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AI, Data and Robotics for the Green Deal (IA)

AI-powered Robotic Material Recovery in a Box

RECLAIM

D2.1: prMRF and RDG requirements and system specifications

Abstract: The current report constitutes the deliverable 2.1- prMRF and RDG requirements and system specifications for project RECLAIM which is founded by the European Commission under the program “Horizon Europe” (Grant Agreement nr 101070524). This deliverable provides an initial vision of the required performance of the prMRF and RDG and the specifications of the system components.

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List of Abbreviations

Abbreviation	Definition
AI	Artificial Intelligence
prMRF	Portable Robotic Material Recovery Facility
RDG	Recycling Data Game
PMD	Plastic, Metals, Drinking cartons
DL	Deep Learning
PET	Polyethylene Terephthalate
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
PP	Polypropylene
PS	Polystyrene
RoReWos	Robotic Recycling Workers
CSG	Citizens Science Games
RGB Camera	Red, Green, Blue Camera
HSI Camera	Hyperspectral Imaging Camera
EPR	Extended Producer Responsibility

Executive Summary

This document reports on the preparatory work that has been carried out to specify the working principles and the key functional characteristics of the technology products targeted by RECLAIM. In particular, the first months of RECLAIM focused on specifying the portable robotic Material Recovery Facility with all the machinery and high-tech components that will be installed and used in it, as well as the Recycling Data Game that will enable the wider public to participate in project activities and provide the means to increase its awareness on recycling and the circular economy.

The report provides a review of the main RECLAIM objective, namely the development of a robotic Material Recovery Facility (prMRF) tailored to small-scale material recovery. This regards a short description of the targeted problem and how it specializes in the area that the project developments will be deployed and actually assessed, the Ionian Islands.

The area specific requirements are then used to specify the functional assumptions and functional requirements of the prMRF as a stand-alone product accomplishing material recovery. Then, this is elaborated further to specify the requirements of the individual technological components (machine vision and AI, robotic material recovery and multi-robot team performance, new material gripping technology) installed in the prMRF and how they collaborate to implement the targeted task.

The last part regards the preparatory activities conducted for the design and implementation of the Recycling Data Game. In order to determine the features of an engaging game that will attract the participation of many users, a study was carried out, the process and results of which are described in this text.

1 Introduction

1.1 Purpose of the document

The main purpose of this document is to summarize the work done in Task 2.1 “Requirement analysis for prMRF and Recycling Data Game” and Task 2.2 “prMRF & Recycling Data Game specification and design”. This regards the collection of data about the requirements and specifications for each component of the portable robotic Material Recovery Facility (prMRF) and the initial requirements to develop the Recycling Data Game (RDG). Moreover, this document has the function of explain the actual context for the waste management in the Ionian Islands, Greece and set the ground for the deployment/assessment of RECLAIM developments in this particular area.

Additionally, this document will serve as a starting point and reference for the development of the prMRF and to ensure the communication and coordinated work between the different project partners. In particular, to enhance the interdependent and cooperative functionality of the components installed in the prMRF, the current document summarizes their individual working assumptions, and provides a view of how the integrated system would perform.

Following the above the current deliverable will be used as a point of reference for RECLAIM partners and the components they are developing, in an attempt to align the planned work and facilitate future integration activities.

1.2 Intended readership

The report, describing the specification of productivity, is a sensitive (SEN) document. Its readership is considered to be the European Commission and the consortium with minimum unnecessary disclosure of information outside the RECLAIM project. Only the Project Officer the reviewers and project partners involved in the RECLAIM consortium can have access to the document.

1.3 Relationship with other RECLAIM deliverables

This deliverable is related to all follow-up technological deliverables of the RECLAIM project. This deliverable works as a start point for the components of the prMRF, describing the performance assumed for the equipment and the different operational requirements. Because of this connection this deliverable is related with the other deliverables in which the different components of the prMRF are involved.

Table 1: Other RECLAIM deliverables related.

Del. No	Deliverable Name	WP	Month
3.1	Material recognition based on RGB and Hyperspectral imaging	WP 3	M18
3.2	prMRF operation monitoring and repeating advancement	WP 3	M30
4.1	Gripping mechanisms and RoReWo units for material recovery	WP 4	M18
4.2	Multi-robot/multi-gripper RoReWo-Team configuration	WP 4	M30
5.1	Early prMRF development based on available enabling technologies	WP 5	M9
5.2	Preliminary assessment of prMRF performance	WP 5	M18
5.3	Final assessment of prMRF and sustainability plan	WP 5	M36
6.1	Waste Data for material recognition and Recycling Data Game	WP 6	M9/M18
6.2	Algorithms and pipelines for Recycling Data Games	WP 6	M9/M18 /M30
6.3	Assessment of the Recycling Data Game	WP 6	M18/M36
1.3	Final Project Report	WP 1	M36

2 Context

2.1 European context

Besides the fact that many large-scale Material Recovery Facilities (MRFs) have recently been equipped with AI and robotics that enable smart and automated material recovery, the transportation of post-consumer waste to these plants is costly and makes material recovery more difficult due to the compression of waste during transport. Clearly, there are several cases far away from the urban centers where waste treatment needs are not efficiently catered for by this model. For example, transport hubs produce locally high volumes of waste, high popularity social events do the same with the additional characteristic of short production time, islands and other touristic destinations suffer from seasonality that greatly affects population density and consequently waste production. In all these cases the installation of stationary waste sorting stations is impossible/impractical, but at the same time the transportation of fresh, high-quality waste to MRFs by using garbage trucks degrades the collected items and makes it difficult to sort them into different material categories.

To tackle this issue, RECLAIM will develop the, globally first, “portable, robotic MRF” (prMRF) that will be capable of significantly enhancing local-scale material recovery activities providing them with industrial-level efficiency.

In the context of RECLAIM, the prMRF will be deployed in the group of Ionian islands, Greece that provide the opportunity to assess its performance in complementary use-case scenarios. The Ionian group consists of seven main islands being very popular tourist destinations. All islands face major difficulties in waste management especially during the summer period (Satta, A. 2004).

In fact, the problems discussed about the Ionian Islands are found in almost the entire Mediterranean coast. Many areas in the Mediterranean have very high population density changes, which increases the variability in the size of waste to be processed for material recovery, thus making it difficult to develop a plan that is universally applicable all year round (Ariza et al 2008). Moreover, there are winter destinations that face the same waste management problems caused by the high number of visitors. Besides population variability, there are several isolated, difficult to access areas across Europe, with increased monthly costs for transporting waste to centrally installed prMRFs.

RECLAIM integrates state of the art AI, data and robotic solutions for the development of the first prMRF which is transferable to the areas of interest to accomplish local scale material recovery. The development of low cost, portable, easy to install and increased productivity prMRF will, in the future, enable the use of distributed prMRF-fleets that will achieve full material recovery anywhere, even in the most remote areas.

2.2 Local context

The Hellenic Recovery Recycling Corporation (HERRCO) is the result of an initiative taken among Greek companies active in the packaging production and trading of packaged goods, aiming to effectively meet their legal obligation for the recovery and recycling of packaging waste deriving from their products, through the administration of their funds, within the framework of the National and European legislation. To respond to the above requirements,

HERRCO has developed and implemented in Greece the national Collective Alternative Management System – RECYCLING (CAMS – RECYCLING) as approved by the competent authorities, known widely as Extended Producer Responsibility (EPR) scheme.

HERRCO is a non-profit organisation that constitutes an exceptionally successful example of collaboration among local packaging producers placing their products in the Greek market, packaging importers and Local Authorities that are legally bound for the collection and recycling of the municipal packaging waste.

The collection and recycling of the packaging waste in the Ionian Islands is currently implemented through HERRCO's established activities with the collaboration of the local Municipalities and Intermunicipal Authorities.

The so-called "blue bin" is the key element in the relevant recyclable collection activities. The blue bins are used to collect and temporarily store the municipal packaging waste disposed of by the residents. The targeted materials that fall into the blue bins are post-consumer packaging waste consisting of paper, plastics and metals. The purpose of the blue bin is the commingled collection of the above categories of materials in a single point, which makes easier the participation of the residents in the municipal recycling activities. A variant of this approach is found on the islands of Zakynthos, Kefalonia and Ithaca where the implementation of two streams, (i) paper packaging and (ii) PMD that includes plastics, metals and drinking cartons has been chosen. In all cases, a separate network of glass bells has been installed to accomplish the early separation of glass from the materials collected in the blue bin. In the coming months these separate glass networks are scheduled to operate in all the Ionian Islands with the exception of Paxos (Lefkada started and Kefalonia – Ithaca is also scheduled to start in 2023). The following table summarizes the scheduled collection streams in Ionian Island.

Table 2: Temporary storage networks in Ionian Islands in 2023.

ISLAND	BLUE BIN	PAPER BIN	PMD BIN	GLASS BIN
Corfu	✓	×	×	✓
Paxos	✓	×	×	×
Lefkada	✓	×	×	✓
Kefalonia	×	✓	✓	✓
Ithaca	×	✓	✓	✓
Zakynthos	×	✓	✓	✓
Kythera	✓	×	×	✓

The specific characteristics and the diversity of the Ionian Islands in terms of terrain, human geography, statistics, economics, etc., dictate the variations of the recyclable collection and processing methods that are followed in the region. On the larger and densely populated islands (Corfu, Zakynthos) local sorting facilities have been built and operate, while on the other islands (Paxos, Lefkada, Kefalonia, Ithaca, Kythera) the collected packaging waste are transferred to the mainland facilities for sorting mainly due the lack of adequate quantities to justify the installation of local sorting facilities.

3 Field requirements

Besides the intention of RECLAIM to develop an all-purpose prMRF that is applicable in a range of different locations and circumstances, the particular needs of Kefalonia will provide the driving force for the development and installation of the prMPF to be based on real world constraints and operational requirements. In fact, it is expected that the focus on Kefalonia will substantially strengthen the application potential of prMRF beyond RECLAIM.

Following the above, prior to the design and the implementation of the prMRF, we examine the material recovery characteristics of the waste processing stream in Kefalonia island. As mentioned in the previous chapter, HERRCO is the national EPR scheme that is responsible for the organization, in collaboration with the local Municipalities and Intermunicipal Authorities, of the collection, recovery and recycling of packaging waste in Greece, and therefore it has very good knowledge of the relevant project that is currently in operation in Kefalonia.

The permanent population of Kefalonia amounts to 35.801 residents and it nearly doubles in the summer. As designed by HERRCO and the local authorities, Kefalonia follows a recyclable collection model that assumes three streams of packaging waste one for paper, one for glass and one for PMD materials (plastics, metals, drinking cartons).

The collection of the paper and the blue bins that target PMD is operated by the Intermunicipal Authorities with three (3) 15-16 tones collection vehicles. The composition of the materials resulting from a recent analysis in the classic blue bin stream is as follows:

Table 3: Blue bins collection composition in Kefalonia.

Recovered Materials	**% Synthesis of blue bin in Kefalonia**
Packaging Paper/cardboard	33,95%
Printed paper	11,16%
Drinking Cartons	0,71%
Plastics packaging	13,94%
Metals packaging	3,4%
Glass packaging	3,47%
Other non-packaging recovered materials	0,62%
Residue	32,75%
Total	100,00%

In the context of RECLAIM, the waste stream that will eventually be sent at the prMRF for treatment and material recovery will focus on PMD, in other words, the blue bin. The targeted packaging materials from this stream are the following:

- Plastics
  - PET bottles (e.g., transparent and colored water bottles, beverage bottles, transparent and colored PET containers)
  - HDPE Bottles (e.g., household detergent bottles including secondary)
  - LDPE Film (e.g., carrier bags, large pieces of LDPE, sacks)

        - PP/PS (e.g., yogurt cases, margarine bowls, crates, big bags including secondary components such as lids, labels, etc./packaging of disposable cups and plates)
    - Ferrous (e.g., beverage and food containers)
    - Aluminum cans (e.g. soft drink cans)
    - Drinking Cartons (packaging of milk, juice etc.)

