by (Marine) Debris Tracker, DFKI APLASTIC-Q and Litterati, could be of great help.

c. **Possible corresponding pairs between the typologies, which would enable to 'translate' datasets from one framework into another framework:**

- Since only a few directly corresponding objects (e.g., bottles, lids, wrappers) were listed in more than one framework, direct 'translations' of the majority of objects between the frameworks were generally only possible from a framework with a higher level of detail to a framework with a lower level of detail (see above, under b): ISWA PPC). To enable full data interoperability the core information of each litter object (e.g., pictures) would be required as a common ground, followed by the individual classification of each framework.

In addition, it is important to mention that each framework collects not just data on the litter objects and materials. Typically, additional data is recorded, like data source, quantity, location, time, or even weather and item brand. To enable full data interoperability, it is crucial to register the same parameters for each detected litter object. Based on our case study we recommend the following essential mandatory core parameters:

- Item: Object, material, quantity
- Location: region, country (ideally latitude & longitude)
- Time: timestamp
- Other: Data source and registering organization

This comparative analysis helped us to gather crucial insights to form a robust classificatory framework. We used our classificatory framework to draft the harmonization of raw data samples gathered from PREVENT members and other actors in the network.

**Step 2: Litter Monitoring Dashboard Example**
Next, we created a synthetic dataset and visualized the data with Tableau (see Figure 3) – a data visualization software. For the dataset creation, we used primary data from PREVENT members where possible and filled the gaps with assumptions. The density of relevant information in the dashboard shall empower waste management coordinators to easily pinpoint hotspots and derive conclusions. This streamlined approach to decision-making could ultimately save time, resources, and money. In addition, data-driven decision-making can meaningfully improve the efficiency and effectiveness of waste management interventions. Going forward, we encourage practitioners to further align their dashboards with the digital platform hosted by the Global Partnership on Plastic Pollution and Marine Litter (GPML)[6].

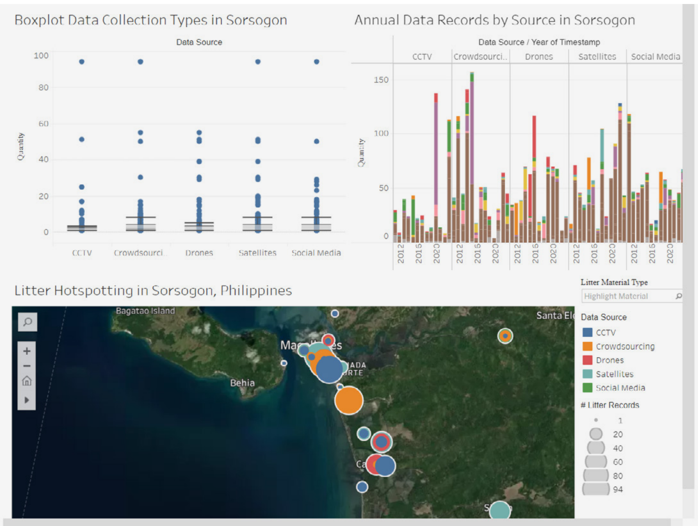



**Figure 3**: Marine litter monitoring dashboard example for municipal decision-makers. The displayed data is only partially based on reality and is only used for illustration purposes. You can access the dashboard here: https://public.tableau.com/app/profile/dominic.santschi7935/viz/LitterMonitoringCockpit/Story.

**Step 3: Chatbot for Knowledge Base Interaction**
Lastly, we created a digital knowledge management system in the form of a chatbot to enable interaction with our classificatory framework which is still in a piloting phase. For this purpose, we tested different platforms and compared the advantages and disadvantages for each of the tested technologies (Table 4). The contents of this chatbot include information about data interoperability, specifically in the context of marine litter monitoring. Moreover, the chatbot provides details about a standard process model for data mining and the role of inter-system connectors in communication effectiveness. Furthermore, it also provides a Toolbox for practitioners and the potential benefits of data mining and data understanding in solving specific problems.

