PlastiCircle
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D3.1

General architecture of the collection and transport system: user/system requirements

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Abstract

Over the last two decades, European countries have increasingly shifted their focus with regard to municipal waste from disposal methods to prevention and recycling. In this line, the main objective of PlastiCircle is to improve the Circular Economy of Plastics (Closure of the European Plastic Loop). The PlastiCircle approach is based on innovation in the four stages associated with plastic packaging treatment: collection, transport, sorting and recycling.

WP3 focuses on transport activities, aiming to develop, integrate and validate an innovative transport process from municipalities to sorting plants that will decrease the final price of recovered plastic. The PlastiCircle transport system will be based on sensors which will recognise the filling levels of containers in real time, thus automatically optimizing collection routes through a truck traceability system. The system will be completed with pressing systems in the waste collection trucks, with a view to maximizing the amount of plastic waste transported per route. Efficient driving will also be considered. It should be noted that the whole system on collection and transport will be connected through an IoT cloud platform based on the external communication capacity of the containers.

Deliverable 3.1. collects those results achieve in WP2 during the first months of the project and the initial expectations of WP3, considering the truck traceability, routing optimization, eco-driving guidelines and compensation procedures. This report finally describes the general architecture of the system as well as the requirements of users and the system in general, being the basis for all the tasks of the WP.

Abbreviations

BB: Bring Banks

CAN: Controller Area Network

CAN FD: CAN with Flexible Data-Rate

CVRP: Capacitated Vehicle Routing Problem

CVRPPDTW: Capacitated Vehicle Routing Problem with Pick-up and Deliveries and Time Windows

CVRPTW: Capacitated Vehicle Routing Problem with time windows

DtD: Door-to-Door

EEA: European Environment Agency

EU: European Union

GHG: Green House Gases

GLONASS: Global Navigation Satellite System

GPS: Global Positioning System

GPRS: General Packet Radio Service

MDVRP: Multiple Depot Vehicle Routing Problem

MDVRPTW: Multiple Depot Vehicle Routing Problem with Time Windows

MFVRP: Mixed Fleet Vehicle Routing Problem

OBD: On Board Diagnostics

OSI: Open System Interconnection

PAYT: Pay-as-you-throw

VRP: Vehicle Routing Problem

VRPB: Vehicle Routing Problem with Backhauls

VRPBTW: Vehicle Routing Problem with Backhauls and Time Windows

VRPPD: Vehicle Routing Problem with Pick-up and Deliveries

VRPTW: Vehicle Routing Problem with Time Windows

Partners short names

1. **ITENE:** INSTITUTO TECNOLÓGICO DEL EMBALAJE, TRANSPORTE Y LOGÍSTICA
2. **SINTEF:** STIFTELSEN SINTEF
3. **UTRECHT:** GEMEENTE UTRECHT
4. **INNDEA-LAS NAVES:** FUNDACION DE LA COMUNITAT VALENCIANA PARA LA PROMOCION ESTRATEGICA EL DESARROLLO Y LA INNOVACION URBANA
5. **ALBA:** PRIMARIA MUNICIPIULUI ALBA IULIA
6. **MOV:** MESTNA OBCINA VELENJE
7. **SAV:** SOCIEDAD ANONIMA AGRICULTORES DE LAVEGA DE VALENCIA Spain
8. **POLARIS:** POLARIS M HOLDING
9. **ECOEMBES:** ECOEMBALAJES ESPAÑA S.A.

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1. Introduction

According to a study developed by the European Environment Agency (EEA)[1], over the last two decades, European countries have increasingly shifted their focus with regard to municipal waste from disposal methods to prevention and recycling. Moving municipal waste management up the 'waste hierarchy' is essential to extract more value from resources while reducing the pressures on the environment and creating jobs.

Although municipal waste represents only around 10 % of total waste generated in the European Union (Eurostat, 2016a and 2016b), it is very visible, and prevention of this waste has the potential to reduce its environmental impact not only during the consumption and the waste phases but also throughout the whole life cycle of the products consumed. Countries that have developed efficient municipal waste management systems generally perform better in overall waste management (EC, 2015).

Taking into account the Eurostat data[2], in 2014, 162.9 kg of packaging waste was generated per inhabitant in the EU-28. This quantity varied between 48.3 kg per inhabitant in Croatia and 220 kg per inhabitant in Germany. 'Paper and cardboard', 'glass', 'plastic', 'wood' and 'metal' are, in that order, the most common types of packaging waste in the EU-28. Other materials represent less than 0.3 % of the total volume of packaging waste generated in 2014.

Table 1 shows the recovery and recycling rates of the EU-28 Member States and EFTA countries for 2014, according to which Belgium held both the highest recovery rate (99.2 %) and the highest recycling rate (81.3 %).

***Table 1**. Recovery and recycling rates for packaging waste, 2014.*

Country	Recovery rate	Recycling rate
EU-28*	78.6 %	65.5 %
Belgium	99.2 %	81.3 %
Bulgaria	62.2 %	62.0 %
Czech Republic	78.6 %	73.0 %
Denmark	89.5 %	67.4 %
Germany	97.8 %	71.4 %
Estonia	82.0 %	60.3 %
Ireland*	88.1 %	70.2 %
Greece*	52.8 %	52.4 %

[1] https://www.eea.europa.eu/themes/waste/municipal-waste/municipal-waste-management-across-european-countries
[2] http://ec.europa.eu/eurostat/statistics-explained/index.php/Packaging_waste_statistics

Spain	75.0 %	68.7 %
France	74.6 %	65.2 %
Italy	76.4 %	65.4 %
Croatia	52.8 %	52.7 %
Cyprus	58.7 %	58.7 %
Latvia	58.4 %	54.9 %
Lithuania	57.9 %	57.7 %
Luxembourg	96.1 %	64.9 %
Hungary	59.7 %	52.3 %
Malta	41.3 %	41.1 %
Netherlands	93.9 %	68.5 %
Austria	96.2 %	66.6 %
Poland	60.0 %	55.4 %
Portugal	64.1 %	61.0 %
Romania	56.4 %	54.8 %
Slovenia	88.1 %	70.4 %
Slovakia	68.0 %	65.4 %
Finland	98.3 %	57.4 %
Sweden	77.9 %	70.5 %
United Kingdom	64.1 %	59.2 %
Iceland*	56.5 %	41.8 %
Liechtenstein	91.2 %	51.9 %
Norway	96.7 %	55.7 %

* Estimated: Iceland (2012 data); Ireland, Greece (2013 data)

The EC set some targets for European countries to be adopted in 2001 (50–65 % target on recovery) and in 2008 (60 % recovery rate, between 55 % and 80 % of packaging waste to be recycled with minimum rates of 60 % for glass, paper and cardboard, 50 % for metals, 22.5 % for plastics; and 15 % for wood). In 2015 (EC, 2015), the European Commission proposed new targets for municipal waste of 60 % recycling and preparing for reuse by 2025 and 65 % by 2030.

These targets are calculated according to weight, by dividing the amount of packaging waste recycled by the total amount of packaging waste generated.

Waste to be reused on a different site, recycled or disposed of needs to be transported to the location of treatment or disposal. Transportation of waste materials increases the number of polluting vehicles on EU roads both between place of production and treatment of waste creating air and noise pollution, congestion and all other problems relating to road transport.

Transportation of waste will always be an issue, however tools and methods for ways of reducing waste transportation will be essential to support companies Europe wide and where there is a need to transport waste, considerations should be made to utilise the most sustainable mode of transportation available.

1.1 Scope

The work in WP3 is focused on the optimization of the transport process of packaging waste from the urban containers to the sorting plants. It includes:

- A software platform to gather all data

WP3 will develop a web-based platform with a geolocation layer to track containers position and all the information associated to them, including filling status of each container, remaining labels, alarms and alerts, etc. In addition, the platform will register the users' information and their performance. Finally, it will also include information about the position of the truck and the parameters measured on it (speed, acceleration, fuel consumption, etc.)

The platform will include an interactive interface, which will provide information to users: checking their recycling bonuses, communicating day-by-day questions or incidents, sending their opinions, etc.

- A truck traceability system

A system of sensors will be connected to the CAN-Bus of each vehicle of the waste collector fleet. These sensors will measure the key parameters to optimize the performance of the vehicles and the driving: time of use of the power take-off (PTO) of the waste collectors, excess of speed, RPM excess, acceleration, sudden braking, fuel consumption and excessive idling, etc.

The data from the sensors will be sent via GPRS in a programmed way and saved in the digital cloud platform.

- Algorithms for route optimization

Algorithms for the design of a route optimization system will be defined, based on the information collected from containers. These algorithms will be integrated in the platform, allowing to define and modify routes in a GIS-based solution, accordingly to the containers status.

The module for route optimization will be tested in order to confirm that all requirements established in the description of the general architecture of the collection and transport system are fulfilled.

- Guidelines for efficient driving

After analysing the information gathered by the truck traceability system, the optimal operating values will be established.

Based on this information and the optimal operating values, a guidance and best practices report will be developed, to be applied in the pilots in other parts of the project.

Finally, the definition of the compensation policies, based on a characterization protocol of unitary garbage bags, is also defined in this WP.

Incentive policies will be designed taking into account the public administrations and stakeholders such as neighbourhood associations. This will be based in the smart container gathered information, but also on current legislation and tendencies in the different pilot countries.

Characterization protocol will also be developed, which leads to a cost-efficient way to know the quality of segregation of single garbage bags with packaging waste.

It should be noted that WP3, and specially D3.1., is highly connected to 'WP2: Collection' and 'WP6: Integration and validation'.

1.2 Objective

D3.1. should integrate the main initial results of WP2 and the initial expectations defined in the first task of WP3, therefore, its objectives should be aligned with the objectives of both WPs.

PlastiCircle project has stablished the main targets for WP3, including:

- The development of innovative and efficient transport systems aligned with the smart container developed in WP2.
- The definition of the route optimization algorithms.
- The development of efficient driving guidelines for waste collectors.
- The definition of the compensation procedures to increase the quality of collected packaging.
- The integration of the information received from the different sources of data.
- The reduction of the cost of packaging waste collection: compaction level (35 kg/m3), filling level when collection (80%), fuel consumption (15 l/t)

By its side, WP2 pretends to:

- Design and develop an optimized solution for smart collection.
- Increase packaging collection rates to 87%.
- Design a smart container able to identify each user and garbage bag.
- Assure robustness of the solution adopted, including anti-fraud measures.

1.3 Methodology

In order to avoid overlaps among D2.1 and D3.1. (same deadline), D3.1. is focused on the work to be developed in WP3, including: truck tracking, routing, eco-driving, communications protocols and rewarding and incentive policies, while D2.1. establishes the main requirement of the collection system, focusing on the development of the container characteristics.