The collected targeted packaging materials (from PMD stream), will be deposit on a concrete area, where manual preprocessing will be held by ION to ensure that all bulky objects are removed from the material feeding the prMRF, thus ensuring continuous and damage free operation of the automated sorting equipment.

HERRCO will carry out quarterly composition analysis of the incoming materials to provide information regarding the effect of seasonality on the input stream.

4 prMRF Requirements

Following the RECLAIM Grant Agreement, the main objective of what we call the "prMRF" is the implementation of a portable, fully automated mini Material Recycling Facility that can be easily transported to any location in the world to enable material recovery at a local scale. To this end, the entire prMRF equipment will be installed in a common container, to be easily transported and deployed to the sites of interest.

The design of the prMRF considers the waste management conditions in the island of Kefalonia and the three different use-cases, material recovery from mixed recyclables streams[1], cleaning of material-specific streams[2] and immediate close to source material recovery[3]. In order to have a good fit with the local waste treatment requirements. HERRCO, being the main responsible for material recovery from municipal packaging waste in Kefalonia, has largely contributed in specifying the operational requirements of the prMRF, with the close and active support of all RECLAIM partners. The compiled list of prMRF requirements is summarized in Table 4, and has been used to set the framework for implementing the prMRF.

Table 4: Functional requirements for prMRF.

Requirement	Comment on functionality
Quality of input material	PMD Recyclables (according to the specifications of the "blue bin")
Material pre-processing	Guarantee there are no bulky objects that may damage the equipment. Ensure quality requirements of input material
Material pre-processing installation	Use a vibrating distributor, which removes dirt and spreads recyclables on the conveyor belt. It is important to minimize vibration of the prMRF due to the vibrator.
prMRF processing capacity/h	340 Kg/hour, approximately 10000 items/hour
Conveyor belt width	Facilitate minimum overlap of materials
Conveyor belt speed	Facilitate minimum overlap of materials
Number of expected materials types	Targeted packaging materials (PET, HDPE, PP, PS, PE film, Drinking Cartons, ferrous, non-ferrous metals) and non-targeted materials that will be either pre-sorted or left to residue.
Number of recovered material types	Targeted packaging materials: PET, HDPE, PP, PS, PE film, Drinking Cartons, ferrous, non-ferrous metals
Number of installable grippers	At least three (softcup, hard cup, pneumatic fingers, mechanical, etc.)
Input stream synthesis	Able to handle variable material compositions
Robot roles	Adjustable according to input composition

[1]In this case prMRF will treat mixed recyclable waste streams (PMD), preforming positive separation of multiple types.

[2]In Corfu the citizen-powered separation of recyclables is promoted, which assumes the use of multiple material-dedicated bins. In this case, prMRF will preform a negative separation to remove impurities.

[3]In this scenario RECLAIM will exploit the portability of prMRF, processing waste from an event to which the equipment will be moved.

Requirement	Comment on functionality
Multi-robot orchestration	A central processing unit to distribute tasks to robots
Hyperspectral monitoring	Use material-specific spectral signatures and features
RGB monitoring	Use appearance specific material features
Power requirements /KW	<30 KW
Eco-friendly operation	30% green
prMRF mobility	Container installation
prMRF deployment time	Target: 1 day, max 2 days
prMRF operation	Fully automated, no people in the container
Max number of workers in prMRF	0
Press operation	Manual / human operated
Max number of workers outside prMRF	3
On the fly robot maintenance	Robots accessible through prMRF windows
Daily prMRF maintenance	At the end of the shift, all prMRF equipment stopped
Demo operation	Material looping
Visitor view	Make visible through windows the robot subgroups, the magnet, and if possible the cameras.

5 Design and implementation of the prMRF

5.1 Overview of the prMRF

Since the first month of RECLAIM, the consortium focused on the design of the prMRF taking into account both the achievement of the project objectives outlined in the GA and the timeline of a realistic implementation plan that will be executed without delays, as prMRF is a prerequisite for many technologies to be explored and improved in the project. All partners provided their experience from relevant previous projects, to highlight critical details regarding the design of the prMRF, so that all the functional requirements summarized in the previous section are adequately addressed.

The prMRF housing will actually be implemented as a standard container box partially modified to improve the efficiency of the bounded/limited space available in the container. Inside, the prMRF will host (i) ordinary mechanical waste treatment equipment to feed, distribute and convey recyclable waste along the prMRF, (ii) a combination of RGB and hyperspectral cameras to monitor the input stream and make decisions on the individual recyclables, (iii) a number of autonomous robots, the so called “Robotic Recycling Workers (RoReWos)” to recover recyclables in material-specific bins.

The prMRF will be fed using a hopper that will help placing a batch of mixed recyclables (typically the content of a blue bin) on a conveyor belt, at a rate specified by the user. Then, by using an inclined belt recyclables will be conveyed to the height of the prMRF input door.

At the prMRF, the incoming stream of recyclables will be received by a vibrator that aims to uniformly distribute objects over the whole width of a forward moving belt. This is the main belt that spans almost the entire length of the container to convey recyclables and enable autonomous material recovery and sorting. A short distance after the vibrator, where it is expected that recyclables will have stabilized their location on the belt, the Hyperspecrtral Imaging (HSI) camera will be installed, followed by the first RGB camera. The two cameras will continuously scan the objects conveyed by the belt to identify, localize and categorize objects of interest for recovery that will be registered as picking targets. Next, the first group of RoReWos (in particular, three Cartesian Robot 1.5axis line-pickers, see section 6.2.2) will be installed above the conveyor belt to perform material recovery and sorting. The first RoReWo group will be followed by a magnet that provides robust recovery of ferrous metals.

Then, a second RGB camera will be used to scan again the objects on the conveyor belt (less object overlap is expected at this stage) to re-identify and re-categorize the object remaining on the belt. In a short distance after the RGB camera a new RoReWo will be installed (in particular, the Cartesian Robot 2.5 axis area-picker, see section 6.2.2) to recover objects that pass within its working area. Finally, one last RoReWo will be installed close to the end of the belt (in particular, the more flexible Cartesian Robot 3.0axis area-picker, see section 6.2.2). This RoReWo will host the sophisticated grippers that will be designed and implemented in RECLAIM to deal with difficult cases of recyclable object picking.

To facilitate the demonstration of the prMRF to interested stakeholders and the wider public, a backward moving belt will be occasionally installed in the container to enable the endless looping of recyclables. For the same demonstration reasons three windows will be attached on the sides of the container to enable external observers watch the fully autonomous

operation of the individual prMRF components. An overview of the targeted prMRF configuration is provided in Figure 1.

It is necessary to note here that at the time of designing the prMRF several decisions made have aimed at avoiding harsh irreversible restrictions that, due to currently unforeseen issues, could significantly impede the follow up development steps. On the contrary, our decisions aimed at maximizing flexibility and the ability to develop fallback solutions (if necessary). In that sense, the current, globally unique, first version of the prMRF is suboptimal by design, but still very efficient and highly appropriate to showcase the operation of the prMRF and how it can support distributed material recovery, anywhere in the world.

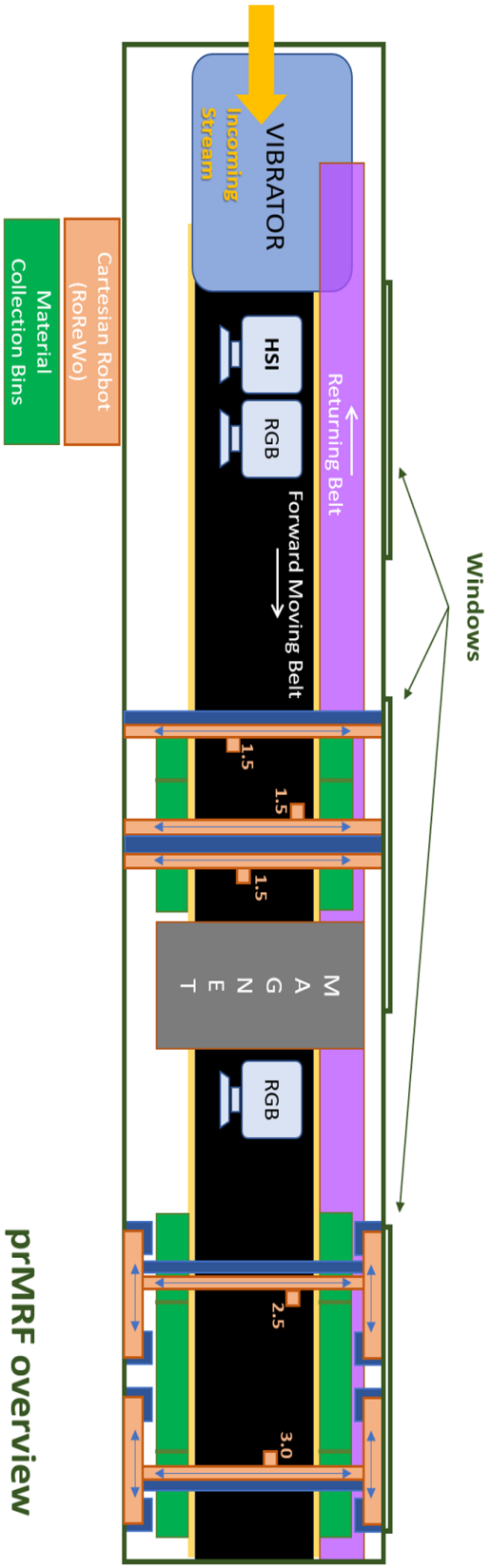


Figure 1: A sketch showing the installation of the equipment inside the prMRF, from a top view.

5.2 General operating assumptions

As noted above, the operational goals of the prMRF focus on the recovery of PMD recyclables, making the assumption that very large and bulky items that could defeat the operation of the sophisticated, high-tech equipment installed in the container, will be avoided. The early inspection of the waste stream and the occasional preprocessing of the waste will be conducted by the local crew provided by ION, which will safeguard the operational standards of the prMRF and will handle the small-scale, day-to-day requirements of the project.

Further to qualitative characteristics of the input stream, the design of the prMRF has relied on a number of operating assumptions that are listed in Table 5.

Table 5: Operation assumptions.

Operation Parameter	Min	Max	Typical	Comment
Recyclable weight (gr/item)	5	100	34	The typical weight corresponds to empty packages of the targeted materials
prMRF input (kg/hour)	100	350	340	Full sorting performance and uninterrupted operation is assumed
prMRF input (Items/hour)	5000	15000	10000	Full sorting performance and uninterrupted operation is assumed
Feeding belt speed (cm/sec)	10	40	20	To achieve feeding 340 Kg/hour
Conveyor belt speed (cm/sec)	10	50	25	To balance between material input handling and minimum material overlap
Robot productivity (picks/min)	0	45	35	100% sorting of recyclable items is targeted (occasionally, a robot may be idle because there are no items to sort)
Number of Robots	2	6	5	Given the prMRF container space limitations and project budget constraints
Items overlap %	0	50	20	To facilitate item identification, categorization and enable physical separation by the robot
Hyperspectral image processing (fps)	0.3	0.8	0.5	To ensure all items are examined and detected (after taking also into account the speed of the conveyor belt)
RGB image processing (fps)	1	5	3	To ensure all visible items are examined and detected and there is time for blending multi-modal information

5.3 Theoretical scenarios assessing the cooperation of the prMRF equipment

Clearly, the productivity of the prMRF depends on the performance of the individual modules installed in the container (robots, belts, vibrator, cameras, etc) and also on their effective

cooperation to recover the maximum number of recyclables. This means that the characteristics of the RoReWos need to comply with two key parameters of the mechanical equipment, in particular the width and the speed of the conveyor belt, which greatly affect the volume of the processed waste and the quality of material recovery.

Taking advantage of the knowhow available in RBNS and HERRCO from previous industrial robotic waste sorting applications, a key parameter that greatly affects the quality of autonomous material recovery is the distribution of recyclables on the conveyor belt. More specifically, the single-layer distribution of the waste on the belt (i.e. the minimum possible overlap between objects) is crucial for both the successful identification of objects and their successful picking without pushing and repositioning nearby materials.