[6] The GPML platform aims at hosting all the tools waste management practitioners need for (marine) litter management in one digital place. The platform is available under: https://digital.gpmarinelitter.org/

**Table 4**: Comparison of different digital knowledge management systems.

| | DanteAI | Voiceflow | OpenAI | HuggingFace | AzureCoPilot |
|---|---|---|---|---|---|
| **Notes** | Cloud-based software-as-a-service (SaaS) chatbot solution with easy access to different large language models (LLMs) and easy web deployment | Online provider of chatbot services and automated workflows | Custom GPTs allow for simple custom knowledge base powered by the leading OpenAI models | Open Source Platform for development and deployment of machine learning (ML) and artificial intelligence (AI) models and applications | Microsoft's cloud-based suite for development and hosting of chatbots on Azure services |
| **Pros** | • Easy web deployment<br>• Easy access to various LLMs<br>• Built-in conversational chatbot (i.e, thematic follow-up questions) | • Easy web deployment<br>• Access to various LLMs<br>• Customization of conversation flow and option to trigger backend workflows | • Built-in user interface (UI)<br>• Default integration with OpenAI LLM<br>• Simple setup and feeding-in of custom knowledge | • Free use and setup<br>• Full customization potential – can allow for document upload<br>• Hugging Face is very established in developer community | • Trusted brand and security standards<br>• Full customization potential – can allow for document upload<br>• Microsoft Azure is very established in developer community |
| **Cons** | • No document upload<br>• Limited customization options (e.g., server location cannot be chosen) | • Requires some coding (low-code)<br>• No document upload | • Restricted access to the chatbot (only to GPT Plus users)<br>• No conversational flow / follow-up questions | • Requires coding and repository setup<br>• No built-in user interface (UI) | • Requires coding and setup of resources<br>• No built-in user interface (UI) |

# 3 Toolbox

## 3.1 Overview

Our Toolbox starts with an emphasis on data mining and continues with further guidance for data interoperability. Data mining plays an important role in data preparation and data interoperability testing. Most data scientists invest a large proportion of their time in the data mining process before they can start analytics and data science projects. Hence, the time invested in data interoperability could be substantially reduced thanks to more efficient data mining. The CRISP-DM standard process model presented in this Chapter helps practitioners streamline data mining.

By harnessing efficient data mining via CRISP-DM, we lay the foundation for data interoperability. The analysis and modeling of the prepared data help inform the implementation of the inter-system connector (e.g., an API[7]). The connector plays an integral role in the communication effectiveness between the different data. After the successful setup of the connector, the collaborating entities should monitor the flow of information and continuously assess the associated costs and benefits. These insights will ultimately inform the business understanding, which restarts the interoperability process cycle (see Figure 4).

## 3.2 Establish the Context

We informed our Toolbox with the Cross Industry Standard Process for Data Mining (CRISP-DM). CRISP-DM is a process model that suggests six sequential phases (see Figure 4). Table 5 provides a step-by-step application example of CRISP-DM for litter monitoring data interoperability. In this paper, we integrated Phases 1-3 into this sub-chapter. Phases 4-6 are discussed in the subsequent sub-chapter on data interoperability testing.

1. **Business Understanding:** What is the specific problem we want to solve? How could more and/or better data provide a solution? What is the business case behind the project?

2. **Data Understanding:** What are the properties of the data we have? Do we need anything else (more data, better data, more context)? Is the data clean and are the semantics clear?

3. **Data Preparation:** How do we organize the data for analysis and further use? Do we have to harmonize the semantics of different data sources? What would be the consequences of harmonizing semantics?