D3.1. analyses the current situation concerning waste collection and transport in Europe (*Section 2*), but specially focusing on the three pilot cities which are part of the PlastiCircle consortium: Alba Iulia, Utrecht and Valencia (*Section 3*). For this purpose, a questionnaire (see *Annex A: City description questionnaires*) has been developed to be completed by city responsible and waste management companies operating in these cities. Data collected is the basis for an optimal definition of the systems to be developed in PlastiCircle following tasks.

In addition, D3.1. reviews the main available systems and technologies in use for optimizing waste transport systems. A research on technologies and guidelines have been performed, in order to extract the main considerations and requirements to take into account for the definition of systems (Section 4).

Section 5 includes the identification and definition of main users of PlastiCircle transport management and rewarding procedures and technologies and its specific requirements and necessities.

Finally, the document presents and schemes and a description of the whole collection and transport systems (*Section 6*) and its interrelation with the complementary modules, which will be replicated in D2.1. focusing on the collection module.

2. Different collection systems in Europe

In the European Union, several types of collection systems for packaging waste have merged. A description for the most relevant collection systems is showed below: bring banks, Door-to-Door and recycling yards, on the one hand, or separate collection vs. co-mingled collection on the other side.

2.1 Collection types

2.1.1 Bring banks

Bring banks are fixed recycling site facilities that allow members of the public to bring their dry recovered materials for recycling whenever they want to. They are usually positioned in easily accessible locations with good roadside parking to make recycling as convenient as possible.

The Bring Banks collection system lets the collection of waste and recyclables in separate container, above ground or underground, in close proximity to the end user (usually max. 100-200 m distance) and spread in sufficient number across residential areas[3].

The advantage of bring banks systems over door to door (D-t-D) collection is that they allow people to recycle in the most convenient way for them, rather than having to wait for fixed collection days and hours[4].

WRAP[5] (Waste & Resources Action Program in UK) has published a guide for local authorities to help Officers improve the performance of bring recycling sites. The guide describes how to review current bring recycling provision, including performance monitoring, to better inform future decisions about on bring recycling, as part of the overall service provided to residents[6].

2.1.2 Door to Door (D-t-D)

The D-t-D collection (also called kerbside collection) consists on the direct collection of materials from individual households (or shops), either from door or kerb. Almost any domestic waste stream can be collected from the streets by a D-t-D system: residual waste, bio-waste, packaging, paper and cardboard and

[3] IMPACTPapeRec Project (2016) http://impactpaperec.eu/wp-content/uploads/2016/11/IMPACTPapeRec-D3.1_public-version.pdf.
[4] Palm Recycling (2017) http://www.palmrecycling.co.uk/materials-recycling/bring-bank-collections/.
[5] Consider that WRAP is the Waste & Resources Action Program in UK which means that exist differences with the European collection systems
[6] 12. WRAP (2013) http://www.wrap.org.uk/sites/files/wrap/Bring%20Site%20Draft%20Report%20v5%20JB%20amends_0.pdf.

glass. D-t-D collection of glass is more unusual, due to possible breakage and the risk of accidents that entails. It is also possible to limit D-t-D collection to residual waste and bio-waste and combine it with road containers for the other fractions. The results of D-t-D collection achieved in municipalities could be superior in some cases, both regarding the amount collected and the quality of separation. Indeed, in areas with D-t-D collection, separate collection rates rise up to 60 - 85% regarding the total MSW generation, whereas other systems range between 20% and, at most, 50%[7]. This difference is to a great extent since in D-t-D schemes the residual waste is collected individually and only on few established days of the week, whereas in other systems there is always the possibility to dispose of residual waste in publicly accessible containers. The philosophy behind D-t-D is to turn separation at source into the most convenient option and discourage the delivery of great amounts of residual waste.

Implementation of D-t-D collection has proved very successful in areas with lower population density, where it is easier to identify the origin of the waste and recyclables. D-t-D collection systems require a change of habits on the part of the public, which could be achieved through an adequate communication campaign.

D-t-D collection models make possible to identify waste generators and therefore enable to implement fairer payment systems, such as PAYT (payment for generation, e.g. payment per bag or payment per bin)[8]

2.1.3 Recycling yards

Recycling yards are public installations with free and open access for the citizens, where urban waste and recyclables that must not be deposited in standard street containers is collected, selected and recovered. They are particularly aimed at those residues whose components, after a treatment process, can be reused as raw material in the process of manufacturing new products[9]. This kind of installations require usually qualified staff available[10].

The kind of materials that are accepted in each recycling yard varies depending on the site, so it is important to publish in the municipality website the location, opening hours and type of material collected.

[7] Regions for Recycling http://www.regions4recycling.eu/upload/public/Good-Practices/GP_ARC_door2door-collection.pdf
[8] ZERO WASTE http://www.med-zerowaste.eu/deliverables/DST_Final/index.files/Page1712.htm
[9] Ecovitrium http://www.ecovitrum.eu/ver/146/Qu%C3%A9-es--punto-limpioecoparque-.html
[10] IMPACTPapeRec Project (2016) http://impactpaperec.eu/wp-content/uploads/2016/11/IMPACTPapeRec-D3.1_public-version.pdf

2.2 Separation grade

2.2.1 Separate collection

The Waste Framework Directive (WFD) defines separate collection in Article 3[11] as follows: 'separate collection' means "the collection where a waste stream is kept separately by type and nature to facilitate a specific treatment". In other words, ´separate collection´ is setting aside recyclable materials from the waste stream before they are collected with other municipal solid waste, to facilitate recycling. In addition, separate collection of compostable materials, to facilitate composting[12].

In these sense, separate collection of individual waste fractions is seen as a pre-condition for fostering high quality recycling and high recycling rates. Thus, Article 10 of the WFD sets the general requirement of separate collection and obliges the Member States to set up separate collection systems for at least paper, metal, plastic and glass by 2015[13].

The waste separate collection facilitates the recycling of this waste, which allows to[14]:

- Decrease the consumption of raw materials
- Save water and energy
- Minimize greenhouse gases emissions
- Increase useful life of landfills

In this kind of collection, citizens play a key role in the separation of the waste in the households, markets, offices and services, placing the urban waste in the different containers.

2.2.2 Co-mingled collection

Co-mingled collection is the traditional system in which all recyclables are collected together. The main drawback of this system is the difficult in the subsequent treatment of the materials collected due to their low quality.

In co-mingled collection, the paper and board is collected together with other recyclables such as metal, plastics and glass in a different stream than residual waste. Also called multi-material collection.

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[11] European Comission (2015) http://ec.europa.eu/environment/waste/studies/pdf/Separate%20collection_Final%20Report.pdf
[12] IMPACTPapeRec Project (2016) http://impactpaperec.eu/wp-content/uploads/2016/11/IMPACTPapeRec-D3.1_public-version.pdf
[13] European Comission (2015) http://ec.europa.eu/environment/waste/studies/pdf/Separate%20collection_Final%20Report.pdf
[14] Extremadura, Junta de http://extremambiente.gobex.es/index.php?option=com_content&task=view&id=377&Itemid=578

Co-mingled collections face quality problems from three sources: householders putting the 'wrong' materials into the collection, compaction of the waste which breaks glass into small pieces and tends to bind materials together, and the technical and physical capacity of the MRF to separate materials in the volumes delivered to them[15].

A simple example of quality issues is paper and board. If paper and board is stored separately from other waste streams and kept dry it can be recycled. If contaminated with food, and the paper is allowed to get wet, it will become unrecoverable. It will not be recyclable because as fibers within the paper or cardboard become too short, they cannot be knitted again together to make a new product.

WRAP is advising local authorities who are reviewing their arrangements to base their choices on four considerations:

- Quality of materials
- Cost Efficiency
- Cost Effectiveness
- Public acceptability

[15] Cowleys http://cawleys.co.uk/uncategorized/what-does-commingling-mean

3. Description of current system in place in pilot cities

3.1 Alba Iulia

Alba Iulia is a Romanian city, placed in the Transylvania Region, which counts with a population of 74.000 inhabitants (2017), with an extension of 103.6 km^2 and a density of 566 inhabitants/km^2.

Figure 1. Alba Iulia location

The population of Alba Iulia has been slightly increasing during the last years, with an age distribution as indicated in **Table 2**:

Table 2. Alba Iulia population distribution.

Age range	%
0-15	15 %
16-59	65 %
>60	20 %

Population in Alba Iulia lives mainly in flats and individual houses distributed almost equally. According to the statistics provided by the municipality, 31,921 persons lived in 172 associations[16] of apartments in flat buildings. Other part of the population lives distributed among 14,548 individual houses.

There still some work to develop in the environmental awareness of the Alba Iulia

[16] One association is composed by several flat buildings

population, being classified as medium.

Alba Iulia collects separately the 'dry fraction'[17] (all recyclables) from the 'humid fraction'[18] (garbage) for individual homes. A door-to-door collection system is used for the waste collection of individual houses, while in the apartments associations citizens should carry their waste to the bring banks. Alba Iulia collects yearly about 18,000 t of household waste (over 600 kg/household). Collection is performed weekly for individual households and daily for associations of flat apartments.

The Romanian Law of Environment Protection and Local Council Regulation requires selecting the waste in four separate fractions (paper and cardboard, plastic, metal and glass) for associations, while for homes is still in use a two system fraction (wet and dry) The dry fraction, based on a provided "yellow bag" contains recyclable waste. During the pilot test in Alba Iulia, the waste will be selected from the 4 fractions system, using the container dedicated to plastic waste.

The typology of containers available in Alba Iulia for waste collection attends to the next classification:

***Table 3**. Type of containers available in Alba Iulia.*

Type of building	Capacity of container	Number of containers
Apartments in flat buildings	120 l	509
	240 l	n.a.
	1.1 m^3	509 (61 for plastic)
Individual houses	120 l	7,830
	240 l	30
Companies	120 l	828
	240 l	626
	1.1 m^3	273

In the next images are shown the different kind of bins used in Alba Iulia[19].

[17] Stimated weight: 80 kg/m^3
[18] Stimated weight: 280 kg/m^3
[19] Source: Dedeman Romania

Figure 2. Example of 120 l bin.

Figure 3. Model of 240 l bin.

Figure 4. Examples of 1.1 m^3 bins (garbage, light packaging glass and paper)

After collection, Alba Iulia waste manager (Polaris) sorts a big part of waste manually and sells the recyclable materials to specialized companies, for final collection and recycling. Rest of materials and garbage are transported to the waste dump.

Tariffs for waste disposal are approved by Local Council, based on contracts with waste management companies, background notes and other taxes (like waste dump operation). For public areas (like parks, stadium, streets) city hall is paying the services. An environmental tax will also be introduced during 2019. Most of waste collection system is paid by citizens and companies; there are no subsidies. Municipality is paying from local budget for subordinated institutions and for cleaning public spaces, or for educational institutions.