To achieve single-layer distribution for a given supply of recyclables, besides the use of a vibrator that is already included as part of the prMRF feeding mechanism, there are mainly two approaches (i) to increase the width and (ii) to increase the speed of the conveyor belt. We opted for the former because a fast-moving belt would greatly increase requirements for all computational processing units in the container (e.g. hyperspectral and RGB cameras) and additionally would limit our options to only fast-moving but also high-cost robotic equipment (e.g. delta robots).

To make decisions about the optimal configuration of the prMRF equipment we have examined several "what-if" scenarios, some of them summarised in Table 6. The scenarios are related to the distribution of recyclables on the conveyor belt, and how they could affect the productivity of the RoReWo Team. Considering for example the first line, the table reads as follows. We assume we have a conveyor belt of 100cm width, which moves at a speed of 30cm/sec. That means, every second we need to monitor the content of an area being 3000cm^2. Then assuming a non-perfect distribution of recyclables on the belt with 25% overlap (close to single layer distribution) and also that the average area of a recyclable object is 400cm^2, we expect to have 5,6 recyclable objects to process every second. Then we assume that the object identification algorithm will successfully recognize and categorise 90% of the objects (this is only a conservative/realistic assumption[4]), we conclude that the whole RoReWo Team should make 5.1 picks every second. This is particularly challenging, given that existing, state of the art single robot solutions achieve in practice up to 0.9 picks/sec in real world[5] operating conditions. In other words, to have the composite prMRF achieving 5.1 picks/sec we need to have installed 5 Robotic Waste Workers working non-stop at a rate higher than 0.9 picks/sec.

Another complementary issue regards the difficulty to keep RoReWos continuously busy in a controlled and stable way. This is because of the highly dynamic composition of the waste stream, which for certain periods, may either render the robots unable to pick all available materials (i.e. too many PET bottles at a given second), or keep a RoReWo idle (i.e. no PET

[4] In fact RECLAIM targets 99% success rate in material identification and categorization

[5] Some robotic waste sorters make the claim of achieving 1.1picks/sec in controlled, laboratory setups.

bottles to pick at a given second). This practical detail may reduce the performance of the RoReWo team by about 10%, even if the actual working potential of the team remains intact.

Turning back to the conveyor belt, the RECLAIM consortium believes that selecting a wide (rather than fast) belt would better fit the prMRF operational requirements. However, from the scenarios examined in Table 6the conveyor belt with a width of 120cm actual working range would in practice be a more than 150 cm wide machine, which may introduce currently unforeseen but irreversible limitations to the installation of the equipment inside the container. Therefore, we decided to go for a 110cm wide conveyor belt which is close to the maximum width we could install in the limited and pre-specified space of the prMRF container, so that all the rest equipment fits and works properly.

Following the above decision, and the analysis of the expected RoReWo Team picking rate, the third scenario summarised in Table 6, provides a realistic summary of the average expected prMRF operation. This scenario assumes a 110cm wide conveyor belt, an average conveyor speed of 25 cm/sec, the objects being overlapped by 30%, which finally results in the assumption that the RoReWo Team should be able to recover approximately 4.3 recyclables every second.

Table 6: prMRF waste sorting scenarios

Belt Width (cm)	**Belt Speed (cm/s)**	**Processed area (cm^2/s)**	**Overlap %**	**Recyclable Size (cm^2)**	**Recyclables to sort/sec**	**Categor. Success Rate**	**Items to sort /sec**
100	30	3000	25	400	5.6	0.9	5.1
110	30	3300	25	400	6.2	0.9	5.6
110	25	2750	30	400	4.8	0.9	4.3
120	25	3000	30	400	5.3	0.9	4.8

It is necessary to note that, in addition to the RoReWo Team, the productivity of the prMRF will be further enhanced by the use of a magnet that will recover all ferrous metals. Overall, it is expected that the prMRF will be able to recover more that 5 recyclable items per second.

6 Intelligent prMRF components

6.1 Cameras

Recyclable sorting assumes the uninterrupted monitoring of the belt conveying recyclables, which need to be identified and categorised according to their material type. To this end, we will use two different types of cameras that facilitate accurate object detection and material based categorizations. In particular, we are going to use a hyperspectral imaging sensor that collects a whole spectrum in a pre-defined wavelength range at each individual pixel of an image. The wavelength operates as a spectral signature for the material type represented by the given pixel. Complementary to hyperspectral imaging RECLAIM will also employ ordinary RGB imaging to enable the segmentation and the visual identification of objects based on well known deep learning computer vision methods.

The specifications for the two cameras are summarised below.

6.1.1 Hyperspectral camera

The principle of the hyperspectral camera to be installed is to obtain the reflection spectra of the objects on the conveyor in a specific part of the spectrum, similar to Henriksen et al. (2022), Kraśniewski et al. (2021). A pushbroom scanning camera is foreseen, to take advantage of the translation of the objects. For the separation in between cardboards and different types of plastics, the spectra of interest are situated in the short-wave Infrared (SWIR) wavelengths. The part of the spectrum considered will be from 1µm up to 1.7µm.

The illumination will be performed by halogen lamps, installed on a ramp, with their light beams focused along a line. After being reflected by the object under test, the reflection spectrum is acquired by the camera and sampled along several bands of the spectrum. Comparison of the reflection ratio from the object at different wavelengths allows a fine distinction regarding the type of material which is tested.

The principle of the pushbroom camera is to acquire the image of the object along a line, perpendicular to the conveyor belt translation axis. This line is divided into several pixels and each pixel size on the object depends both on the type of camera and on the focal length of the lens installed in front of the camera. The movement of the conveyor gives the remaining dimension of the object along the conveyor belt movement. By choosing an appropriate number of frames per second, it is then possible to obtain an image keeping the ratio of the original object. For each pixel, we obtain a hyperspectral cube, in which each pixel of the image contains a sampling of the reflection spectrum.

By comparing the spectrum of each pixel with a database containing the spectra of standard materials seen inside recyclables, it is possible to sort the type of material represented inside the object. As the hyperspectral cubes are huge when it comes to memory size, specific algorithms running on GPUs are used to process the data recorded by the camera. To sort out the materials, those algorithms compare the measured spectra with previously acquired spectra.

6.1.2 RGB camera

Along with the hyperspectral monitoring of recyclables which are conveyed by the belt inside the container, an RGB camera should be installed to enable the objects to be computationally perceived in the visible domain. The use of the RGB camera is necessary mainly for the following two reasons:

- to separate between two different objects of the same material type that partially overlap on the conveyor belt and will be identified as a single unified object by the hyperspectral camera,
- to handle cases where labels of a material type different than the main material of the object is placed on the recyclable, and in that case, hyperspectral imaging would identify the actual object and the label as two separate things.

Using the images and the videos captured by the RGB camera, we plan to exploit state of the art algorithms achieving very good performance in the identification and categorization of recyclables Koskinopoulou et al. (2021), Bashkirovaet al. (2022). Furthermore, we will combine the output of the RGB image processing with the results of the hyperspectral imaging to improve the overall accuracy of the categorization.

Given that the objects will be transported on a moving belt, it is necessary that the employed camera will use global shutter technology, so that the images taken above the belt depict the objects with the maximum possible clarity, with no motion blurring. However, it is also important to consider that the algorithms searching objects in images work by scanning the entire image to identify pixel locations of interest and combine them into identified objects. This means that the use of very high-resolution images, although desirable as it provides clarity, is expected to greatly increase the computational requirements for image processing. Therefore, it is necessary to balance between clarity which requires high resolution images and real-time processing which is more easily achieved with limited resolution images.

FORTH has performed experiments with available cameras capturing images of 1MP, 2MP and 5MP resolution collecting small-scale data sets that have been used for early object identification, localization and categorization. For this experiments, a pretrained Mask R-CNN model was used, on an ordinary NVIDIA GeForce RTX 3060 Mobile GPU. Without considering the increase of the time needed for training the relevant models, the processing speed we achieved during inference with the three different image resolutions is 4fps in the case of 1 MP images, 3fps in the case of 2 MP images and 1.5 fps in the case of the 5 MP images. Following these early experiments, we decided to proceed by using the 2 MP camera, which seems to balance successfully between object identification accuracy and processing time, while also being very affordable in terms of market cost.

As mentioned above, the prMRF will host two Global Shutter RGB cameras. The first will operate in combination with the hyperspectral camera to deal with the identification and categorization of objects

6.2 Robots

The next thing necessary for the automated sorting of recyclables is the use of robots, which will undertake the selection/picking and physical separation of the objects of interest. Besides the fact that large-scale Delta robots have been typically used in industrial waste sorting we have examined several available options to identify the one that better fits the prMRF application.

In this point it is important to note that the robotic systems available in the market have not been designed and implemented with the waste treatment problem in mind. In other words the available robots are indeed efficient high-tech solutions with a perfect fit in other other industrial applications, not necessarily for recyclable separation. Within RECLAIM we are interested in investigating robotic systems with a very good fit in material recovery in terms of investment cost and productivity.

In particular, we considered several robot types, from 4 different manufacturers to come up with the one that better fits the prMRF use case.

The following paragraphs provide a brief analysis of the problem, as well as a discussion of how the characteristics of each robot fits to the given application domain, and the reasons behind our final choices.

6.2.1 prMRF operation and robot selection

As discussed in section 5.2 the operational requirements of the prMRF assume a RoReWo team configuration that will be able to make, on average, 4.3 picks /sec. Although Delta robots have largely dominated the field of robotic waste sorting, Raptopoulos et al. (2020), Leveziel et al. (2022), the RECLAIM consortium explored a wider set of available options in an effort to identify robotic system architectures with a higher “pick per invested-euro” rate.

Keep also in mind that the alternative solutions will be applied over a 110 cm wide conveyor belt that moves with average speed 25cm/sec (see Table 6, line3). Taking this into account we examined robotic systems with different architectures implemented by four different manufactures, namely ABB, FESTO, IGUS and Universal Robots. Overall, the robots we have considered for potential use in RECLAIM are summarized in Table 7, together with the key parameters we have considered for making our choice.

The ABB IRB 360 is a Delta robot with a wide working range that has already been successfully used by RBNS and FORTH in material recovery applications Raptopoulos et al. (2020), Koskinopoulou et al. (2021). This robot is clearly applicable for the task because of its very fast and accurately controlled movements that enable the use of a range of different grippers. However its long delivery time and particularly its high cost does not allow the development of multiple RoReWos working as a team for material recovery.

The FESTO 1.5axis (X-electric, Z-pneumatic) is a low cost linear robot solution that relies on using a piston to move towards the surface of the belt. The fully controlled X-axis moves the carrier of the robot vertically to the flow of the belt, at a predefined height. This robot can easily fit to the width of any conveyor belt, achieving approximately 0.84 picks per second. Its main limitations are the inability to host any other gripper other than suction cups, the fact

that it can recover up to two different materials (i.e. move either left or right) and that it is only applicable to slow moving belts.

The FESTO 2.0axis (X-electric, Z-electric) is a robot similar to the previous option, that is however a bit more expensive, because of the fully controlled movement on the z axis, which, in this case, enables the use of complex, sophisticated grippers.

The FESTO 2.5axis (X-electric, Y-electric, Z-pneumatic) is another configuration that uses two electric motors in the X and Y axes, to move at any position over a hypothetical plane parallel to the conveyor belt, but again uses a piston to move vertically towards the surface of the belt, and thus it limits the grippers to only suction cups. The speed of the robot is a bit slower than the choices above, because of the increased weight of the moving parts.

The FESTO 3.0axis (X-electric, Y-electric, Z-electric) is the more complex linear robot configuration examined. This is a fully controlled configuration that can accurately position the end effector of the robot to any desired location in the 3D space above the belt. This robot can be ideally combined with complex grippers that work under certain location assumptions.