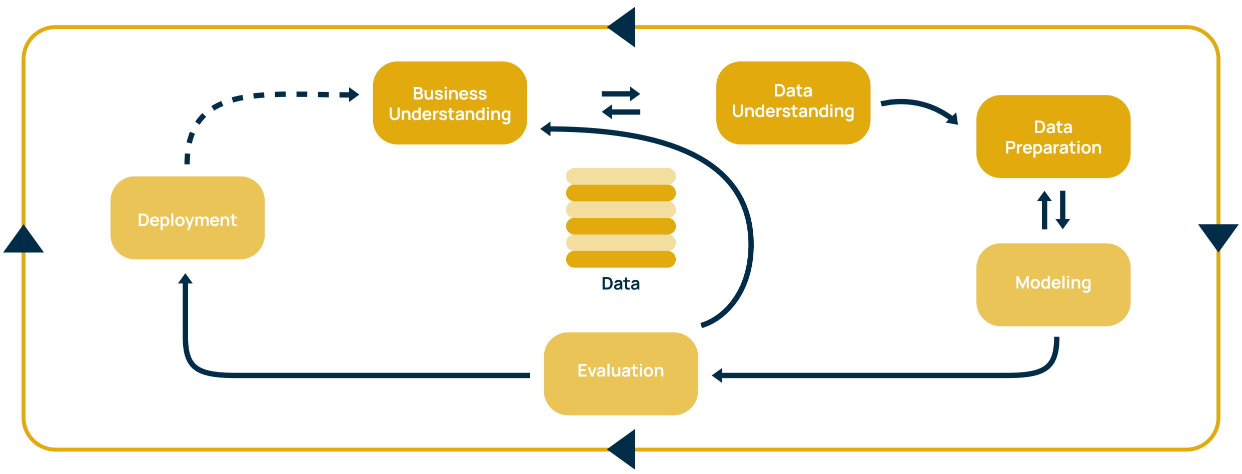



Figure 4: CRISP-DM Framework with a focus on establishing the contextual foundation (Image credits: Datasolut & Data Science Process Alliance)[8]

[7] Application Protocol Interface (API)
[8] Retrieved from https://datasolut.com/crisp-dm-standard/ and https://www.datascience-pm.com/crisp-dm-2/ (Accessed May 13th, 2024)

**Table 5**: Establishing the context via business understanding, data understanding, and data preparation. Based on CRISP-DM.

**Example:** We informed the Toolbox with practical experience gathered from our data interoperability pilot project for litter monitoring and insights from PREVENT members.

### 1. Business Understanding

- **What is the specific problem we want to solve?**
  The core issue at hand is the lack of interoperability among litter monitoring data collected by various organizations. This fragmentation hampers effective analysis, hindering the development of comprehensive strategies to combat litter. Tools such as mind maps and SWOT analyses can be employed to clearly define this problem, identifying key areas where data integration can lead to significant improvements. For example, using mind maps to visualize the landscape of existing data collection efforts can help identify overlaps and gaps in data coverage, while SWOT analyses can assess the strengths, weaknesses, opportunities, and threats related to data integration efforts.

- **How could more and/or better data provide a solution?**
  Enhancing the quality and quantity of litter data can significantly improve detection, analysis, and mitigation strategies. Implementing standardized data collection methods and leveraging advanced data analytics tools, like Big Data platforms and AI-driven insights, can unveil patterns and trends that are otherwise obscured. For instance, using open-source tools like Apache Hadoop for handling large datasets or TensorFlow for analyzing image data of litter can lead to more effective and targeted cleanup operations, policymaking, and awareness campaigns.

- **What is the business case behind the project?**
  The business case for harmonizing litter monitoring data revolves around the potential for cost-effective mitigation strategies, enhanced environmental protection, and sustainable business practices. By leveraging a unified data platform, companies can optimize their operations, reduce cleanup costs, and demonstrate corporate social responsibility, thereby enhancing their brand image. Tools like cost-benefit analyses and ROI calculators can be instrumental in quantifying the financial and environmental benefits of the project, making a compelling case to stakeholders.

### 2. Data Understanding

- **What are the properties of the data we have?**
  Understanding the properties of existing litter data involves examining its volume, variety, velocity, and veracity. Tools like data profiling and exploratory data analysis (EDA) in Python or R can help assess these properties. For example, Python libraries such as Pandas for data manipulation and Matplotlib for visualization can provide insights into data distributions, missing values, and potential outliers, informing the subsequent steps of data cleaning and preparation.

- **Do we need anything else (more data, better data, more context)?**
  Identifying gaps in the current data set is crucial for comprehensive litter monitoring. This may involve seeking out additional data sources, enhancing data quality, or incorporating contextual information that can enrich the analysis. Tools such as data cataloging software and metadata management platforms can aid in this assessment, helping to map out existing data sources and identify areas where supplementary data or context is needed.

- **Is the data clean and are the semantics clear?**
  Assessing data cleanliness and semantic clarity is essential to ensure reliable analysis. Data cleaning tools and semantic technology, like ontologies, can be employed to address these challenges. For instance, the Environment Ontology (ENVO) can provide a standardized vocabulary for describing (marine) environments, improving the semantic interoperability of data. Additionally, data-cleaning libraries in Python, such as Pandas and NumPy, can be used to handle missing values, duplicate entries, and inconsistent formats.

**3. Data Preparation**

- **How do we organize the data for analysis and further use?**
  Organizing data for analysis involves structuring it in a way that facilitates easy access and computational efficiency. This can include the creation of data warehouses or the use of data lakes for storing raw data in a more flexible format. Tools such as Apache Hadoop for distributed storage and Apache Spark for processing can be instrumental in handling large volumes of data, enabling scalable analysis and the application of machine learning models.