Licensed waste collection companies are selected for midterm contracts (min. 5 years) during a public tender. There will be one operator for the entire district as soon as new waste dump will be available. For companies, there are also small recycling companies, approved and controlled by the Environment Agency.

Regarding the legal framework affecting the waste collection, for entities and administration, there are national laws (Law 101/2016 in Romania). As part of contract between municipality and waste services operator, a regulation is in place regarding organisation and operations of a public service.

Focusing on the plastic packaging waste stream, collection is performed weekly for households and daily for the flat building apartments (or more frequently according to estimated quantities and contract). For this purpose, 9 diesel trucks IVECO Euro 3 (2013) with back end loading are used: 7 with a capacity of 16m3 and 2 with 8m3. Trucks are performing their routes around a central local platform, where trucks begin and finish their journey, with an average distance travelled of 33 km/truck/route, giving a total number of 18,000 km/truck/year. The average consumption of trucks used for collection is around 53l/100km. For the route selection, there is a daily routine, established according to contracted frequency.

Analysing waste flow, there is not enough information available on the amount of plastic packaging waste generated; Polaris is recycling approx. 40t/ year, that is 0,62kg/ citizen, other quantities being collected by other companies. The quality of the waste collected is not measured nowadays, but it is expected to be low, containing mainly PET, plastic bags and cans.

Regarding the pilot experience to be developed in WP6, there is a preferred area, but final routes will be developed according to actual routes, distances between containers, route length and available communication systems. In any case, the area affected will contain 4-5 associations of apartment flat buildings and only if needed for project scope around 50-100 individual houses (more difficult sorting). It is expected to involve 600-800 citizens.

Nowadays, drivers are not using technological applications, in their truck cabin, knowing their daily routine and routes. However, each truck has GPS and simple mobile phones, for reporting position to the dispatch (there are not tablets or smart phones available for drivers).

Alba Iulia has not implemented yet any incentives policy for citizens, while some incentives for recyclable waste are paid to companies. Municipality is analysing the idea of incorporating vouchers or discounts to waste collection tariff for the well-performing users, or projects related to improve collection in public areas.

As a final remark, it is relevant to indicate that current operation system may change in future, according to a district project regarding an integrated waste management system.

3.2 Valencia

The city of Valencia represents the 16% of the total population of the Valencia Region being its capital city and is, demographically and economically speaking the third biggest city in Spain.

The following figure shows the most important socioeconomic figures:

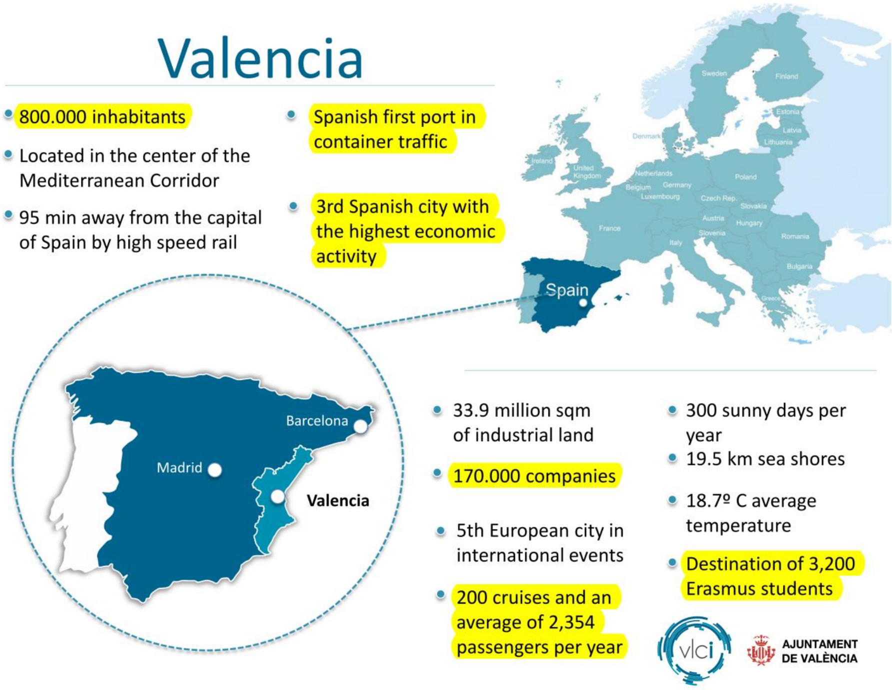

Figure 5. Valencia main figures

Valencia has currently a population around 800.000 inhabitants (787.266 as per census of 2016) and is the center of a vast metropolitan area with more than 1,4 million inhabitants. The city represents the 16% of the population of the Valencian Region and is the third largest city of Spain, after Madrid and Barcelona.

During XX century the population has grown a threefold, especially during the decade of 1960, when the city absorbed a quick and big immigration mass coming from the inner part of the country to work in the industrial areas. This fact triggered not only the housing development, but most important the poor urbanism planning of the new neighborhood built to cover the high demand.

As a result, the city presents the following density map:

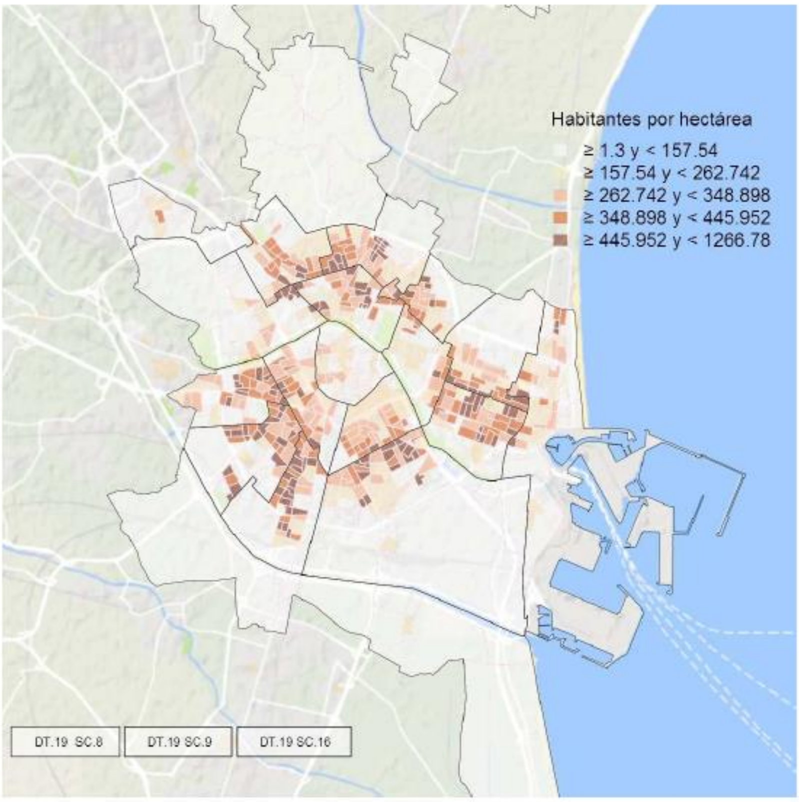

Figure 6. *Population Density Map of Valencia 2016*

During the end of XX century the demographic growth stopped and has lived as slight rise over the first years of XXI century due to the immigration flows and better birth rates.

This fact has enabled the city to bring down the average age of the population, which population pyramid presents a broader based. Currently, the city population is relatively young, with a 15% of the population within the range of 14-29 years and 31 % between 30-49 years old.

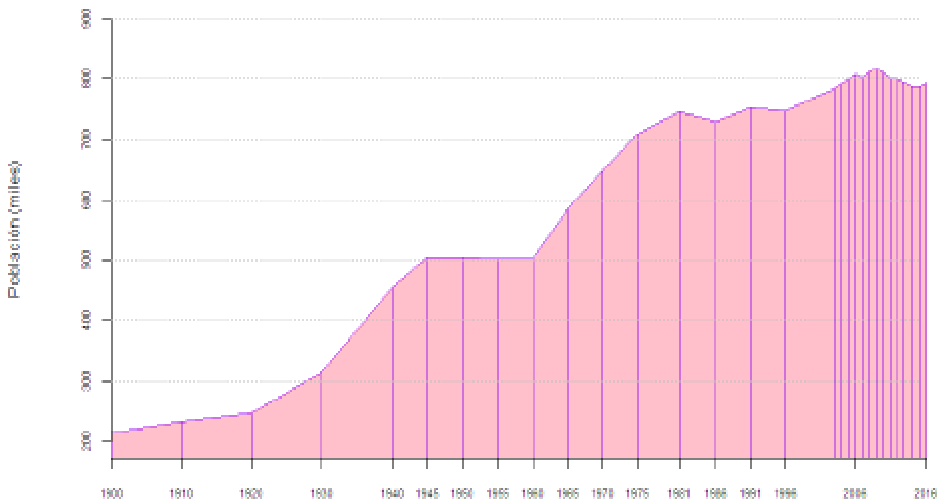

Figure 7. *Demographic evolution*

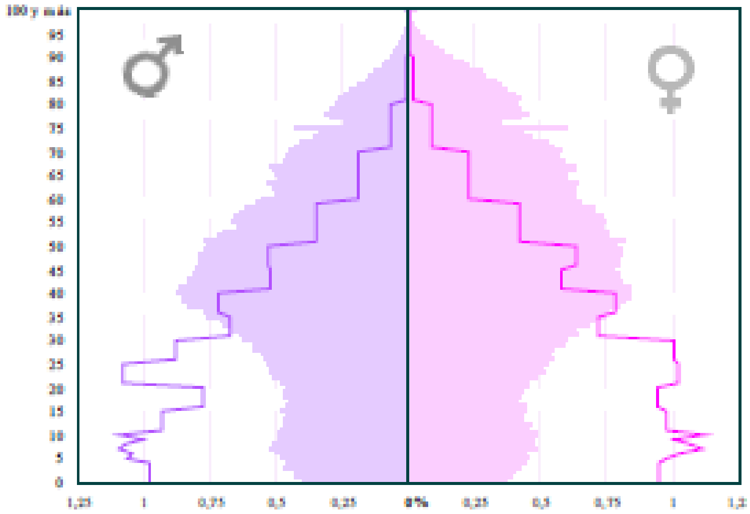

***Figure 8**. Age distribution comparision 1900- 2016*

As a result of the fast urban development of decade 1960, the main kind of housing is the family flat buildings, which rises the population density: Almost 80% of the housing is main family homes and the average size is mainly and almost the 35% of the flats are small-medium sized (76-90 m2).