The IGUS 3D Delta robot is a relatively new, small-scale delta robot that provides high movement flexibility. Despite achieving medium speed, the robot provides the ability to work with semi-fast moving conveyor belts. Interestingly, this robot seems suitable for placing sophisticated grips on its end-effector, however due to the particular design principles of this robot, the overall system results in a very small working range, which is a barrier to current application.

The IGUS 2D Delta shares the same working principles with the one above, however being able to move on a single plane vertically to the moving belt. In this case again, the working range of the robot is limited to about half of the prMRF belt, which means each unit will be able to recover a single material type, while multiple robotic units should be placed one after the other to recover neighbouring recyclables of the same material type.

The arm UR10 provided by Universal Robots, besides being particularly popular these days, is a relatively high-cost robot (for the waste processing field, in particular) which of course could do the targeted job, but with a low “pick per invested euro” rate.

Table 7: Potential use robots.

Robot Type	Cost (euros)	Working Radius (mm)	Picks / sec	All grippers	Delivery Time	Maximum Conveyor Speed	Classes per robot
ABB IRB 360 (Delta)	27000	1600 (3D)	1.0	YES	5 months	6000mm/s	4
FESTO 1.5axis (X-e,Z-p)	6000	Any (1D)	0.84	NO	3 months	200-300 mm/s	2
FESTO 2.0axis (Xe, Ze)	8000	Any (1D)	0.84	YES	3 months	200-300 mm/s	2

FESTO 2.5axis (Xe, Ye, Zp)	10000	Any (2D)	0.8	NO	3 months	5000mm/s	4
FESTO 3.0axis (Xe, Ye, Ze)	15000	Any (3D)	0.8	YES	3 months	5000mm/s	4
Igus 3D Delta (X, Y, Z)	11000	330 (3D)	0.5	YES	2-3 weeks	5000mm/s	2
Igus 2D Delta (X, Z)	7000	400 (2D)	0.8	YES	2-3 weeks	200-300 mm/s	1
UR10	31095	2000 (3D)	0.9	YES	3 months	6000mm/s	4

Following the discussion above, as RECLAIM aims to develop and assess in the real world a Team of RoReWos, we decided to proceed with the linear robot approach for the reasons listed below:

- Linear robots are simple and low-cost machines that can be effectively combined with pneumatic technology to facilitate the development of RoReWos with high “picks per invested euro” rate (this is a key issue for RECLAIM).
- The linear robot approach enables the implementation of RoReWos with a range of different functional characteristics, which will still share the same working principles. Therefore all RoReWos will be universally maintained, and will universally driven by the same piece of software code.
- The linear robots can host different types of grippers, be them simple, low-cost grippers based suction cups, or much more sophisticated grippers that assume accurate 3D positioning.
- Given the RECLAIM budget, linear robots allow the development of a RoReWo team consisting of multiple robots with different functional characteristics and different roles in the team.

6.2.2 Synthesis of the RoReWo Team

Following the above analysis and budget constraints, RECLAIM will implement a Team of RoReWos to power the prMRF. The Team of RoReWos will consists of the following linear robots:

3 x Cartesian Robot 1.5axis (X-electric, Z-pneumatic). These robots will operate as line scanners/pickers that will recover and sort recyclables based on vacuum gripping. The carriage of the robot will move vertically to the flow of the belt, with a piston mounted on it. The piston will rapidly direct the suction cup gripper towards recyclables that will be picked with the help of vacuum. To keep these RoReWos busy the maximum possible time, they will be installed early in the recovery line, just after the hyperspectral and RGB camera. Each RoReWo will be able to recover 2 material types (i.e. put objects either in the left or the right bin), but they may have overlapping roles depending on the composition of the waste (i.e. two RoReWos may target PETE plastics).

1 x Cartesian Robot 2.5axis (X-electric, Y-electric, Z-pneumatic). This is a RoReWo unit that moves on a plane parallel to the conveyor belt, with a piston mounted on its carriage to enable reaching and picking recyclables. In comparison to the Cartesian Robot 1.5axis that operates as a line scanner/picker, the Cartesian Robot 2.5axis operates as an area scanner/picker. In other words, this RoReWo provide higher movement flexibility and will be used to process the left-over of the Cartesian 1.5 axis subgroup. Moreover, it can visit four different bins, which means it can recover up to four different types of materials.

1 x Cartesian Robot 3.0axis (X-electric, Y-electric, Z-electric). This is the most complex RoReWo unit that will be able to move in a fully controlled manner to any position in a predefined 3D space above the conveyor belt. This will be the main platform for hosting the new sophisticated grippers that will be investigated and developed in RECLAIM. The carriage will be able reach the belt from any desired direction with a fast or slow speed depending on the gripper requirements. As above, the Cartesian Robot 3.0axis will be able to place recyclables in four bins that correspond to four different material types. To take advantage of the increased movement flexibility of the current Cartesian unit, it will be installed at the end of the conveyor belt where the new RECLAIM grippers will be able to work with minimum disturbance from neighboring items. The current cartesian unit will work on the left-over of the previous robots to make the final cleanup of the belt.

6.3 Grippers

In order to make the robots capable of manipulating waste objects, they need to be equipped with end effectors. These end effectors will be further referred to as *grippers*. The state of the art shows robotic sorting systems with one or two robots using one type of gripper. Within the project the opportunity to use different types of grippers, on the same system, to enhance picking performance, is researched. Additionally, the performance of different gripper types will be researched, as well as different designs of the grippers.

6.3.1 Gripper functions

The main function of the gripper is attaching the object, which is targeted to be picked, to the robot, in order to be able to move it to the correct sorting bin. This can be performed in different ways, which will be further explained in section 6.3.2. Additional functions the gripper can fulfil are compensating and launching. The compensating function reliefs the robot from stress, and therefore possible damage, in case of a collision. This collision can be induced by an interpretation error from the vision system or objects moving on the conveyor belt. The last feature that the gripper can provide is the launching of the objects. Launching the objects from the conveyor reduces the distance the robot has to move. This reduction in moving distance will reduce the time needed for picking one object (picking time).

6.3.2 Gripper overview

There are two different grippers, soft and rigid. Attachment of different objects to the gripper system can be enabled in multiple different ways. The rigid grippers can grasp in four ways impactive, ingressive, astrictive and contigutive.

Impactive grasping methods use forces that impact the object's surface and are mostly represented by finger grippers. Ingressive grippers permeate the surface of the object in order to include part of the object. Astrictive grasping uses forces created by a field. Examples of this are magnet grippers or vacuum grippers. Contigutive grippers use direct contact for adhesion. Examples of this are gecko or cryogenic grippers or grippers that use chemical adhesion. Since the environment is very polluted and the cost of operation of the contigutive, the contigutive grippers are considered out of the scope of the project.

The soft grippers have three working principles. First, using actuation. Second, by controlling the stiffness of a medium that surrounds the object. Last, by controlling the adhesion. Of those, only the soft grippers with passive structures using external motors are applicable since the other type of grippers are considered too fragile for this rough industrial environment.

6.3.3 Required specifications for gripper selection

In order to select the right grippers and perform tests on the performance of the grippers the following information about the waste stream is required to be gathered during the progres of the project:

- Waste stream composition
- Object weights
- Object size

- Expected material properties
- Throughput in between planned moments of maintenance
- value of each sorted wastestream / cost of the unsorted waste steam
- Energy cost att location of operation
- Available types of energy
- implemented robot types
- investment cost
- operating cost

Based on this information multiple alternative grippers will be designed and tested in the lab. Those with the best performance and increased strength will be mounted on RoReWos to test their operation in the real world and evaluate their contribution in achieving the prMRF objective.

6.3.4 Picking Feedback

A feedback loop will be installed in the test system. This provides the opportunity of recording the result of each of the picks. Saving the input data, image of the object, picking location and grasping pose, together with the result of each pick in a dataset enables the analysis of the performance of the different grippers and enables data-based decisions on improving the grippers.

7 prMRF equipment specification

Following the discussion above, the current section summarizes the characteristics of the equipment to be installed in the prMRF as listed in Table 8.

Table 8: Equipment to be installed in the prMRF.

prMRF Component	Characteristics Specification
Container type & size	45 HC 13.640 mm x 2.340 mm x 2.695mm (Internal L x W x H)
Container modifications	Three windows on each side
Deployment	Container lifted on metal legs
Eco-friendly operation	Solar energy support; 10 KW photovoltaic panels
Feeding mechanism	Inclined cleated conveyor belt (Dimensions: 7 m length; 1.1 m width)
Material pre-processing	Vibrator screening
Forward Conveying mechanism	Conveyor belt EP 250/2 with coverage 3+0 mm (Dimensions approx 11.5 m length; 1.1 m width; speed 0,1-0,5 m/sec)
Looping mechanism Part1	Conveyor belt EP 200/2 with coverage 2+0 mm (Dimensions approx 9.5 m length; 0.75 m width; speed 0,1-0,4 m/sec)

Looping mechanism Part2	Inclined cleated conveyor belt EP 200/2 with coverage 2+0 mm (Dimensions approx 5 m length; 0.55 m width; speed 0,1-0,4 m/sec)
Hyperspectral camera	Line camera (Specs: spectrum range: 900nm-1700nm, 640 pixels, 146 Lines/s)
RGB cameras	Global Shutter Exposure, 2MP Color, at least 40 fps
Controlled lighting conditions	Two external light cut-offs
Hyperspectral/RGB lighting	Halogen lighting
RGB lighting	Led strings
Cartesian robot C1.5	Cartesian robot with one controllable DoF(X) and binary, pneumatic elevation (Z)
Cartesian robot C2.5	Cartesian robot with two controllable DoF (X,Y) and binary, pneumatic elevation (Z)
Cartesian robot C3.0	Cartesian robot with 3 controllable DOF (X,Y,Z)
Robots installed in the prMRF	3 x C1.5, 1 x C2.5, 1 x C3.0
Gripping mechanism	Ordinary vacuum grippers + newly designed grippers
PC1	Processing of Hyperspectral input
PC2	Hyperspectral /RGB fusion and processing
PC3	Processing of RGB images/Robot Orchestrator
Over-belt Magnetic Separator	Dimensions: 1150 mm x 500 mm x 160 mm (L x W x H) ; power 1.5 KW
Material collection bin size	1100Lt
Number of bins for material collection	20

8 Recycling data games

Complementary to the implementation of the prMRF, a key pillar of RECLAIM is the development and deployment of educational environmental gaming for social awareness and training. The aim of Recycling Data Games (RDGs) is to leverage current trends in using gamification for the purposes of citizen science with an explicit focus of collecting human data that can assist AI algorithms developed within RECLAIM in better identification, localization and categorization of recyclable material imaging data. The core goal of RDGs is to enrich data from the prMRF with annotations from a broader userbase to improve AI performance which in turn can inform the generation of better and more accurate RDGs. Beyond this goal, RDGs also aim to engage users of diverse age, gender, and background, to increase awareness and to inform users about the basic principles of Data Science and AI.

Designing RDGs hinges upon collecting requirements from stakeholders and end-users. Some of these requirements share common elements with broader citizen science projects and games, which we survey in 8.1. However, given the unique challenges of data re-use and the message of recycling, we have conducted multiple studies with users, which we detail in 8.2. Based on analysis of our primary and secondary data, we establish some high-level requirements in 8.3.

8.1 Requirements collected from the literature review

A wide range of factors affecting player motivation and engagement have been identified by research on citizen science (CS) projects and games. Self-interest seems to be one of the most common motivations for participation in citizen science projects (Preece, 2016); participants may be interested in local, national, or global issues, the interest may be related to a hobby, or the recognition and reputation gains of their involvement in the project. Further studies though have shown a wide range of motivations. For instance, (Tinati et al. 2017) proposed a framework of motivations for participation in a gamified citizen science project which consisted of two groups: a) intrinsic motivations relevant to the act of contribution, user experience, and support of a worthy cause and b) extrinsic motivations such as external rewards, reaching an elevated status in the community, leaderboard, and winning competitions.