- **Do we have to harmonize the semantics of different data sources?**
  Harmonizing the semantics of different data sources is critical for ensuring that data is interpretable and comparable across datasets. This can involve aligning data formats, units of measurement, and classification schemes. Ontology management tools, such as Protégé, can facilitate the creation and application of common vocabularies and standards, ensuring that data from diverse sources can be integrated and analyzed cohesively.

- **What would be the consequences of harmonizing semantics?**
  Harmonizing semantics can lead to improved data quality, enhanced interoperability, and more reliable analytics, ultimately resulting in more effective litter monitoring and mitigation strategies. However, it also requires significant upfront investment in terms of time and resources to establish and maintain standardized data models. The long-term benefits include facilitating data sharing and collaboration across organizations, reducing redundancies, and enabling more sophisticated analyses and predictive modeling efforts.

## 3.3 Explore Data Interoperability

Building upon the established context, we continue with data analyses, before we evaluate the outputs and prepare the deployment of the inter-system connector. As visualized in Figure 5, these steps are informed by the business understanding, data understanding, and data preparation performed in the previous sub-chapter. Table 6 continues with the step-by-step application example of CRISP-DM for data interoperability in litter monitoring.

4. Modeling: What analyses do we want to perform on our dataset? What should be the end outcome of our modeling? What modeling techniques should we apply and why?

5. Evaluation: What are the results obtained from the data analysis? How do these results inform our modeling? Which model best meets the business objectives? Can we address the problem defined in Step 1? How do the actual business case and data mining outcomes differ from reality?

6. Deployment: How do stakeholders access the results? How can we measure and monitor the outcomes/impact of the data mining process?

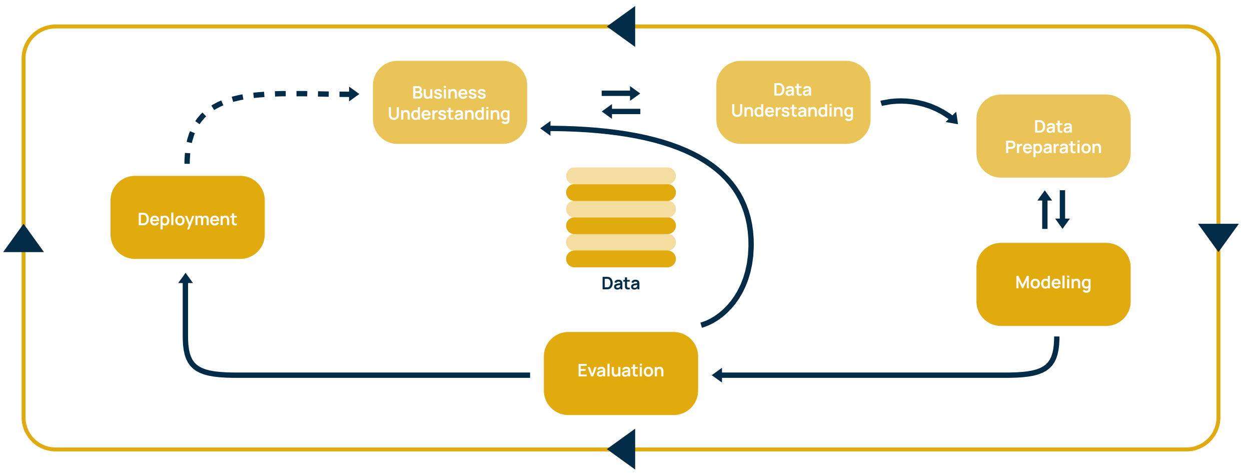



Figure 5: CRISP-DM Framework with a focus on data interoperability testing
(Image credits: Datasolut & Data Science Process Alliance)

**Table 6**: Testing data interoperability via data analyses, modeling, evaluation, and deployment. Based on CRISP-DM.

**Example (continued):** We informed the Toolbox with practical experience gathered from our data interoperability pilot project for litter monitoring and insights from PREVENT members.

### 4. Analysis & Modeling

- **What analyses do we want to perform on our dataset?**
  The analyses aim to identify patterns, trends, and correlations within litter data to inform mitigation strategies. Techniques like time series analyses for tracking litter accumulation over time, spatial analysis for identifying hotspots, and predictive modeling to forecast future litter scenarios could be employed. Tools like Python for scripting, libraries like Pandas for data manipulation, and Matplotlib for visualization, alongside spatial analysis tools such as QGIS or ArcGIS, can be utilized to conduct these analyses effectively.