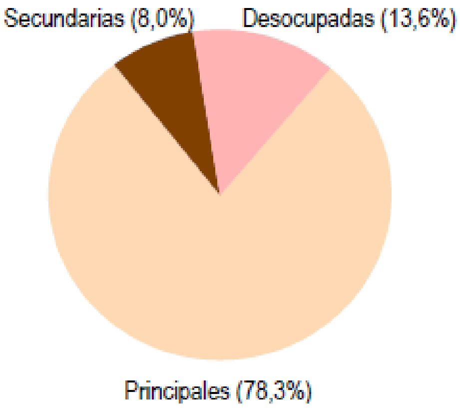

***Figure 9**. Housing use (Statistics 2016)*

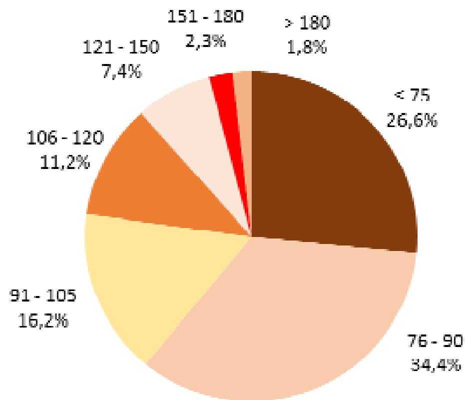

***Figure 10**. Flat size average (Statistics 2016)*

According to the last report on environmental awareness in Spain of EAE business School, there has been a positive evolution in the Spanish society and, of course, in the Valencia Region, which is the fourth region in terms of waste generation. This positive evolution is based in following facts:

- The rate of domestic waste recycling has improved from 4.8% to 74,8% in 2015.
- The use of urban transport, sorting of domestic waste and energy home costs reductions are issues considered as already assumed by Spanish population. The sorting rates are, however, still to be improved in case of electric and electronic devices, plastic, batteries and oils. The main reasons for not sorting are: lack of space at home, lack of containers and distance from home to the containers.
- Population begins taking into account environmental issues in consumption decisions such as cars and long travels
- Population is highly concern about air and water population, whereas it is not aware of the impact of our habits in the extinction of wild habitats and animal species.

Regarding waste collection, nowadays Valencia city is collecting 8 different kind of domestic waste streams:

- Paper & cardboard
- Light packaging: plastic, cans and beverage carton
- Glass
- Used oil
- WEEE
- Bulky products
- Other waste
- Organic (now as a trial pilot)

Waste collection is being performed using a combination of different methods: door-to-door collection for commercial cardboard, bring banks for almost every domestic waste (domestic paper & cardboard, glass, light packaging, organic and other waste) and, finally, eco-parks and mobile eco-parks for other kind of materials (bulky waste, oil, WEEE, etc.)

According to the last data collected by SAV (Valencia's waste manager) in 2016 101,804 t of household waste has been collected.

Table 4. Waste collected in 2016.

Kind of waste	t
Paper & board	4030.468
Light packaging	3026.67
Other domestic waste	94,747.26

The frequency of collection in Valencia varies depending on the waste stream. It is stablished an everyday collection for organic and rest fraction and a 3 days per week frequency for packaging waste streams (paper, light packaging and glass). The company for waste collection also depends on the waste stream: glass is collected directly by Ecovidrio, while all the other different waste streams are collected by SAV & FCC, two waste management companies.

Waste management is legislated by the Municipal Ordinance called 'Ordenanza Municipal de Limpieza Urbana de Valencia', which is needed to be considered for PlastiCircle solutions and pilots.

After collection, garbage and organic waste is transported to a treatment plant in Manises, in exception to the packaging plastic fraction contained in garbage:

- PET
- HDPE Bottles
- HDPE Boxes
- Mixed plastic
- Film

These fractions are sold to the packaging manager company 'BINARIA'.

It is also directly sold to 'BINARIA' the packaging fraction separate collected corresponding to: plastic, cans and beverage cartons. Finally, paper & board is directly sold to a paper manager in Alzira.

Regarding light packaging waste stream, in Valencia it is collected by 3 different companies, depending on the area of the city:

- Sociedad de Agricultores de la Vega (SAV)
- Fomento de Construcciones y Contratas (FCC)
- Fomento Valencia (previously Secopsa but now bought by Grupo Gimeno)

SAV is using around 45 trucks for the waste collection management, being 11 of them specifically used for packaging collection. In the next table are presented the main models and characteristics:

Table 5. Waste collected in 2016.

Brand	Model	Waste stream	Units
DAF	FALF45.220	WEEE (in mobile Eco-parks)	1
MERCEDES-BENZ	ACTROS 2532L – Lateral right	Garbage and light packaging	1
		Garbage, paper and light packaging	3

		Garbage, paper, light packaging and organic	1
		Garbage, paper, light packaging and rest	3
	ACTROS 2532L – Lateral left	Garbage	3
		Garbage and organic	2
	ATEGO 1523	Garbage and bulky waste	1
		Bulky waste	1
	ATEGO 1523 with crane	Bulky waste	1
	ATEGO 2528-L self-loading	Garbage, debris, waste from beaches and gardening	2
	ATEGO 2528-L 18 m3 - SEL with two compartments	Garbage from restaurants and board boxes	2
	ATEGO 2528-L 26 m3 lateral loading right	Garbage and light packaging	1
		Garbage, paper and light packaging	1
	ATEGO 2528-L 26 m3 lateral loading left	Garbage	3
	ATEGO 2529-L 26 m3 lateral loading right	Garbage, paper, organic and light packaging	1
	GAS - ECONIC 1828 GNC 16 m3	Garbage	6
		Garbage and organic	2
	SPRINTER 616 – 6 m3	Garbage	4
		Garbage and bulky waste	3
NISSAN	CABSTAR 105.35 L1	Waste from beaches	1

The majority of vehicles used are collectors or single-side-loading equipment Ros Roca FMO 17 with MB Actros 320 HP motorization. The collection process of the collector is done with a single operator who will be the driver of the vehicle, performing the tasks without having to get off the truck. He carries out the tasks with the help of a control panel placed in the cabin. The visualization of all the operations is done through the different television cameras (6-8), placed in strategic places of the vehicle.[20]

The control panel incorporates two 6" television monitors that allow to observe the align of the equipment with the container, and the evolution of the process of loading, emptying and unloading.

Figure 11. Example of truck used i Valencia

It has the following characteristics:

- **Brand:** ROS ROCA FARID
- **Model:** FMO 17
- **Capacity:** 17 m3
- **Chasis:** Mercedes Benz
- Lateral elevator with arms for 2 containers of 2.400 and 3.200 litres loading, according to the norm EN 12574.
- **Equipment:**

Three external cameras (centered of the container, lifting action area and global vision) with monitors in the cabin.

- • Three white lights for night work
- • Approved amber colored rotating beacons
- • CE certification according to the Machine Safety Directive 98/37 / EC
- • CE certification according to acoustic emission directive 2000/14 / EC
- • CE certification according to the electromagnetic emission directive 95 /

The analysis of the characteristic curves of the specific performance of the

[20] Jerónimo Franco PhD Tesis. "Diseño de una metodología para la obtención de soluciones a la recogida de FORM en entornos Smart Cities"

engine, will allow to determine the rpm range with a suitable power of the engine and a discrete consumption. This will allow to achieve more efficient driving with a reduction in GHG emissions.

In some models it is difficult to access the curves, since most manufacturers do not provide it in the technical documentation of the engines. Fortunately, Mercedes Benz Spain has provided almost all of the necessary curves for the experimental part.

The curves of the MB Actros 320 kW motor indicate that at 1800 rpm maximum power is available, as well as a lower specific consumption than at higher rpm, **Figure 12.** Therefore, these are the values that should be used in the optimized driving model.

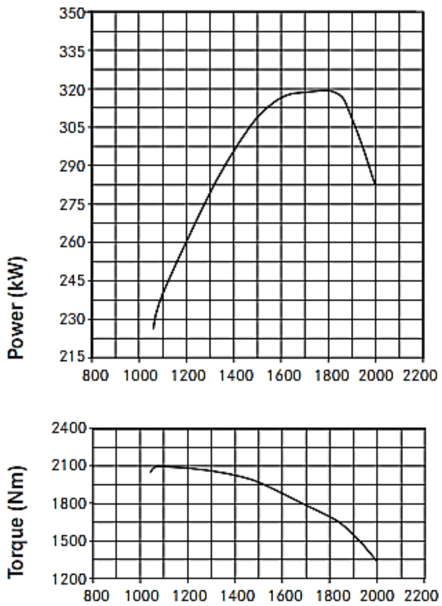

***Figure 12.** Power curve (MB Actros 320 kw)*

Collection trucks date from 2006 and their average consumption varies around 47l/100km.

Each vehicle travels in average between 3,500 km and 92,000 km per year (depending to the vehicle). Usually, packaging collection trucks are distributed in 4 routes, with 90 containers each one, and a capacity of 3,200 litres per container. Routes start in SAV facilities placed in the municipality of Papiporta (16 km far form Valencia) and usually end in the treatment plants of Manises (15 km) Picassent (18 km) and Alzira (45 km), travelling in average around 109.82 km/truck-day. They are established through predefined lists that have been developed considering the experience of drivers over the past years.

Regarding the pilot experience to be developed in WP6, Valencia has decided to use ‘San Marcelino’ area as ‘pilot neighbourhood’. In the following tables are included some statistic data about this neighbourhood.

Table 6. Evolution of the population.[21]

1991	1996	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
10,555	10,154	10,386	10,385	10,427	10,187	10,115	10,058	9,905	9,923	9,971	9,963

Table 7. Extension and population density.

Population	Extension	Density
9,963	33	301.9

Table 8. Population per gender and age.

	Total	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	+80
Total	**9,963**	764	897	1,003	1,336	1,600	1,483	1,352	872	656
Men	**4,884**	414	480	508	672	836	720	628	394	232
Women	**5,079**	350	417	495	664	764	763	724	478	424

Table 9. Origin of the population.

	Valencia region	Rest of Spain	Rest of EU	Europe (no EU)	Africa	North America	Central America	South America	Asia
Total	6,617	2,300	305	43	181	2	50	241	224
Men	3,297	1,031	152	20	111	2	25	103	143
Women	3,320	1,269	153	23	70	0	25	138	81

Table 10. Gender and level of education.