The main themes relevant to the motivation and engagement of players of citizen science games (CSGs), as identified by Miller et al. (2022), are relevant to: the educational value of the game, the game structure and pace, supporting alternate play modalities, intrinsic game enjoyment, intellectual challenge, socialisation and community, boring or repetitive play, gamification elements, power user functionality, user interface and input controls, software, paratexts such as game wikis and YouTube videos, developer communication, scientist communication, making scientific contributions, understanding the science of the game, game difficulty, knowledge of how to play, and the quality of the game instructions. Elements such as confusion about how to play, unintuitive user interface (UI) and control scheme, poor quality or quantity of instructions, examples and learning assistance, software issues such as

bugs, freezing, and crashes, lack of scientific communication, task quality such as the resolution of the data in the game, seem to hinder gameplay.

Beyond linking the project to the personal interests and motivations of the participants, the challenge for any CS project is to sustain long-term engagement of the participants and support continuing contribution by people who have developed their skills throughout their participation in the project. The factors that encourage such long-term participation, as discussed by Preece (2016) are: development of trust between participants and scientists, setting common goals and frequent communication between volunteers and scientists, acknowledgement and attribution of the volunteers' contribution and the sense that their efforts are scientifically validated, mentoring and training of the volunteers by the scientists, external relationships and understanding the impact they may have on the environment and on others.

It seems, therefore, that for the development of an effective CSG the following guidelines should be considered (Miller & Cooper, 2022):

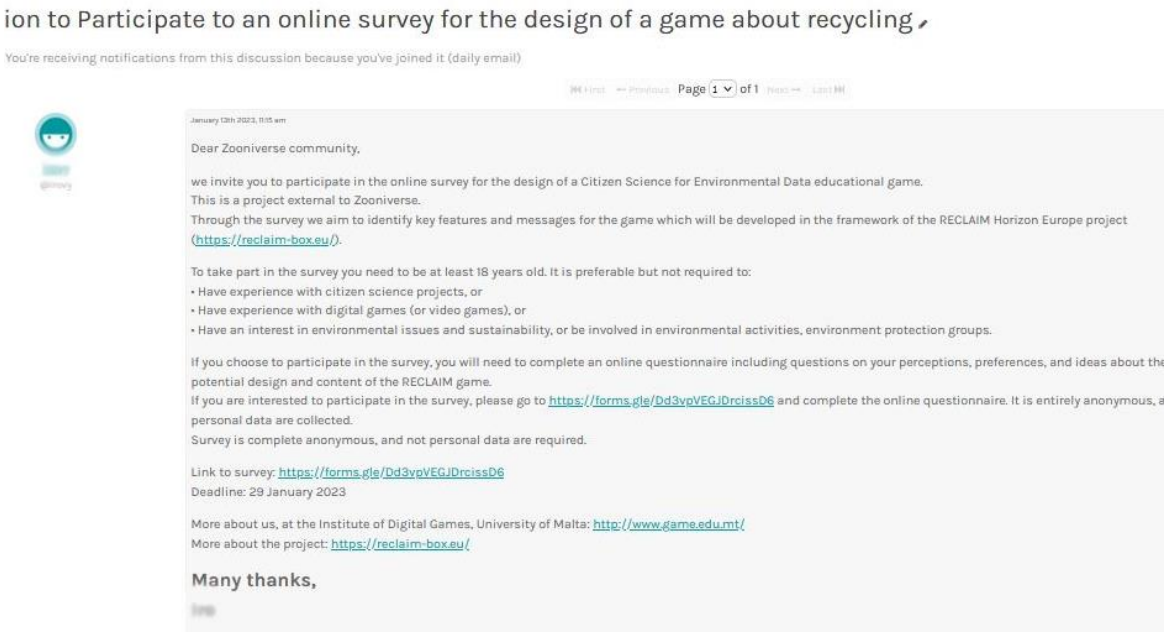
- appropriate instructional design and scientific communication
- well-designed tutorials and teaching players how to play
- Incentives to log in daily, such as daily quests or bonuses
- puzzle and strategy elements
- make even difficult problems accessible to all
- clear and quick communication on the scientific progress made and the contribution of the players
- listening to the players' feedback on technical issues and bugs regarding the interface and controls
- well designed user interface and user experience
- task quality

8.2 Requirements collected from users

As shown by the literature review in the previous section, there are multiple factors affecting participation beyond the technical specifications, the interface, and the task itself. For designing a successful citizen science game we need to understand the users, their needs, the community, and how to foster the volunteers' extrinsic and intrinsic motivation (Tinati et al., 2017). It is essential, therefore, to examine the preferences and practices of both the target group, as well as of experts in the field of environmental sustainability, waste management and recycling, and data annotation, specifically in the partner countries of the project.

8.2.1 Protocol for collecting user requirements

Data for the preferences and requirements of the target group and experts were collected through focus groups and an online survey. The call for participation (Appendix I) was distributed through the consortium's network, the social media of the project, and fora of citizen science platforms (e.g., Zooniverse) (Figure 2).


ion to Participate to an online survey for the design of a game about recycling

You're receiving notifications from this discussion because you've joined it (daily email)

Page 1 of 1

January 12th 2023, 11:15 am

Dear Zooniverse community,

we invite you to participate in the online survey for the design of a Citizen Science for Environmental Data educational game.
This is a project external to Zooniverse.
Through the survey we aim to identify key features and messages for the game which will be developed in the framework of the RECLAIM Horizon Europe project (https://reclaim-box.eu/).

To take part in the survey you need to be at least 18 years old. It is preferable but not required to:
• Have experience with citizen science projects, or
• Have experience with digital games (or video games), or
• Have an interest in environmental issues and sustainability, or be involved in environmental activities, environment protection groups.

If you choose to participate in the survey, you will need to complete an online questionnaire including questions on your perceptions, preferences, and ideas about the potential design and content of the RECLAIM game.
If you are interested to participate in the survey, please go to https://forms.gle/Dd3vpVEGJDrcissD6 and complete the online questionnaire. It is entirely anonymous, a personal data are collected.
Survey is complete anonymous, and not personal data are required.

Link to survey: https://forms.gle/Dd3vpVEGJDrcissD6
Deadline: 29 January 2023

More about us, at the Institute of Digital Games, University of Malta: http://www.game.edu.mt/
More about the project: https://reclaim-box.eu/

Many thanks,

Figure 2: Call for participation in the survey on Zooniverse.org

Through the survey and focus groups we aimed to identify key features and messages for the educational, environmental data-game. The call was addressed to the following target groups:

- Participants with experience with citizen science projects (not mandatory requirement)
- Participants with experience with digital games
- Participants with an interest in environmental issues and sustainability, or involvement with environmental activities or environment protection groups.

Before participation in the survey and focus groups, details of the process, the confidentiality, the safety, security, and anonymity of the data were communicated to the participants, in accordance with the Code of Ethics in Academic Research. Participants of the focus groups further signed the Informed Consent form (APPENDIX II).

■ Survey Design

The survey was distributed online and included open and close-ended questions on the participants' perceptions, preferences, and ideas about the potential design and content of the RECLAIM game. It was open for responses during January 2023. The survey sample was N=26. The design of the survey was based on the survey by Golumbic et al. (2019) and CSG elements identified by Miller et al. (2022) and was further adapted to the content and goals of this project. The survey addressed the following themes (see APPENDIX III for the survey items):

- Experience with digital games and preferences
- Experience with citizen science games
- Participation in environment protection activities
- Potential questions to waste management and recycling experts
- Preference of game playing devices (e.g., Tablet, Mobile phone, Desktop/laptop)
- Preferences on types of quizzes, puzzles, or challenges
- Rating of the following game elements: educational value, simple game, structure, fast pace, take my time, intellectual, challenges, socialisation and community communication with the scientists, understanding of the scientific contribution I am making, understanding the science of the game, game instructions, tutorials, puzzle elements, strategy elements, narrative and story, daily login incentives (e.g., daily quests or bonuses), strategy elements, narrative and story.
- Game session duration
- Potential negative elements
- Frequency of content updates

■ Focus Group Design and Process

The focus groups were conducted online through a video-conferencing platform with a duration approximately 1 – 1,5 hours each. They took place during January 2023. Each focus group consisted of 4-6 participants, with a total of 16 participants. See Table 9 for details.

Table 9: Details on the process and participants of the focus groups

Label	Date	Number of Participants	Main expertise
FocusGroup1	23/Jan/2023	6	AI, Recycling, Games
FocusGroup2	27/Jan/2023	4	Robotics, Recycling
FocusGroup3	30/Jan/2023	6	Recycling, Education

For the process of the focus groups, the participants were first welcomed, they were guided through the informed consent form and were given the opportunity to ask questions. They were introduced to the scope and goal of the RECLAIM project and the data-game through a 10 minute presentation. The discussion was focused on the following topics:

- Participants' previous experience with digital games, citizen science projects, and environmental activism.
- Potential features and elements of the game for motivating and engaging the public.
- Elements that could hinder or discourage players from engaging with the game.
- The content of the game regarding environmental issues, messages, topics that should be communicated to the players.
- Perceptions on the potential of the game to raise awareness on environmental issues.

- Any other comments regarding the design, the implementation, the dissemination, and the support of the game.

8.2.2 Results of focus groups

■ Participant Backgrounds

The participants had varying experience with digital games, ranging from no experience at all, experience with mobile games such as Trivia games, to experience with more complex strategy and action games such as Gran Tourismo, Call of Duty, Warcraft, first person shooters, and strategy games. In some cases, the participants expressed the perception that digital games are mainly addressed to younger children and not adults e.g., *"Due to my age, I don't really play games anymore".* They had no experience with citizen science games while most of them were not aware of the field of citizen science.

All of the participants were aware of and sensitive towards recycling and the protection of the environment, with varying degrees of participation in environmental actions; some of them were employers of environmental organizations.

■ Motivating and Engaging the Players

One of the aspects of the game, more frequently mentioned by the participants, was the need to have engaging content that would attract the interest of the players. Some of the participants already had experience with the annotation of data and images of waste and acknowledged that such a task can be repetitive and tedious for the players (e.g., quoting one of the participants *"I have done a lot of annotation in the past. Annotating may be extremely boring!*"). To avoid this, the participants discussed the need to include *a* ***variety and a wide range of tasks*** for the players. They discussed a number of approaches for avoiding a repetitive gameplay such as adding new content, inclusion of multiple types of games and different levels, multiple options and choices for the players, daily quests and challenges, non-repetitive patterns and motives, different tasks to attract the interest of players, different levels, different settings and environment in each level, variety of activities, not too predictable tasks, and adding new elements during the progress of the players.

The ***rewards*** were also another theme that emerged as an incentive for playing the game, either external or embedded in the game. Participants discussed the importance of rewards and an appropriate reward system including, for example, points, rewarding sounds, high scores, and leaderboards for recognizing and rewarding the contribution of the most efficient players. Points and scores may not be a strong motivator for all though. As suggested by two of the participants, score and points are of no interest to them; they emphasized the interesting content and the progress in the game as a strong motivation instead *("No, the score would not interest me. I want to level up for myself. I don't need to see the score of the others.").* External rewards for high rated players such as educational visits to recycling facilities, since they are difficult to visit by the public, or participation in the RECLAIM project consortium meetings with paid travel expenses were also suggested. At this point, some of the participants argued that short-term and tangible rewards would be more effective and engaging for the players than long-term rewards. Other external rewards such as monetary

rewards or gift-cards were also suggested. The counterargument by the participants was that the gain from playing the RECLAIM game should not be financial but rather emphasise the impact on the protection of the environment.

Short and simple game sessions further emerged from the discussion as a positive element. In multiple cases, the participants stressed that the game should include challenges but should not require too much effort, time, concentration and skills. The players should be able to spend as much or as little time as they want. Short sessions where the players can achieve goals within 10 or 15 minutes or the possibility to skip part of the game should be included. This would attract casual players who usually play games during their breaks, at work, waiting for the bus, to relieve stress and relax. As one of the participants suggested, it would also be useful if the time needed for each task was indicated at the beginning of the session. As also suggested, more complex or difficult levels of the game could probably be offered in later stages, to more dedicated players. It seems that if we are to address the wider public, elements of casual games should be considered for the design of the game.