- **What should be the end outcome of our modeling?**
  The end outcome of the modeling should be predictive models that can accurately forecast litter accumulation and distribution, alongside models that can classify litter types based on various characteristics. These models should enable stakeholders to make informed decisions on resource allocation for clean-up efforts, policy formulation, and preventive measures. The use of AutoML platforms like Google AutoML, Dataiku, or DataRobot could simplify the development of these models, making them accessible to users with varying levels of expertise.

- **What modeling techniques should we apply and why?**
  Techniques such as regression analysis for prediction, clustering for identifying patterns among litter types, and neural networks for image recognition tasks (to classify litter from photos) should be applied. These techniques are chosen for their ability to handle complex, non-linear relationships inherent in environmental data. Python's sci-kit-learn offers a wide range of algorithms for regression and clustering, while TensorFlow or PyTorch is ideal for developing deep learning models.

### 5. Evaluation

- **What are the results obtained from the data analysis?**
  The results may include identified hotspots of litter accumulation, trends over time indicating an increase or decrease in litter types, and predictive insights on future accumulation patterns. Visualization tools like Tableau, Power BI, or Python's Seaborn can help in presenting these findings effectively, providing clear insights into the litter situation.

- **How do these results inform our modeling?**
  These results inform modeling by highlighting specific features and variables that are most predictive of litter patterns, necessitating their inclusion in predictive models. They also indicate model adjustments needed to improve accuracy, such as tuning hyperparameters or choosing more complex algorithms for better prediction capabilities.

- **Which model best meets the business objectives?**
  The model that best meets the business objectives balances accuracy with interpretability, allowing stakeholders to understand the factors driving litter accumulation. Models with the best predictive performance and ability to inform actionable strategies for mitigation and prevention are preferred. Model selection is informed by evaluation metrics like precision, recall, and the area under the so-called Receiver Operating Characteristic (ROC) curve.

- **Can we address the problem defined in Step 1?**
  This step assesses whether the developed models and analyses effectively address the initial problem of improving litter monitoring and management. Success is measured by the models' ability to inform impactful mitigation strategies, policy formulation, and resource allocation.

- **How do the actual business case and data mining outcomes differ from reality?**
  This evaluation compares expected outcomes, such as reduced litter or more efficient clean-up operations, with actual impacts observed post-implementation. Discrepancies highlight areas for model refinement or the need for additional data inputs to better align predictions with real-world outcomes.

**6. Deployment**

- **How do stakeholders access the results?**
Results should be made accessible through user-friendly interfaces like web dashboards or reports that provide interactive visualizations and actionable insights. Platforms like Microsoft Power BI, Tableau or custom web applications developed using frameworks such as Django (Python) can facilitate this access, ensuring stakeholders can easily interpret and act on the data.

- **How can we measure and monitor the outcomes/impact of the data mining process?**
Measuring and monitoring the impact involves setting up key performance indicators (KPIs) related to litter reduction, such as decreased litter in identified hotspots or successful prediction of accumulation trends. Continuous monitoring through automated reporting and alerting systems can help track these KPIs over time. Tools like Google Analytics for web dashboards or integrated feedback mechanisms in apps can provide ongoing assessment of the data mining process's effectiveness and impact.

# 4 Recommendations

## 4.1 For Organizations

Organizations can benefit from data interoperability in various ways. Generally, an interoperable approach contributes to effective and efficient use of data, breaking silos across organizational units and institutions. For-profit organizations can harness data interoperability to elevate their business value, products, and services. Non-profit organizations can amplify their impact and strengthen their measurement, reporting, and verification capacity. For the assessment of data interoperability potential, the data-driven culture matters more than the organizational setup. Hence, for any organization, the start to data interoperability is the start to becoming a data-driven organization.

Despite their focus on data, modern organizations strengthen inter-human relationships and encourage the human-assisted exchange of information to remain. This hybrid form of communication design - technological exchange supported by human contextualization - is a crucial enabler of effective data interoperability. Without human involvement, the sender and receiver forego the opportunity to establish more resilient relationships. For instance, Company A may not benefit as much from an automated data exchange with Company B (despite interoperable data), compared to engaging in inter-human communication to explore a more holistic partnership. Therefore, we encourage PREVENT members and other organizations to prioritize personal relationship building over fully automated information exchange projects.