	<18 years old	Illiterate	Less than school	School or similar	High school and university
Total	1,488	57	2,586	3,321	2,511
Men	804	12	1,136	1,713	1,219
Women	684	45	1,450	1,608	1,292

[21] Municipal Population Census. 01/01/2017

***Table 11**. Size of households.*

Nº people living	Nº households
Total	4,156
1	1,269
2	1,221
3	863
4	574
5	137
6	46
>=7	46

***Table 12**. Demographic indicators.*

Indicator	Value
Ratio of masculinity[22]	96.2
Average age	45.4
Index of aging[23]	172.2
Over-aging Index[24]	15.3
Demographic dependency index[25]	54.8
Index of structure of the active population [26]	138.0
Replacement index of the population in active age[27]	139.7
Demographic Progressivity Ratio[28]	91.0
Percentage of foreign population	10.5

[22] It is the relationship between the number of men and women in a population given that it is usually expressed as the number of males per each 100 women
[23] Expresses the relationship between the number of older adults and the number of children and young people, calculated as the ratio between people aged 65 and over with respect to people under 15, multiplied by 100.
[24] The number of people over 75 years old of age for each person over 65, calculated as the ratio between people aged 75 and over compared to those 65 and over
[25] It is the relationship between people who by their age are defined as dependents (under 15 years old and over 64) and those who are defined as economically reproductive (15-64 years old) within a population.
[26] Ratio between the population of 40 to 64 years old and the population of 15 to 39 years old.
[27] Percentage of people aged 15 to 24 years old over the total number of people aged 55 to 64 years old
[28] Ratio between the population of 0 to 4 years old and the population of 5 to 9 years old.

3.3 Utretch

Utrecht is a Dutch city and municipality, capital and most populous city of the province of Utrecht. It is located in the eastern corner of the Randstad conurbation and is the fourth largest city in the Netherlands with a population of 345,080 in 2017. Utrecht's ancient city centre features many buildings and structures several dating as far back as the High Middle Ages. It has been the religious centre of the Netherlands since the 8th century.

Utrecht is a growing municipality and projections are that the city's population will surpass 392,000 by 2025. Utrecht has a young population, with many inhabitants in the age category from 20 and 30 years, due to the presence of a large university. About 52% of the population is female, 48% is male. The majority of households (52.5%) in Utrecht are single person households.

About 69% of the population is of Dutch ancestry. Approximately 10% of the population consists of immigrants from Western countries, while 21% of the population is of non-Western origin (9% Moroccan, 5% Turkish, 3% Surinamese and Dutch Caribbean and 5% of other countries).

Management of household waste and recycling in the Netherlands is under the responsibility of local authorities. Different localities implement different systems. Environmental tax is due for the service and may be billed monthly or included in a rental contract.

Municipalities all over the country publish a calendar, on a yearly basis, of the pickup dates and the addresses of the waste separation and recycling stations.

- **General Household Waste**
  - Residual waste (restafval) is any non-recyclable, non-hazardous, household waste. It should be put in the dark green or grey containers on the street. In some blocks, rubbish is put into large underground collection vats accessed via a locked above-ground chute. Local residents are issued keys.
- **Recycling**
  - Organic waste should be put in the green container, in those that collect this refuse to compost.
  - Glass should be put in special containers for class, separating white (wit glas) from coloured (bont glas). Households are not issued with a glass container. Instead there are several drop-off points in each area.
  - Plastic waste should be recycled in containers marked Plastic verpakkingen. Households are not issued with a plastic

container. Instead there are several drop-off points in each area.

- Paper and cardboard should be recycled in designated containers. A designated paper recycling bin can be issued to a household on request to the local council. Otherwise, paper can be recycled at any of the recycling drop-off points in the neighbourhood.

The city of Utrecht has underground containers. For residual waste they connect 50 addresses with pass identification to an underground container. Plastic waste containers are not connected to addresses, yet in a general rule about 60 households can be connected to 1 underground container. This is based on that the containers are emptied once a week

Figure 13. *Example of containers in Netherlands*[29]

In some areas of the city, where there is less space to place underground containers they empty them more often so more households can be connected to 1 container.

So in general, for the pilot activities they are planning to execute it in an area of 2.000 households, which will suppose the use of approximately 40 underground containers.

[29] http://www.tctubantia.nl

4. Waste transport management and rewarding systems and its main requirements

4.1 Truck tracking and data gathering

A vehicle tracking system combines the use of automatic vehicle location in individual vehicles with software that collects these fleet data for a comprehensive picture of vehicle locations. Modern vehicle tracking systems commonly use **GPS or GLONASS technology** for locating the vehicle, but other types of automatic vehicle location technology can also be used. Vehicle information can be viewed on electronic maps via the Internet or specialized software.

Vehicle tracking can be classified as 'passive' and 'active'. Passive devices store location (and additional data required). Once the vehicle returns to a predetermined point, the device is removed and the data downloaded to a computer for evaluation. 'Active' devices also collect the same information but usually transmit the data in near-real-time via cellular or satellite networks (e.g. GPRS) to a computer or data centre for evaluation. Nowadays, many modern vehicle tracking devices combine both active and passive tracking systems: when a cellular network is available and a tracking device is connected it transmits data to a server, when a network is not available the device stores data in internal memory and will transmit it later when the network becomes available again.

Historically, vehicle tracking has been accomplished by installing a box into the vehicle, either self-powered with a battery or wired into the vehicle's power system. Nowadays, many companies are increasingly interested in the emerging cell phone technologies that provide tracking of multiple entities.

Vehicle tracking systems are commonly used by fleet operators for fleet management functions such as fleet tracking, routing, dispatching, on-board information and security.

GPS fleet tracking may include data collecting functions that record driver events such as speeding, harsh braking, rapid acceleration and sudden cornering. This information can be used to evaluate driver performance and develop individualized retraining to improve driver skills. Real-world experience shows that GPS data analysis can promote safer driving habits in personal use and in fleet operations.

The benefits of this are twofold: it can lower the risk of accidents, violations and other incidents that impose a financial penalty on a commercial carrier, and it helps drivers maintain good practices to protect the vehicle.

There are also another series of factors that can define driving behaviour and energy consumption and, which should be measured in order to get a global characterization of the fleet performance as:

- Start & stop
- Break use
- Acceleration
- Electronics devices use
- Engine Spinning
- Etc.

The modern automobile may have as many as 70 electronic control units (ECU) for various sub-systems. Typically, the biggest processor is the engine control unit. Others are used for transmission, airbags, antilock braking/ABS, cruise control, electric power steering, audio systems, power windows, doors, mirror adjustment, battery and recharging systems for hybrid/electric cars, etc. Some of these form independent subsystems, but communications among others are essential. A subsystem may need to control actuators or receive feedback from sensors.

The **Controller Area Network** (CAN, also known as CAN Bus) is a vehicle bus standard designed to allow electronic control units and devices to communicate with each other in applications without a host computer. As an alternative to conventional multi-wire looms, CAN Bus allows various electronic components (such as: electronic control units, microcontrollers, devices, sensors, actuators and other electronic components throughout the vehicle) to communicate on a single or dual-wire network data bus up to 1 Mb/s.

Figure 14 shows a simplified schematic diagram of the CAN system and shows some of the possible units/devices that can be connected onto the CAN bus.

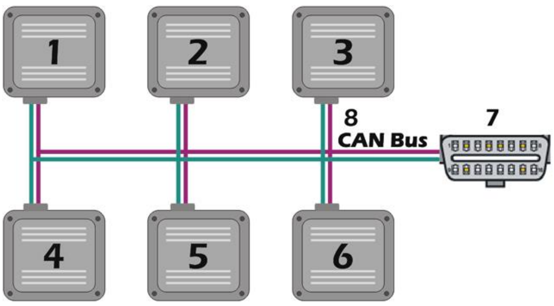

Figure 14. *CAN System Schematic Diagram*[30]

[30] Kiril Mucevski, 2015. Automotive Controller Area Network System.

Being:

1. Engine Management Electronic Control Unit
2. Transmission Electronic Control Unit
3. Anti-Lock Braking Electronic Control Unit
4. Traction Control Electronic Control Unit
5. Airbag Electronic Control Unit
6. Power Steering Electronic Control Unit
7. On-Board Diagnostic (OBD) Connector
8. Controller Area Network (CAN Bus)

However, the continuous increasing in the bandwidth requirements in automotive networks limits the applicability of CAN due to its bit rate limitation to 1 MBit/s. To close the gap between CAN and other protocols, CAN protocol improved in two different ways: support of bit rates higher than 1 MBit/s and support of payloads higher than 8 bytes per frame. A new frame format was developed which can switch inside the frame to a faster bit rate or use a different data length coding. This new protocol is called CAN with Flexible Data-Rate (CAN FD).

As CAN is a multi-master interconnection protocol between nodes, it might be defined two CAN types, according to its connexion and speed:

- High speed CAN: Standardized in ISO 11898-2. Uses a two-parallel wire to interconnect all nodes.
- Low speed or fault tolerant CAN: Standardized in ISO 11898-3. All nodes may be connected by a linear bus, star bus or multiple star buses connected by a linear bus.

The CAN-BUS system covers the two lower levels of the ISO/OSI model protocol (Open System Interconnection): physical and the data link layer (transfer and object).

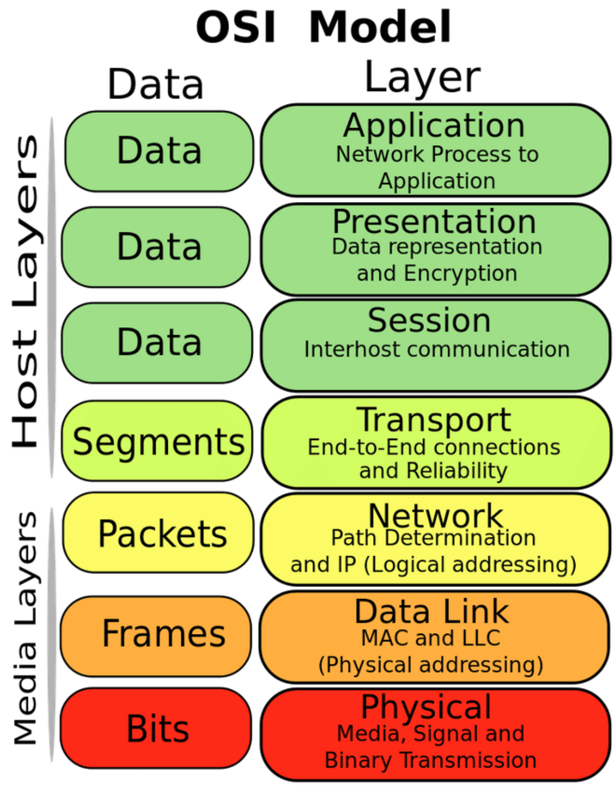

Figure 15. *ISO/OSI model.*

The Physical Layer describes the transmission of the signals taking into account how the physical medium between nodes is defined. The Transfer Layer presents messages received to the object layer and accepts messages to be transmitted from the object layer. The transfer layer is responsible for bit timing and synchronization, message framing, arbitration, acknowledgment, error detection and signalling, and fault confinement.

As exposed before, the International Organization for Standardization (ISO) adopted the CAN-bus protocol in 1993. The ISO 11898 stablishes the standard requirements in CAN protocols and is divided in different parts:

- ISO 11898-1:2015, Part 1: Data link layer and physical signalling.
- ISO 11898-2:2003, Part 2: High-speed medium access unit.
- ISO 11898-3:2006. Part 3: Low-speed, fault-tolerant, medium-dependent interface.
- ISO 11898-4:2004, Part 4: Time-triggered communication.
- ISO 11898-5:2007, Part 5: High-speed medium access unit with low power mode.
- ISO 11898-6:2013, Part 6: High-speed medium access unit with selective wake-up functionality.