In this context, and for addressing the needs and requirements of the players, elements such as the possibility to ***save one's progress*** and ***personalisation of the gameplay*** were further suggested. Players, casual or more engaged, should be able to save their progress. It would further be motivating if they were able to personalise their virtual representations in the game with elements such as "skins" for their characters.

In all three focus groups, the ***social aspect*** of the game also emerged. The elements suggested were: competition among players in sessions such as tournaments or short, fast-paced group sessions, groups and collaboration among players where they could contribute and add to other players' contributions, complementing each other, players being able to interact with each other and exchange items, the possibility to collaborate with others, such as family members, and help each other, and sharing achievements on social media or competitions based on social media. Regarding the links of the game to social media platforms, one of the participants raised the issue that sharing to social media or building upon the players' social media network may not be appealing to all *("[Having to share my achievements on social media] would discourage me. I wouldn't want to have to invite others through social media")*. It seems that elements such as competition and rivalry, fostering an environment of collaboration, and the possibility -but not obligation- to share to and involve social media networks can be considered for the design of the RECLAIM game.

The ***educational and informative*** aspect also emerged as a strong motivator by the participants. Learning something new from the game about relevant real-world issues or about the local communities and practices would motivate players to engage with the game. In fact, the benefits of the integration of educational goals and individual learning to citizen science projects are twofold: a) the project raises awareness, educates participants, and supports the informed and active participation and engagement of citizens, and b) the data collected and analyzed through the citizen science project are more reliable and therefore useful to the scientific community (Preece, 2016). Other elements suggested were humour *("[the game] should not be too serious. It must have humour, be light, not to be too loaded [with strong messages] and not too complex")*, supporting creativity and imagination, and cognitive and problem-solving skills.

Linking the game with real world cases and examples was also another aspect often mentioned. The participants suggested that it should be made clear in the game that the images and the processes depicted come from real-life sorting facilities and real world recycling processes; possibly including video of the actual sorting system and facilities even in real time. As one of the participants suggested, it would be interesting if the players could interact with the actual robotic sorting system in real time. Real world information and statistics on the topic should be given to the players, for example in the form of quizzes or tests. The impact of the gameplay and the contribution of the players on the real world and the society was another issue raised. As suggested, the players should be able to see the real contribution and the actual impact the game has beyond the boundaries of the game, as well as to see the impact of not recycling, and of correctly or wrongly recycling on the environment, on the society, and on our lives. As one of the participants suggested though, showing the actual impact of the gameplay on the environment may be too minor and discouraging for the players, while showing the impact of the players in comparison to the lack of any contribution and action towards the protection of the environment could motivate the players to be more active. In the context of situating the game into real-world settings, the participants suggested communication with actual companies (e.g., companies producing the more or the less waste) and encouraging them for further action and social responsibility.

The participants further provided ***specific ideas for tasks*** or elements to be integrated into the game such as the player assuming the role of the robotic arm to annotate and sort materials, videos that the player will have to process, and multiple choice questions for selecting the correct edge of each material in the image, identifying material or tracking the edges of an item.

■ Environmental Content and Messages

While discussing the environmental content and goal of the game, the main themes emerged were relevant to a) the promotion of behaviours and habits of recycling in real life, b) providing information about good practices of recycling, c) depiction of the consequences on the environment and on society of not recycling or not recycling appropriately, and d) the environmental as well as the financial impact of recycling (or not recycling). The participants further commented on the properties of the environmental content and messages of the game suggesting that it is light, focused, concise, not pessimistic, showing actual solutions to the problems and real-life practices, and use simple and easy to understand language.

Specifically, the participants suggested that the game should ***inspire habits and behaviours*** of better waste management and recycling in real-life, and it should motivate people to recycle. To this end, the game should *provide information and address common misconceptions* and scepticism of the public regarding the process and implications of recycling: what types of materials can be recycled, embedding libraries of information about the properties of different material in the game – a library that can be updated throughout the progress of the player-, what is the correct process of disposing recyclable material, addressing misleading information about the recyclable material, considering which products to buy as a consumer in relation to the materials of their packaging *("Educate the people to the 3 R's; Reduce, Reuse, Recycle"* as one of the participants commented), the overuse of plastic as *"the big plague"*, information about the progress and impact of actual sorting and recycling facilities in the local

communities, and information about the actual use of recycled materials with real life examples (their *"second life"*). Participants with experience in waste management and the recycling processes commented that a lot of mistakes are done while sorting the material in the recycling bins indicating that the public lack the knowledge of the correct types of materials to be recycled.

Showing, through the game, the ***actual consequences and impact*** of improper or lack of recycling practices on the environment and on our surroundings would strengthen the impact of the game on the attitudes and behaviours of the players, as suggested by the participants. *"If I am not careful with my waste, my waste will drown me"* as one participant stressed. The impact of not recycling could be visualized through, for example, videos, as suggested by one of the participants. The need for waste management, as discussed by the participants, is equivalent to the need for water or food.

Beyond the environmental aspect of the recycling process, some of the participants also addressed the ***financial aspect*** as well. Some of the details they shared: Recycling gives value to the material as the material is not wasted but is rather reused. Mistakes in the waste sorting process could result in the damage of all the material in the container. When there is lack of recycling or inadequate recycling processes the landfills reach their capacity sooner, and new landfills have to be constructed. Landfills are expensive, though, and they are usually met by the resistance of the locals to accept a new landfill. In addition, as suggested by one of the participants, addressing current issues such as the cost of energy, the climate change, and the carbon dioxide emissions, and how recycling can be a solution to these problems could further be a strong message of the game.

■ Game Implementation and Dissemination

During the discussion on the potential of the game and the context of its dissemination and implementation, the participants suggested the following directions:

- Collaboration with third parties such as local authorities, local media channels, schools, and promotion through social media platforms. Synergies with similar projects could also promote the reach of the game.
- Targeted campaigns to incentivise people to download and play the game
- Mainly address younger people, as they may be more open to changing their behaviours and practices
- Addressing both the local communities of the area the robotic sorting system will be installed, as well as the wider audience, at a European level. The varying recycling processes in different areas should also be considered.

More broadly, the perceptions of the participants on the potential and impact of a game on the behaviours and beliefs of the public were varying: some suggested that yes, a game can have an impact on the perceptions of the players *("Even within half an hour of gameplay, the players will be different than what they used to be half an hour ago"* as one of the participants commented), while others commented that "probably yes" but they couldn't think of specific examples, or that adults, as opposed to children, are more difficult to change.

In many cases, the participants brought up the educational aspect of the game and discussed its potential implementation to children; they suggested collaboration with schools and

introduction of the game into classrooms, discussed potential elements that could motivate children, and elaborated on the interest the younger children display during school visits to the sorting facilities and the importance of early environmental education for fostering responsible future citizens.

8.2.3 Results of online survey

■ Participant Background

As also in the case of the focus groups, the participants had varying degrees of experience with digital games and little or no experience with citizen science games. Their participation in environmental activities was also mixed, as opposed to the focus groups participants where most of the participants were involved to some extent with environmental protection institutions (see Table 10).

Table 10: Profile of the survey respondents

	Minimum	Maximum	Mean	Std. Deviation
Experience with Digital Games	1	4	2.42	1.027
Experience with Citizen Science Games	1	2	1.12	.326
Environmental Activities	1	4	2.50	1.105

■ Preferences and Habits of Playing

"Mobile phone" was the most popular response regarding the device they would use to play the game, followed by computers and tablets (see Table 11). Survey respondents further opted for *short game sessions*; the average time was 13 minutes, while the most frequent value was 10 minutes (minimum 3 minutes, maximum 30 minutes)

Table 11: Preferred devices for playing the game.

	Frequency	Percent
Desktop/laptop	4	15,4
Mobile phone	21	80,8
Tablet	1	3,8

The most popular responses regarding the preferences of the survey respondents, when asked to rate specific game elements, were the ***intellectual challenges***, the ***strategy elements***, and

puzzle elements (Figure 3). These are consistent with findings of previous studies, as shown in Section 7.1. Among the most important aspects that were deemed "somewhat important" to the users were communication with the scientists, fast paced gameplay and (in contrast) allowing the user to take their time while interacting with the game. The game elements included in this question were adapted from previous studies discussing the design of citizen science games (Golumbic et al., 2019; Miller et al., 2022).

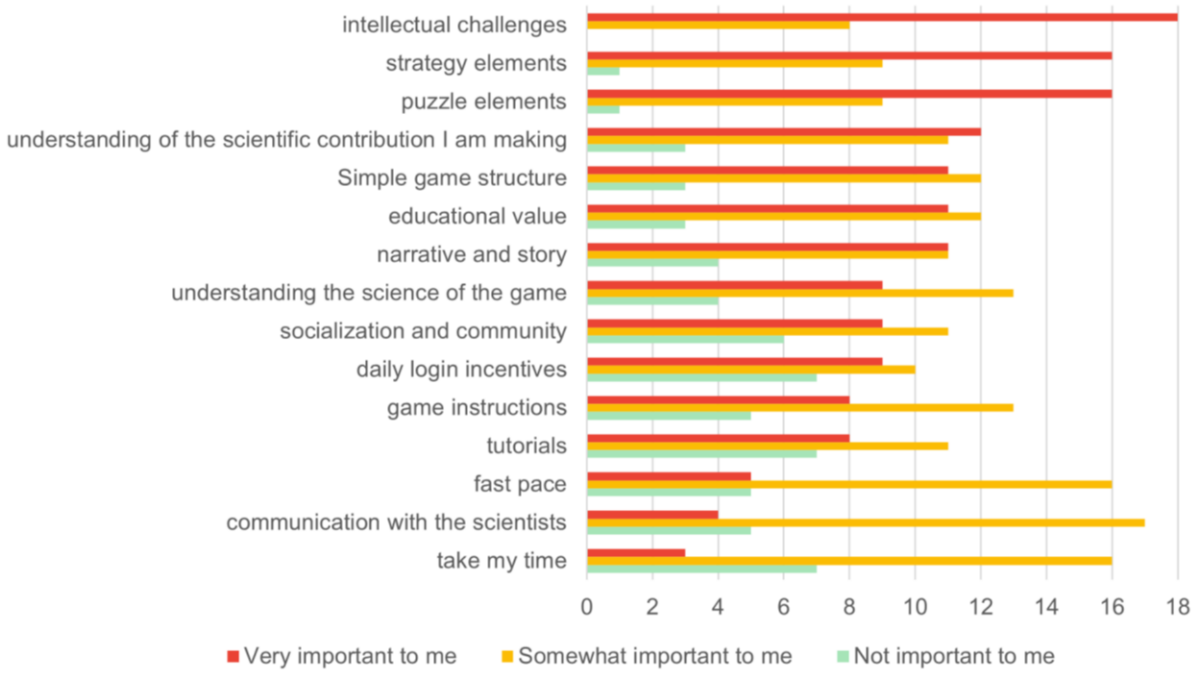


Figure 3: Game elements and motivation (frequencies)

In the open question about any additional comments, some of the respondents further elaborated, suggesting the ***possibility to play with friends*** or ***compete against others***, ***information about the real-life impact*** of the gameplay, ***real-life rewards***, and information about the financial aspects of recycling.

Survey participants further suggested **several different types of activities** (question "What kind of quizzes, puzzles, or challenges would you like to see in our environmental, waste management game? Can you give some examples?")**.** Indicatively, "a challenge where all types of possible packaging waste are listed and explained to the citizens", depiction of "a real environment regarding waste management", "choose-your-ending games", "Candy Crush type of tasks", showcasing the impact of recycling in real-life ("if we recycle a plastic bottle, we save energy that can power a 60W light bulb for 3 hours."), competitive tasks, logic games, multiple choice questions, participation in groups, speed tests, daily challenges to be accomplished, and quizzes on environmental issues.