## 4.2 For Municipalities and Cities

Data interoperability also supports the public sector, particularly on the municipality and city level. These public sector actors are often responsible for the urban planning and waste management services in their region. As a result, they seek data to inform their investments and non-financial resource allocation. Thanks to better and more data, urban environments can turn into smart cities. A smart city relies heavily on intelligent technology, including machine learning and AI data, with connected sensors, intelligent devices, and IoT networks that fully integrate urban infrastructure, security, housing, transportation, and public services.

Unfortunately, most municipalities and cities find it difficult to boost connectivity, due to restricted access to high-quality data. To elevate this status quo, collaborations with data-driven organizations provide various benefits for municipalities and cities. On the one hand, local councils can access external information to fill gaps in their monitoring data. Furthermore, diverse data sources allow for more sophisticated verification of internal data. On the other hand, public sector actors can benefit from data interoperability by sharing selected data with data-driven organizations. The marketing of such information to data-driven organizations could turn into a new revenue stream for the public sector.

To enhance litter monitoring efforts, we further advise municipalities and cities to adopt a collaborative and data-centric approach. This entails not only sharing data but also actively seeking support from data-driven companies that specialize in innovative solutions for environmental challenges. Such partnerships can significantly enhance the efficacy of litter detection and management strategies.

Additionally, there is a pressing need to focus on capacity building for data literacy. Municipalities should invest in training programs that empower individuals to effectively utilize data and tools, enabling them to explore and innovate in the field of litter detection. By adopting these recommendations, municipalities and cities can significantly improve their response to litter, leveraging the power of data and collaboration to create more sustainable and cleaner environments.

## 4.3 For PREVENT Members

Furthermore, we encourage members of the PREVENT network to foster cooperation amongst themselves, sharing data and contributing their unique expertise, routines, and capacities to the Toolbox. This Toolbox can serve as a central repository of knowledge, techniques, and resources, facilitating a unified approach to tackling (marine) litter.

# 5 Outlook

In November 2023, leaders from the INC confirmed the importance of litter measurement and monitoring data. The inclusion of tracking data into the envisioned global agreement to combat plastic pollution by 2024 would create additional incentives for data collaboration initiatives.

To prepare for impending legislation and strengthen their value proposition, PREVENT members are well-advised to foster data interoperability and data collaborations. Thanks to more and better data, PREVENT members will be ideally equipped to support the private and public sectors with transparency services. However, before we reach the full potential of such collaborative services, we need additional learnings and success stories. The PREVENT Secretariat and the digitalization project team will make sure that the Toolbox presented in this discussion paper will be updated accordingly. In the meantime, we invite members to join our pilot project on data interoperability.

Data interoperability will be crucial to achieving precise litter monitoring and monitoring data. Improved precision will only emerge over time and should be seen as a journey instead of an end point. On this journey, the discussions within the PREVENT working groups have highlighted the urgent need and potential for further harmonization and collaboration. To provide the foundation for enhanced collaboration, PREVENT will continue to pursue its mission of connecting circular economy practitioners worldwide. A dedicated PREVENT data (interoperability) training program could be an effective means of enabling PREVENT members to a) better understand their data and b) identify opportunities for data cooperation and c) realize the value of an interoperable data approach.

Furthermore, PREVENT will sustain a strong focus on adjacent opportunities for collaboration and interoperability. We have already explored such opportunities in the Sub-Working Group for Plastic Credits, where PREVENT members harmonize their approach to quantifying and verifying plastic waste recovery initiatives [18]. Hence, various PREVENT members currently assess collaboration potential for interoperable product passports [4, 19]. These types of interoperability are essential complements to data interoperability and will support our mission towards a world without waste.

# 6 Conclusion

With the current momentum towards a data-driven economy the time is right to invest in data interoperability. As we presented in this discussion paper, data interoperability can meaningfully support private and public sector ambitions. The benefits of data interoperability are directly accessible through better and more data. However, preparing data for exchange requires a significant amount of time and resources that are not planned for in day-to-day operations. Our Toolbox provides easy access to the works of data interoperability. Practitioners can access the Toolbox to marry their data with complementary information from fellow actors in the field of litter monitoring. Beyond the Toolbox, PREVENT members can harness data interoperability to revitalize collaboration initiatives and further align their raw data formats and schemas. To realize next-level data collaboration, we invite PREVENT members to join our data interoperability pilot project for litter monitoring. Apart from this pilot project, PREVENT will continue to engage stakeholders and be a force for inclusive collaboration towards a circular economy.

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