In addition, the ISO 16845-1:2016 (and following parts) stablishes conformance testing for CAN devices.

Moreover, CAN in Automation (CiA) was created in 1992 as a group of members with the aim for providing specifications of the CAN protocol and promoting the image of the CAN technology.

On the other hand, on-Board Diagnostics (OBD) systems were designed originally in California by the California Air Resources Board (ARB) with the aim to reduce emissions on fuel injection vehicles in the 1980s. The Electronic Control Unit (ECU) manages all data recorded by the sensors (inputs) to control actuators of the system (outputs). So that, the performance of the engine may be changed according to the situations.

First versions of electronic injection systems might be checked by an indicator, known as "check light" or Malfunction Indicator Light (MIL). In more modern systems, hundreds of parameters are managed by the ECU, so that the entire electronic system may be checked by using a connector or port and an appropriate scan tool. In this first generation of OBD (OBD I) systems, each vehicle manufacturer used its own connector and scan tool.

In the 1990s, Society of Automotive Engineers (SAE) and International Standardization Organization (ISO) developed and standardised how the scan tool and the ECUs intercommunicate each other. Since 1994, every vehicle is required to use a standard connector (SAE J1962) and a standard OBDII protocol.

4.2 Routing systems for waste collection

The routing problem is also analysed in this chapter. The problem to be solved in this phase of the project is to obtain an optimal route, which minimizes the travel distance of household plastic packaging collection form bring banks, these routes have to comply with a series of restrictions:

- Capacity of collection vehicle
- Number of vehicles available
- Maximum schedule for the route
- Cover demand of 'full containers'

Next graph shows a simplified example of the problem to solve:

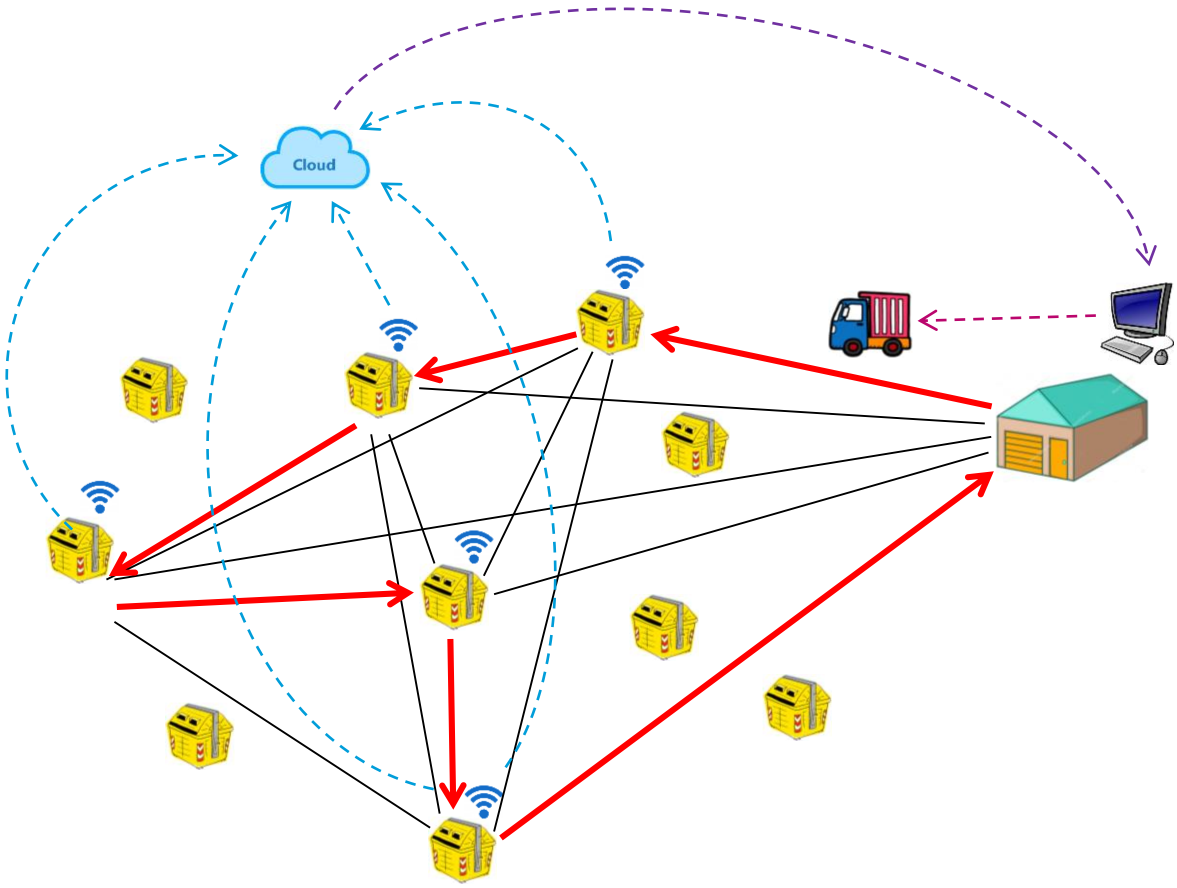

Figure 16. Example of graph for the routing problem.

In this example, it would be 9 containers in an area to be covered by only one truck. Sensors inside the container will send information about their filling level, and this information will be stored in the platform. Optimal route will be calculated considering only those containers being 'full'. The driver will automatically receive this route. The problem would be to also consider the real-time routing. For this purpose, the system will include a re-routing option that will recalculate the route when the truck leaves each node or after a request of the driver (e.g. if an incident occurs).

The problem to be solved is composed of different elements: customers, depots, vehicles and the transport network.

- Customer/demand node (in our case: the container)

Each customer has a certain demand that should be satisfied by some vehicle. In many cases, the demand is a good that occupies a space in the vehicle and it is common that one vehicle alone cannot satisfy the demand of every node or customer in the same route. An equivalent case occurs when customers are suppliers and what is desired is to collect products and transport them to a warehouse. In other cases, the demand is not a good but a service: the customer simply must be visited by the vehicle. The same vehicle could, potentially, visit all customers.

It is usual for each client to be visited exactly once. However, in certain cases it is accepted that a customer's demand is satisfied by different vehicles.

Clients may have restrictions regarding their hours of service (time windows) in which the client can be reached.

The problem with several (different) vehicles is that there may be compatibility restrictions between them and the customers. In these cases, each client can only be visited by some of the vehicles (for example, some very heavy vehicles cannot enter certain locations).

In the particular case of PlastiCircle project, the demand nodes (customers) are the own containers for plastics packaging collection. Containers are suppliers of material that needs to be collected by the waste management companies. It is possible that more than one truck is needed for satisfying the amount of waste generated. Material is usually transported to a sorting plant, so every destination point (for every route) would be this sorting plant. In this particular case, each 'full' container should be visited only once and there are not time windows for each node. Also compatibility between vehicles and demand nodes can be a restriction for PlastiCircle project solution.

- Vehicles

The capacity of a vehicle could have several dimensions, such as weight and volume. When there are different products to be transported, the vehicles could have compartments, so that the capacity of the vehicle depends on the product. In general, each vehicle has a fixed cost associated to it when it is used and a variable cost proportional to the distance travelled.

The problems in which the attributes (capacity, cost, etc.) are the same for all vehicles are called homogeneous fleet, and, if there are differences, they are usually known as heterogeneous fleet problems. The number of available vehicles could be an entry data or a decision variable. The most usual objective is to use the least amount of vehicles and in a second stage to minimize the distance travelled.

Legal regulations may impose restrictions on the maximum time a vehicle may be in circulation and even prohibit the passage of certain vehicles through certain areas. In some cases, it is desired that the amount of work done by the vehicles (usually the travel time) is not very different.

In general, it is assumed that each vehicle travels only one route in the planning period, but lately models have been studied in which the same vehicle can travel more than one route.

For the specific case of PlastiCircle project, vehicles can be different among them (different capacity, engine, average consumption, etc.), so we face a heterogeneous fleet problem. However, there will not be differences in the product to be transported in each city (only one compartment per truck needed). In general, each vehicle will travel only one route in the planning period and the total time to do the complete route will be a restriction.

- Depots

Vehicles are usually located in warehouses. Routes frequently begin and end in the same deposit, although this may not be the case in some applications (e.g. the route could end up in the sorting plant).

In the problems with multiple depots each of them has different characteristics, for example, its location and maximum capacity. It could happen that each deposit has a fleet of vehicles assigned a priori or that allocation is part of what needs to be determined.

Depots, like customers, could have associated time windows. In some cases, you should consider the time necessary to load or prepare a vehicle before your route begins, or the time spent cleaning it when you return. In addition, due to the limitations of the deposits themselves, it might be necessary to avoid too many vehicles operating in the same warehouse at the same time (e.g. the congestion of the depot).

PlastiCircle routes will start from waste manager facilities and, depending on the situation, could end in the same facilities or in a sorting plant, recycling company facilities, etc. Time spent in depots is initially not relevant for our problem definition.

A Vehicle Routing Problem (VRP) can be split in different sub-problems, attending to the different conditions affecting it:

- Capacitated Vehicle Routing Problem (CVRP): It is a VRP where the vehicles have limited carrying capacity of the goods.
- Vehicle Routing Problem with Time Windows (VRPTW): VRP where the delivery locations have time windows within which the deliveries (or visits)

must be made.

- Vehicle Routing Problem with Pick-up and Deliveries (VRPPD): It is the problem where a number of goods need to be moved from certain pickup locations to other delivery locations. The goal is to find optimal routes for a fleet of vehicles to visit the pickup and drop-off locations.
- Vehicle Routing Problem with Backhauls (VRPB): It is a pickup/delivery problem where on each route all deliveries must be made before any pickups.
- Capacitated Vehicle Routing Problem with time windows (CVRPTW): It is a combination of CVRP and VRPTW.
- Capacitated Vehicle Routing Problem with Pick-up and Deliveries and Time Windows (CVRPPDTW): It is the combination of the three initial problems (CVRP + VRPTW + VRPPD).
- Vehicle Routing Problem with Backhauls and Time Windows (VRPBTW): It is a combination of VRPB and VRPTW.
- Multiple Depot Vehicle Routing Problem (MDVRP): In the MDVRP there are several depots available for goods distribution. If the customers and the depots are intermingled, then a Multi-Depot Vehicle Routing Problem should be solved. A MDVRP requires the assignment of customers to depots. A fleet of vehicles is based at each depot.
- Multiple Depot Vehicle Routing Problem with Time Windows (MDVRPTW): It is a combination of MDVRP and VRPTW.
- Mixed Fleet Vehicle Routing Problem (MFVRP): The MFVRP generalises the VRP by including a vehicle fleet composition decision, using a number of heterogeneous vehicle types. Each vehicle type is characterised by its capacity, fixed cost and variable travel cost.