One of the main ***negative elements*** identified by multiple survey respondents, that would demotivate them to play the game (question *"What elements would you find negative for the game? What would make you stop playing the game?"*) was the boring and repetitive

gameplay ("*repetitive quests", "when the game is repeating"*). A time consuming or a too complex or difficult game were also some of the most common responses regarding the negative elements. Other elements identified were: technical problems, non-engaging narrative, very slow or very fast progress, content that is not updated, and lack of communication about the contribution of the players. Again, these findings are consistent with the negative elements discussed in the literature review section.

■ Environmental Content and Messages

In the open-ended question *"If you were with waste management and recycling experts what questions would you ask them?"* responses were in-line with issues addressed in the focus groups as well. Survey respondents addressed the need to know the ***actual impact of recycling*** (*"Realistically, how much of an effect can citizens have on mitigating or reversing climate change?", "Furthermore, success rates and experiences in recycling, fake news try to demotivate to recycle."*), they wanted to know ***more information about the proper way to sort materials for recycling*** (*"Could you explain about the recycling process?", "Particularities about the recycling of different packaging. Sometimes sorting is a bit confusing"*), ***information at a local level*** (*"If recycling procedure has been achieved in my area"*), and ***wider policy issues*** relevant to recycling (*"why there aren't waste management and recycling experts in politics.", "Why are there no plastic bags although almost everything in the supermarket is in plastic?", "How is marine littering addressed in my country?"*)

8.3 Specifications

Based on feedback from both focus groups and the survey, the ideal platform for Recycling Data Games (RDGs) is mobile devices which players can interact with during downtime for short periods of time (approximately 10 minutes). Based on an analysis of ease of development and deployment, Android devices were identified as ideal. The technical specifications are aimed to include earlier generation devices. However, due to the data collection aspect of the RDGs, online connection will be necessary.

Furthermore, based on the same feedback, we identified a number of critical information that the RDGs should convey. This information should address misconceptions about recycling, convey the impact of recycling on the environment (both financial and societal), links to other societal and environmental issues, allow for engagement with the RECLAIM activities and its scientists, and inform about technical aspects of the collected data (in terms of AI algorithms and robotics components). In terms of game mechanics, while a plethora of suggestions was provided, the core requirements include the ability to resume progress, provide intellectual and strategic challenges, adaptation to the user's skill (through a progression system), and potentially the ability to compete or collaborate with other players.

Regarding the target group, focus groups tended to assume that games are played by children and thus often provided feedback regarding educational and pedagogic content. However, RECLAIM targets citizen scientists who are assumed to be young adults (e.g. university students), which was another suggestion from focus groups. Therefore, while we expect that ecologically-minded individuals will play RDGs, the game design should be appealing and incentivizing towards the general public. The above are summarized in Table 12.

Table 12: Requirements for Recycling Data Games

Hardware/operation requirements	
Platform	Mobile devices (phones or tablets)
Operating system	Android 6 (minimum), Android 10+ (recommended)
Aspect Ratio	16:9 (although ideally support 20:9 and 4:3)
Resolution	540x960 (minimum)
Minimum specifications	CPU: dual core, 1GHz; RAM: 2GB
Other requirements	Online access, 8+ Mbps (minimum)
Playability requirements	
Desired play time	Around 10 minutes (per session)
Game features	Progression system (rewards), savegames, intellectual challenges, strategy elements, competition/collaboration
Environmental content and messages	Information about the impact of recycling, real-world examples, technical information on the project (robots, AI), communication with scientists
Target group	Citizen scientists (young adults)

9 Conclusions

The underlying document provided a summary of the requirements analysis conducted to guide the design of the prMRF and the RDGs. Then the requirements have been used to take decisions, specifying key features and components of the two targeted systems.

In the case of the prMRF the requirements have been specified using prior applied experience of the RECLAIM consortium on waste management, on the broader field of material recovery, but also on the use of AI and robotics for recyclable sorting.

The applied know-how of the consortium has been leveraged to carefully transfer the operating principles of industrial MRFs to the much smaller scale prMRF. To this end we have taken into account that the productivity and robustness of the prMRF should be maximized to make the system useful in the real world but additionally the prMRF should be flexible enough to be able to cover all the scenarios which will be considered in the project. Based on the above, we have taken several decisions regarding the equipment to be installed in the prMRF, targeting the early implementation of a first, integrated prMRF prototype.

In the case of the RDGs, we collected requirements from stakeholders and end-users, which will help RECLAIM capitalize on the current gamification trends, to collect and process data in the context of citizen science. Given the unique challenges of data re-use and the message of recycling, we have conducted multiple studies with users, which have provided insight on how these two can be combined, in an appealing application. Based on the conducted analysis we establish high-level requirements that will enable the development of early versions of RDGs that will be further refined in the next stages of the project.

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Appendix I Call for Participation

RECLAIM Game Design - Data collection for user requirements

Invitation for Participation @ focus group or survey

Citizen Science for Environmental Data-Game at the RECLAIM Horizon Europe project

At the Institute of Digital Games, University of Malta, we are developing an environmental data-game, in the framework of the RECLAIM project. The purpose of the RECLAIM game is threefold:

- promote awareness and increase social sensitivity in the recycling process, implications, and challenges
- involve citizens in the data-analysis process which will address scientific challenges, contribute and optimise the function of the robotic, AI-powered waste management system developed in the framework of the RECLAIM project, and
- engage citizens in material recovery research and the project's activities

About the RECLAIM game

The game combines gamification and social computing technology with data collection procedures, highlights the related challenges, and encourages citizens to participate in project activities through a citizen science approach for providing data for training the advanced AI for material identification, localization and categorization (AI-ILC) unit. It will further provide the means to communicate the general principles of AI and Data Science to the public. The game aims to operate as a data collection hub and implement enjoyable information diffusion cores about recycling.

About the RECLAIM project

The goal of the RECLAIM project is to develop an AI-powered robotic portable waste recovery and sorting facility. It will cover waste processing needs at places where installation of stationary waste sorting stations is impossible or impractical. This portable facility will address issues such as the high loss of recoverable material during the transportation to centralised waste management facilities, and the increased workforce required for the operation of such centralised facilities, which assume humans to be transported to remote workplaces, trained in the recovery and sorting of materials, and work in difficult and unhealthy conditions. The project is funded by the Horizon Europe programme.

The consortium consists of 10 partners from Europe:

1. FORTH Foundation for Research and Technology Hellas (Greece)
2. UoM University of Malta (Malta)
3. KUL Katholieke Universiteit Leuven (Belgium)
4. HERRCO Hellenic Recovery Recycling Corporation (Greece)
5. IRIS Iris Technology Solutions, Sociedad Limitada (Spain)
6. RBNS ROBENSO PC (Greece)
7. AIMPLAS Technological Institute of Plastics (Spain)
8. AXIA Axia Innovation UG (Germany)

9. ISWA International Solid Waste Association (Netherlands)
10. ION Periferiakos Foreas Diaxirisis Stereon Apovliton Ionion Nison Anonimi Eteria Ton Ota (Greece)

Purpose of the Study

Through the survey and focus groups we aim to identify key features and messages for the educational, environmental data-game which will be developed in the framework of the RECLAIM project.

Who is this call for?

To take part in the survey or the focus groups you need to be aged 18 years or over.

It is preferable if you belong in any of these groups:

- Have experience with citizen science projects
- Have experience with digital games (or video games)
- Have an interest in environmental issues and sustainability, or be involved in environmental activities, environment protection groups.

For the focus groups, you need to be willing to have the discussion audio or video recorded, for further analysis by our research team.

What do I have to do if I choose to participate?

If you choose to participate in the survey, you will need to complete an online questionnaire (e.g., through Google Forms) including questions on your perceptions, preferences, and ideas about the potential design and content of the RECLAIM game.

If you choose to participate in the focus group, you will participate in a 1.5-hour group interview with approximately 4-10 volunteers and discuss the potential design and content of the RECLAIM game. The group interview will be conducted online, via Zoom. It will take place in January 2023. You will receive the link via email. Before the focus group you will have to read the information about the process, the safety and security of your data, and give your consent.

What if I change my mind?

Although it would be great to hear your insights about the design and content of our environmental data-game, you can always and at any point withdraw from participation in the survey or focus group. The participation is entirely voluntary, and it may be withdrawn for any reason without explanation and negative consequences. You may withdraw your consent at any time and until the data are processed by the project researchers.

How can I participate?

If you are interested to participate in the survey, please go to this link and complete the online questionnaire. It is entirely anonymous, and no personal data are collected.

If you are interested to participate in the focus group, read the information and informed consent document which you will need to read and accept if you decide to take part in the focus group. Further details (date and time scheduling, link for the online focus group) will be sent to your email.

For any comments or questions contact:

Institute of Digital Games, 20 Triq L-Esperanto, Msida, MSD2080, MALTA, +356 2340 3510, digitalgames@um.edu.mt

Dr. Iro Voulgari, Researcher at the Institute of Digital Games, University of Malta, email: iro.voulgari@um.edu.mt

Dr Antonios Liapis, Senior Lecturer, Institute of Digital Games, University of Malta, email: antonios.liapis@um.edu.mt

Thank you for your interest in the RECLAIM project game!

Appendix II Informed Consent Form

INFORMED CONSENT FORM

Please read carefully before submitting this document

This document provides information about the focus group you are invited to participate in. Before participating, it is important that you learn about the procedure and that you give your informed consent for voluntary participation. Please read this document carefully. If you agree to participate, please sign in your details below and submit it back to us.

Title of the study: Requirements for the design and content of the RECLAIM project game

Purpose of the study:

Through the focus groups we aim to identify key features and messages for the educational, environmental data-game which will be developed in the framework of the RECLAIM project.

The goal of the data-game is to increase social awareness of recycling. It will highlight the related challenges and encourage citizens to participate in project activities through a citizen science approach for providing data to AI-ILC (AI for material identification, localization and categorization) training. It will further provide the means to communicate the general principles of AI and Data Science to the public.

About the RECLAIM project:

The goal of the RECLAIM project is to develop an AI-powered robotic portable waste recovery and sorting facility. The project will exploit and implement AI-driven robotic waste management technology that will be improved and embedded in a state of the art “portable, robotic Material Recovery Facility” (prMRF) that will be capable of significantly enhancing local-scale material recovery activities providing them with industrial-level efficiency. It will cover waste processing needs at places where installation of stationary waste sorting stations is impossible or impractical. This portable facility will address issues such as the high loss of recoverable material during the transportation to centralised waste management facilities, and the increased workforce required for the operation of such centralised facilities, which assume humans to be transported to remote workplaces, trained in the recovery and sorting of materials, and work in difficult and unhealthy conditions. The project is funded by the Horizon Europe programme.

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10. ION Periferiakos Foreas Diaxirisis Stereon Apovliton Ionion Nison Anonimi Eteria Ton Ota (Greece)

Data collection:

For this study, data will be collected through focus groups. The group will be coordinated by the researchers who will address the issues to be discussed (e.g., What do you think the main social message of the game should be?). All participants will be free to share their ideas and insights.

The data collected will mainly consist of audio and/or video recordings, or field notes. The data will be anonymous and will only be used for recording the comments of the participants regarding the topic (RECLAIM game design and content).

Selected photographs may be used for communicating and disseminating the research project and research findings to the press and scientific publications, only if the participants explicitly agree. Any features identifying the participants may be blurred in the final photographs upon request.

Confidentiality and Data Protection:

Only data absolutely required for this study will be collected. All data will be anonymised, random pseudonyms will be used for each participant, and it will be impossible to identify the participants. Your identity will not be stored and linked with the data collected. A random code number will be assigned to your personal data. The processing and analysis of the data will be done by the researchers of this study.

Withdrawing participation:

The participation is entirely voluntary, and it may be withdrawn at any time for any reason without explanation and negative consequences. You may withdraw your consent at any time and until the data are processed.

You can withdraw your consent by contacting the researchers of this study (listed below).

Principles & Regulations Followed:

Protection of personal data, privacy or public liberties is a fundamental human right. All procedures for data collection, storage, protection, retention, and destruction comply with national and EU legislation and the “General Data Protection Regulation (EE 679/2016)” are followed.

Rights:

Participants, under the Data Protection Act, have the right, upon request to the researchers, to access, rectify, and erase the data concerning them until the data are processed. The participants may also request written information about their personal data being processed by the researchers. For any information regarding your rights about this study please contact the researchers (listed below).

Potential risks and benefits:

There are no physical, psychological, legal, economic, social or other risks.

Rewards and Benefits:

No rewards or compensation are offered. Participation is entirely voluntary. There will be no direct benefit to you, but your participation will help us design an efficient, relevant, and engaging educational, environmental data-game.

The Institute of Digital Games at the University of Malta is thankful and greatly appreciates your voluntary participation.

For any comments or questions:

For any questions or comments about the research, participants' rights, or related matters, please contact

Institute of Digital Games, 20 Triq L-Esperanto, Msida, MSD2080, MALTA, +356 2340 3510, digitalgames@um.edu.mt

Dr. Iro Voulgari, Researcher at the Institute of Digital Games, University of Malta, email: iro.voulgari@um.edu.mt

Dr Antonios Liapis, Senior Lecturer, Institute of Digital Games, University of Malta, email: antonios.liapis@um.edu.mt

Certification of Consent:

- I have read the foregoing information and I have had the opportunity to ask questions about it.
- I have understood and I agree with the processes and procedures described above regarding my data and I consent voluntarily to be a participant in this study.
- I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without disadvantage.
- I understand that data collected in the study may be looked at by the researchers. I give permission for these individuals to have access to these records and to collect, store, analyse and publish information obtained from my participation in this study. I understand that my personal details will be kept confidential.
- I understand that the focus group session will be video, or audio recorded and that anonymous direct quotes from the interview may be used in the reports.
- I understand that information about me recorded during the study will be made anonymous before it is stored in a secure database.
- I agree to my contact details being stored for the purpose of this study.
- Photos may be taken during the event, only after the explicit permission of the participants, for our historical records and archival purposes and to promote the University. These photos may be published on the University's web and Social Media pages. Selected photographs may be used for communicating and disseminating the research project and research findings to the press and scientific publications.
- I agree to participate in this study in the framework of the RECLAIM project regarding the RECLAIM data-game.
- "I understand that I am NOT to record the focus group discussion in any format".

Fill in your name, surname, and contact email only if you agree with the above statements. If you fill in your name, surname, and email and click on the submit button, this will act as a

signature, and it will mean that you consent to participate in this study. Confirmation will be sent to your contact email, so make sure you have written your email correctly.

- Name
- Surname
- Email

Appendix II Survey for RDG requirements

Online Survey

Design of an educational, environmental, data-game

in the framework of the RECLAIM project

Please read carefully before answering the questions of this survey.

Before participating, it is important that you learn about the procedure and that you give your informed consent for voluntary participation.

The purpose of the survey is to identify key features and messages for the design and content of the educational, environmental data-game which will be developed in the framework of the RECLAIM project.

The goal of the RECLAIM project is to develop an AI-powered robotic portable waste recovery and sorting facility. It will cover waste processing needs at places where installation of stationary waste sorting stations is impossible or impractical. This portable facility will address issues such as the high loss of recoverable material during the transportation to centralised waste management facilities, and the increased workforce required for the operation of such centralised facilities, which assume humans to be transported to remote workplaces, trained in the recovery and sorting of materials, and work in difficult and unhealthy conditions. The project is funded by the Horizon Europe programme.

The goal of the data-game is to increase social awareness of recycling. It will highlight the related challenges and encourage citizens to participate in project activities through a citizen science approach for providing data to AI-ILC (AI for material identification, localization and categorization) training. It will further provide the means to communicate the general principles of AI and Data Science to the public.

Confidentiality and Data Protection:

No personal data is stored. All data will be anonymous, random pseudonyms will be used for each participant, and it will be impossible to identify the participants. The processing and analysis of the data will be done by the researchers of this study.

Withdrawing participation:

The participation is entirely voluntary, and it may be withdrawn at any time for any reason without explanation and negative consequences. After submission of your responses, it may be impossible to identify your data, and therefore upon submission of your answers it may be impossible to withdraw your consent to process and analyse your responses.

Principles & Regulations Followed:

Protection of personal data, privacy or public liberties is a fundamental human right. All procedures for data collection, storage, protection, retention, and destruction comply with national and EU legislation and the “General Data Protection Regulation (EE 679/2016)” are followed. For any information regarding your rights about this study please contact the researchers (listed below).

Potential risks:

There are no physical, psychological, legal, economic, social or other risks.

Rewards and Benefits:

No rewards or compensation are offered. Participation is entirely voluntary. There will be no direct benefit to you, but your participation will help us design an efficient, relevant, and engaging educational, environmental data-game.

The Institute of Digital Games at the University of Malta is thankful and greatly appreciates your voluntary participation.

Researchers' Contact Information:

For any questions or comments about the research, participants' rights, or related matters, please contact:

For any comments or questions contact:

Institute of Digital Games, 20 Triq L-Esperanto, Msida, MSD2080, MALTA, +356 2340 3510, digitalgames@um.edu.mt

Dr. Iro Voulgari, Researcher at the Institute of Digital Games, University of Malta, email: iro.voulgari@um.edu.mt

Dr Antonios Liapis, Senior Lecturer, Institute of Digital Games, University of Malta, email: antonios.liapis@um.edu.mt

Certification of Consent: (yes/no)

- I have read the foregoing information and I have had the opportunity to ask questions about it.
- I have understood and I agree with the processes and procedures described above regarding my data and I consent voluntarily to be a participant in this study.
- I agree to my contact details being stored for the purpose of this study.
- I agree to participate in this study in the framework of the "RECLAIM" project regarding the RECLAIM data-game.

Please check the boxes if you'd like to be kept informed about future events and research at the Institute of Digital Games and/or any RECLAIM project activities and updates. Tick all that apply.

- Yes, please subscribe me to the IDG Newsletter where I can learn about future events, cutting edge research, and activities of the IDG. You will need to fill in your email below.
- Yes, please subscribe me to the RECLAIM Project network where I can learn about project activities and outcomes. You will need to fill in your email below.
- No, I am not interested in future events of the IDG and the RECLAIM Project

Please fill in the following details (optional)

Email address

Name

Organisation/Affiliation (if any)

Age

Gender

Survey

Introduction: A few words about the RECLAIM game

Through the RECLAIM game, the players will be shown images of waste material and will be asked to identify the different types of recyclable material. The images may be real waste images, hyperspectral images (see Figure 1), or recyclable sorting videos.

Figure 4a: Example of a real waste image

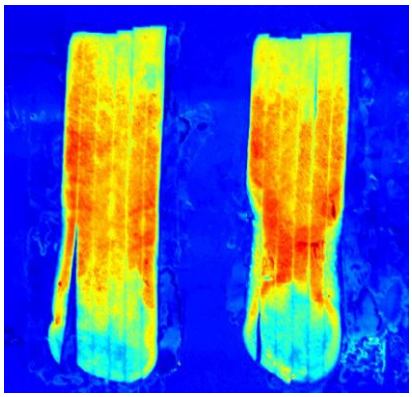

Figure 4b: Example of a hyperspectral image of "sugar end" potato strips. Image by: SortingExpert, CC BY-SA 3.0 via Wikimedia Commons

Figure 4 Examples of game images the players will be asked to examine.

In addition, the game will provide the players with information about the processes, the challenges, and the benefits of recycling for the environment and for our quality of life.

The game will support the portable, AI-powered robotic system (see Figure 4). The goal of the robotic system is to recover and sort waste, making the management of recyclable materials more efficient and facilitating the work and lives of the workforce.

Through the gameplay of the RECLAIM game, the players will train the robotic system to better recognise and sort the different waste material.

Read the following questions and answer based on your own experience, preferences, and insights.

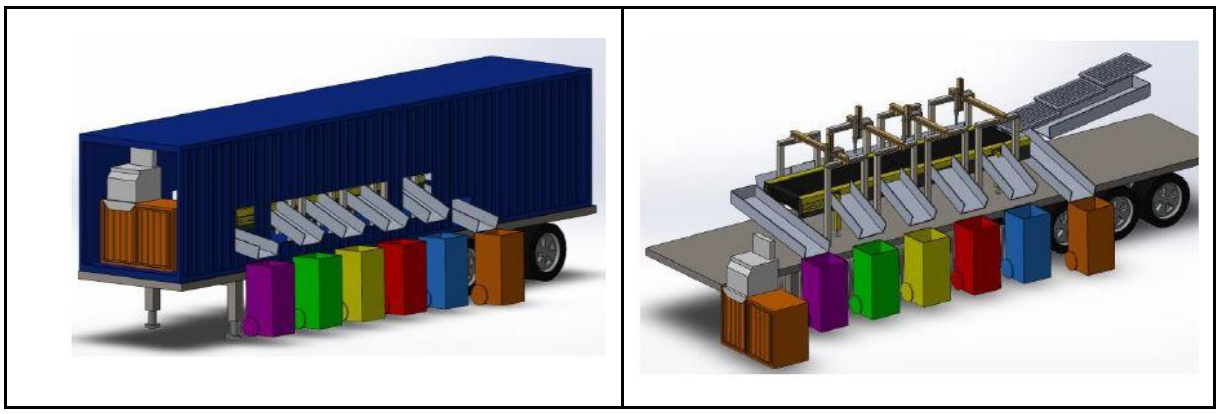

Figure 4: Indicative concept images of the robotic, AI-powered portable material recovery facility

Indicative game scenario

The players are shown real waste images captured by cameras installed in the portable robotic Material Recovery Facility and asked to complete one of many reviewing tasks.

Players receive virtual prizes for their contribution in recycling research.

Reviewing tasks may regard the annotation of materials appearing on images, the assessment of the outcomes of the currently best trained AI module, the assessment of AI inferred masks, the correction of AI inferred masks to be re-used for training, etc.

All inputs provided by individual anonymous users will be assessed by several other users to verify quality before they are included in the training dataset (experienced recycling staff will have the overall inspection of the gamified data-collection process).

The improved dataset will be used for retraining the AI module which will afterwards be considered the new current AI to drive the game (i.e., produce new images for the users).

Now that you have a general idea about the game we are planning to make, we'd like to know your opinion about the following:

1) Do you have any experience with digital games (e.g., on mobile, PC, game consoles)?
    a) Not at all 1 2 3 4 Yes, I play a lot of games
2) If you have played any digital games, can you write some of their titles?
3) If you have played digital games, which one would you say was your favourite game?
4) Do you have any experience with citizen science games (e.g., Foldit, EyeWire, Zooniverse)?
    a) Not at all 1 2 3 4 Yes, I have played citizen science games
5) If you have played any citizen science games, can you write some of their titles?
6) Are you involved in any environmental activities or environment protection groups?
    a) No I have not participated in any environment protection activities. 1 2 3 4 Yes, I am an activist in environment and sustainability activities.
7) If you were with waste management and recycling experts what questions would you ask them?
8) What kind of quizzes, puzzles, or challenges would you like to see in our environmental, waste management game? Can you give some examples?
9) On which device would you prefer to play our game?

a) Tablet
b) Mobile phone
c) Desktop/laptop

10) What elements of the game would make you want to play the game? Rate how important you find the following elements. 1 Not important to me 2 Somewhat important to me 3 Very important to me
    a) educational value
    b) simple game
    c) structure
    d) fast pace
    e) take my time
    f) intellectual
    g) challenges
    h) socialization and community
    i) communication with the scientists
    j) understanding of the scientific
    k) contribution I am making
    l) understanding the science of the game
    m) game instructions
    n) tutorials
    o) puzzle elements
    p) strategy elements
    q) narrative and story
    r) daily login incentives (e.g., daily quests or bonuses)
11) What elements would you find negative for the game? What would make you stop playing the game?
12) How much time would you be willing to spend on each game session of our game? Write your answer in MINUTES (e.g., 10, 90)
13) How often would you want the content of our game to be updated (e.g., new images to examine)
    a) Daily
    b) Weekly
    c) Monthy
    d) Every few months
    e) Every year
    f) I don't really care
14) Do you have any other comments for the design of our game?