The problem to be solved in PlastiCircle project can be defined as a MFVRP, where the capacity and characteristics (and associated cost) of each vehicle is variable, but all the vehicles start from the same depot and finish in the same point.

A first research on different solving algorithms has been performed. Solving strategies can be classified as:

- Exact: The exact algorithms are those that allow to obtain the real optimal solution to a problem. The exact resolution methods have been applied successfully to a high number of problems. Some examples of these methods are voracious algorithms, divide and beat algorithms, branch and pruning algorithms, backtracking, etc. All these procedures solve optimally and in a reasonable time, problems to the P-class. However, there is a class of problems, called NP, with great practical interest, for which exact algorithms with convergence times in polynomial time are not known. That is, although there is an algorithm that finds the exact solution to the problem, it would take so long to find it that it makes it completely inapplicable. In addition, an exact algorithm is completely dependent on the problem (or family of problems) that it solves, so that when the problem is changed, a new exact algorithm must be designed and its optimality demonstrated.

- Heuristic: For most interesting problems there is no exact algorithm with polynomial complexity that finds the optimal solution to this problem. In addition, the cardinality of the search space for these problems is usually very large, which makes the use of exact algorithms unfeasible since the amount of time it would take to find a solution is unacceptable. Due to these two reasons, it is necessary to use approximate or heuristic algorithms that allow obtaining a quality solution in a reasonable time. The best definition of a heuristic method is provided by Zanakis et al: "Simple procedures often based on common sense that are supposed to get a good (not necessarily optimal) solution to difficult problems in a simple and fast way".

  The heuristic algorithms are usually classified as:

  - Constructive methods: Procedures that are capable of constructing a solution to a given problem. The way to build the solution depends strongly on the strategy followed.
  - Search methods: They start from a given feasible solution and from it they try to improve it.

  The main problem presented by heuristic algorithms is their inability to escape from local optima. To solve this problem, other, more intelligent search algorithms are introduced that avoid being trapped in them as much as possible. These more intelligent search algorithms, called meta-heuristic, are high-level procedures that guide known heuristic algorithms, preventing them from falling into local optima.

- Meta-heuristic: To obtain better solutions than traditional heuristics, it is necessary to choice techniques that carry out a better exploration of the solutions space. Metaheuristics are generic procedures for exploring the space of solutions for optimization and search problems. They provide a design line that, adapted in each context, allows generating solution algorithms that, in general, obtain better results than classic heuristics, although incurring in longer execution times (which, in any case, are inferior to those of the exact algorithms). Some examples of application of these algorithms are:

  - Ant algorithms are agent-based procedures that use randomized construction methods and cooperate with each other by sharing information.
  - Tabu-Search Algorithms are local search methods that accept to

make the solutions worse to escape local optima.

- Genetic Algorithms are based on keeping a set of solutions diverse enough to cover a large part of the solution space.

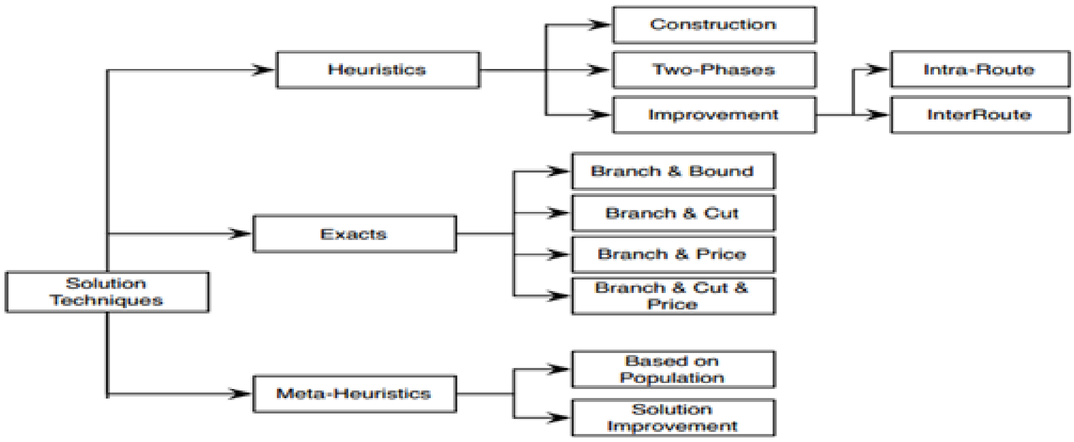

Figure 17. VRP solution techniques[31].

For the resolution of PlastiCircle routing problem, due to the need for a high resolution speed, it is not feasible to use an exact resolution algorithm, so the most convenient option could be to use a route construction heuristic algorithm, which we would later improve with two improvement heuristics.

In the last four decades, an enormous effort has been made to solve the routing problems. In 1959, *Dantzig and Ramser*[32] made for the first time a formulation of the problem for a fuel distribution application. Five years later, *Clarke and Wright*[33] proposed the first effective algorithm for its resolution: the popular Savings Algorithm. From these works, the Vehicle Routing area has notably grown. On the one hand, towards models that incorporate more and more characteristics of reality, and, on the other hand, in the search for algorithms that allow solving problems efficiently.

The central idea of the Savings Heuristics is that the routes are combined, so that when they become a single route, they represent cost savings. A possible solution would combine two different routes (0 ... i, 0) and (0, j ... 0) in a new route (0 ... i, j ... 0).

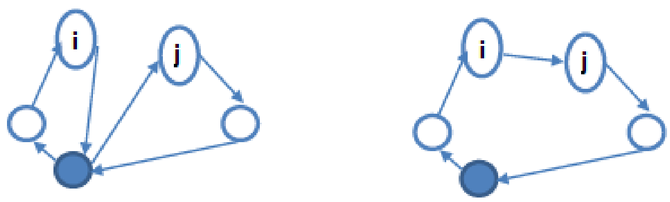

Figure 18. Savings Algoritm graph.

[31] Eliana M. Toro et al. (2014)
[32] Dantzig, G., Ramser, J. (1959). 'The truck dispatching problem'.
[33] Clarke, G., Wright, W. (1964). 'Scheduling of vehicles from a central depot to a number of delivery points'.

Distance savings are calculated as follows:

$s_{ij} = c_{io} + c_{oj} - c_{ij}$

Where s represents the saving of introducing route i, j. The variable c represents the cost of going from i to the origin, or from j to the origin and from i to j. The new solution obtained is the one that generates the greatest savings as long as the restrictions of the problem are not violated. The steps to follow in this methodology are the following:

- Create route (0, i, 0) for each demand node.
- Calculate savings matrix
- Take the maximum saving value and verify if the solution is feasible. If it is, take it as a new solution, otherwise re-calculate savings with a new node.

One of the drawbacks of the *Clark & Wright* algorithm is that it tends to produce good routes when starting, but less interesting routes at the end. To mitigate this, a penalty in the savings function can be introduced for the union of routes with distant customers.

To improve the quality of the solutions obtained, Solomon (1987)[34] developed a variant of the Saving algorithm, which consists of generating a route from the warehouse to each node and the way back to the origin. These routes are merged using the maximum savings of Clarke & Wright. Although this resolution improves the previous solutions, this improvement is quite limited since it only randomizes part of the decision of the candidate's choice.

To improve even more the quality of the solution, GRASP methods aim to solve difficult problems in the field of combinatorial optimization. This technique focuses its effort on building high quality solutions that are subsequently processed to obtain even better ones.

In the construction of these solutions a "greedy" or random criterion is used, creating a list of candidates, which includes the best options to be part of the solution. From that list, a candidate is chosen randomly.

This algorithm, applied to a particular case, consists of iterating the savings algorithm a large number of times (e.g. 500), changing in each of these iterations randomly the candidate that is selected in each joining phase of the nodes of the savings algorithm. In this way they are obtained almost all the optimal possibilities that can occur, selecting the best of them. In addition, local optima are avoided and therefore solution is much closer of the optimal one.

[34] Solomon, M.M. (1987). 'Algorithms for the Vehicle Routing and Scheduling Problems with Time Window Constraints'.

4.3 Eco-driving guides

During the last decade, many national, European authorities and private companies have developed their own eco-driving guidelines[35]. Different European projects have analysed the efficiency of eco-driving style. Some examples of this kind of initiatives are ECOWILL: Ecodriving - Widespread Implementation for Learners and Licensed Drivers[36] or Together on the move[37] projects that developed a guideline related efficient driving.

All the reviewed studies highlight the influence of driving style on the vehicle consumption. Certain habits increase fuel consumption and even lead to premature deterioration of vehicles. In addition, these consequences have an impact in the cities increasing their pollution[38].

Eco-driving is the new way of driving a vehicle efficiently, which aims to achieve low fuel consumption while reducing environmental pollution. At the same time, driving comfort is improved and road risks are reduced.

All the documents analysed specify the main advantages in eco-driving are, being them mainly:

- Energy saving: The driver with his behaviour has a great influence on the fuel consumption of the vehicle, resulting in fuel savings around 15%[39]. This means considerable energy savings.
- Economic saving for companies: Fuel is the main item of expenditure generated by the activity of a commercial vehicle. Higher efficiency in fuel consumption will lead to cost savings and therefore a greater economic benefit for the company.
- Less maintenance costs: Eco-driving reduces not only fuel costs, but also costs for maintenance and costs for repairing cars after accidents. Eco-drivers cause less wear and tear on car parts (tyres, brakes and engine) and are less prone to accidents[40]. Using efficient driving techniques, the average reduction in gearbox utilization has been 30%.
- Greater road safety: Moreover, Eco-driving increases traffic safety. Following eco-driving trainings, the costs for car accidents have decreased by 40%[41]. This is mostly due to driving techniques are based on foresight and anticipation.

[35] Eco-driving uncovered. The benefits and challenges of eco-driving, based on the first study using real journey data. FIAT
[36] https://ec.europa.eu/energy/intelligent/projects/en/projects/ecowill
[37] http://www.together-eu.org/index.php?id=50
[38] Conducción eficiente. Dirección General de Tráfico. Ministerio del Interior (España).
[39] Eco-driving Uncovered. The benefits and challenges of eco-driving. Source: Fiat (2010)
[40] Benefits of Eco-driving. Together on the move.
[41] Drive and save with security. Drive safely, economically and environmentally friendly. Hamburg Water Company.

- Suits to modern engines: The technological evolution in the last few years has significantly changed the design of vehicles, introducing important modifications to the engine and various systems. These modifications have increased vehicle's performance, reducing fuel consumption and emissions. These technological improvements require a new driving style for the drivers in line with the changes to take advantage of the benefices provided[42]. Eco-driving represents a driving culture which suits to modern engines and makes the best use of advanced vehicle technologies.

- Improves comfort and reduces stress levels: Eco-driving is a style of driving more relaxed and calm. Thus, has benefits for drivers' health and improves driver satisfaction because reduces stress and aggressiveness caused by the traffic. A smooth use of the accelerator, steering, transmission and brakes means not only efficient driving, but is also more comfort for the driver and passengers.

- No time loss: Eco-driving style reduces the vehicle stops due to accelerating traffic flow with the vehicle's inertia on the road. The benefit is equal or less travel time, eco-drivers do not take longer to reach their destination, but are often even faster.

- Environmentally and climate friendly: Reduction of fuel consumption through the implementation of efficient driving is linked to a reduction in CO2 and pollutant emissions into the environment.

  Reduction of CO2 emissions achieved by efficient driving reduces local air pollution. Hence, if Eco-driving becomes the norm rather than the exception, it has the potential to significantly reduce emissions from road transport.

- Less noise: Eco-driving has a high impact on the noise that is generated. Avoiding unnecessary high acceleration and using low engine speeds and low vehicle speed values achieve a reduction of the noise in a vehicle.

Driving style is influenced by a complex mixture of social, psychological and cultural factors[43] that affect directly to the driver. But, eco-driving is also influenced by technical factors related to the vehicle. Working parameters that affect the emission of contaminant gases are:

- Speed: High speed driving is one of the key factors in fuel consumption, wind resistance raises exponentially at high speeds, and engines are optimized for a specific speed, temperature and rpm range. Driving outside this parameter goes against the conception of the engine, thus reducing the efficiency.

  The effect of speed increment over the consumption, with engines spinning

[42] Conducción eficiente para conductores industriales. Ministerio de Fomento
[43] https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/ecowill_guidelines_short_duration_trainings_en.pdf

regime, has been one of the key parameters in the experimental part of this study in order to obtain the optimum energy consumption. In graph 4.4 is presented the consumption curve over the speed, where it can be seen that the increase of speed from 120km/h to 140km/h in a diesel vehicle, increases the energy consumption up to a 24,8%

Figure 19 shows how the consumption increases exponentially with the speed. This is caused because at low speeds, between 50-70km/h, fuel consumption depends on the vehicle weight, acceleration and rpm. When the speed increases, aerodynamic resistance becomes the key factor, it increases with the speed.

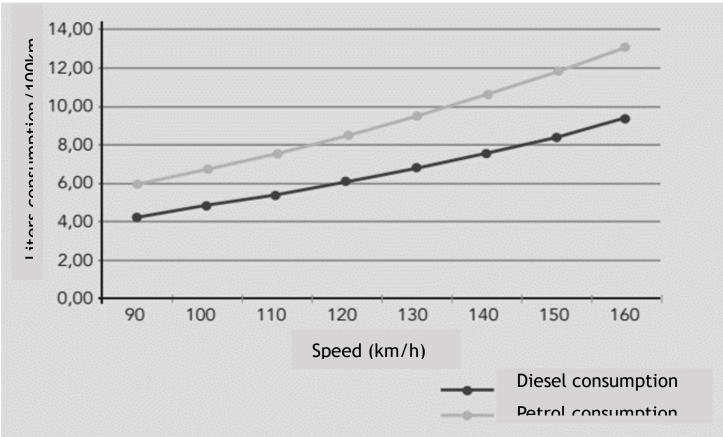

Figure 19. Consumption curve over speed

Aerodynamic resistance depends on the frontal area of the vehicle. This frontal section moves the volume of air by unity of time when the vehicle moves, and defines the mass of air that is needed to move. It is obvious that the more air is moved, more work is required.

The shapes used in trucks are considered dull bodies, being the contribution to the aerodynamic resistance of each part:

- 70% front part design
- 20% back part design
- 10% friction over the body surface.

In nowadays trucks the resistance coefficient varies between 0,55 and 0,75

In conclusion, the consumption of the vehicle increases with speed and that circumstances may arise during the journey. From certain speed the increase of consumption becomes disproportionate.

- Engine Spinning Regime: The workload of an engine is determined by the rotation speed of the crank. The crank transmits the engine potency to the transmission and the wheels. Crank speed is measured in revolutions per minute (rpm). It has been described that a spinning regime is defined by the study of the curves of potency, torque and specific consumption.

Keeping the engine working conditions close to the minimum consumption specification will provide with lower consumption for the same energy produced. Thus, it is recommended to work as close as possible to this point as long as it does not reduce the quality of service.

The lowest specific consumption zones of an engine are those indicated by the manufacturers with the 'green colour' in the revolutions counter. The minimum consumption corresponds to engine speeds in the lower range of maximum torque or slightly lower speeds in modern engines. This speed varies according to engine capacity between 1000 and 1500 rpm.

- Slow motion time: Slow motion time is defined by the period of time when the vehicle is stopped with the engine turned on. Reducing the slow motion time of the vehicles is one of the primary objectives in the experimental part, in order to obtain a significant reduction of fuel consumption, and associated emissions. When the vehicle is working empty, it cannot obtain the maximum working temperature and the combustion is incomplete. In this not ideal combustion conditions the level of emissions increases.

  When slow motion time exceeds 10s, the engine consumes more fuel in comparison to turning it off and on. The fuel consumed during 8 km of driving equals 10 minutes of slow motion. Periods of idling engine operation should be avoided as far as possible, since they generate useless fuel consumption of about 1.5-2 l/hour.

- Power take off time: Modern vehicle electronics control the ignition conditions and fuel flow required for power take off. Pressing the accelerator pedal when the engine is started only results in higher fuel consumption and a mismatch of the ignition electronics. The recommendation therefore is to turn the key and start the engine without pressing the accelerator pedal.

  In addition, accelerator pedal shall be used with the gears engaged and the vehicle in motion.

  In waste container elevation procedure and waste press, the power take-off is active, increasing the spinning regime greatly over slow motion. This raises the consumption promptly, so reducing the time that takes to empty a waste container may reduce the consumption.

- Acceleration and braking: Other relevant factor in performing an efficient driving is the use of vehicle inertia. Putting in motion of an industrial vehicle, due to its great weight, increases consumption, but on the other hand it supposes a generation of energy that can be used.

  To this end, unnecessary braking and acceleration will be avoided. During braking, the vehicle losses energy and as a result of the accelerations made to recover the circulation speed, the vehicle increases the consumption.

  It is recommended to maintain a stable average speed, eliminating as far as possible the peaks and valleys of speed that increase consumption and don't mean reaching the final destination sooner. This means that in order to obtain an efficient driving we need to anticipate the factors that affect a continuous driving, especially in urban cycles.

- Tyres: Over time, tyres will naturally leak a bit of air. A study developed by the RAC[44] indicates that fuel consumption can be improved by up to 2% with a regularly check and maintenance of tyre pressure. Low rolling resistance offers great fuel efficiency. As the tyres wear down, the rolling resistance will likely change, alongside a multitude of other driving factors, such as driving comfort and grip. In addition, well tyre performance increases safety: dozens of people a year die due to poorly-inflated tyres.

  Some considerations to take into account for tyres maintenance are:

  - Checking tyre pressures regularly (monthly) including spare. Over or under inflation can reduce the life of tyres, whilst correct pressures can increase fuel efficiency and save money.
  - Balancing tyres when one is changed will reduce rapid and uneven tread wear.
  - Harsh acceleration and braking or late braking puts more pressure on tyres. Smooth acceleration and planned braking will help prolong the use of tyres and improve fuel efficiency.
  - Overloading the vehicle can have an impact on tyre wear and tyre pressures. Dry steering and high cornering speeds put undue strain on tyres which can cause too much friction and premature wear.
  - Driving or parking up kerbs can seriously damage tyres, causing undue wear and putting undue strain on them.

- Air conditioning use: The air conditioning is the most fuel hungry accessories in a car, increasing fuel consumption by up to 20% when it is in use. With a smaller vehicle the reduction in power is more significant and so is the effect on fuel economy.

  Automatic climate control systems can cause the air conditioning to run, even in winter, to reduce moisture content. This increases the amount of time that air conditioning is running.

  Some studies recommend to roll down the windows for a significant reduction of fuel consumption. At speeds above 60 km per hour, it is best to close the windows as the increased drag will offset savings. With the windows up, it may be necessary to use the air conditioning, however it is better to use it intermittently (turn it off and on) to reduce the amount of time that the system is running.

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44 https://www.rac.co.uk/

Also turning off the air conditioning off 5 minutes before you arrive at your destination can help to save fuel. If the vehicle has an automatic climate control system, either manually driver can shut off the air conditioning when not needed or select the “economy” mode.

In conclusion, many different technical and human parameters affect to the driving efficiency. All the above mentioned parameters should be analysed during the project and as a result, an efficient driving guideline for waste collectors will be developed. In the pilot activity, the actions developed in the guideline will be implement by the drivers to verify the efficiency of the guideline.

4.4 Compensation procedures in Europe

The use of tax instruments in the area of waste management is an increasingly popular option to create incentives that help to achieve better prevention and selective waste collection results, ensure appropriate allocation of waste management charges, and guarantee that tax collection is effective.

At local level, the main economic instrument that is available are waste charges. Traditionally, waste charges were conceived without incentives in mind. However, nowadays in some countries, pay-as-you-throw (PAYT) systems are commonly used. Such systems enable the real production of waste in each home or business to be calculated, and the tax is determined by the amount and type of waste that is thrown away. Thus, pay-as-you-throw systems promote waste prevention and recycling and enable the 'polluter pays' principle to be applied.

A pay-as-you-throw system is based on the application of a mechanism by which the user of the waste collection service pays a waste charge according to their real waste generation and the waste management service that is used.

Such schemes incorporate the 'polluter pays' principle into the waste charge. Consequently, residents or businesses who make an effort to reduce their waste and separate it correctly are rewarded.

Therefore, pay-as-you-throw systems encourage the participation of residents and businesses to meet waste policy objectives, through the creation of an economic incentive that consists in establishing a link between waste charge payment and the amount and type of waste that is generated.

The first pay-as-you-throw schemes have been in operation in the USA since the start of the twentieth century[45]. Such schemes became more widespread from the 1970s onwards, particularly in California, Michigan, New York and Washington. Currently, over 7,000 US towns have deployed PAYT schemes, which is almost a quarter of the total number of municipalities and population of the United States. PAYT are used in 30 of the 100 largest municipalities in the country[46]. The operation of these schemes is particularly notable in large cities such as Seattle (Washington), San José (California) and Vancouver (Canada).

Subsequently, the scheme began to spread to almost all European countries. It is extremely widespread in Switzerland and the north-eastern area of Germany[47], as well as in the rest of Germany, the north of Italy, Denmark and the Netherlands. Some examples of European cities that have introduced these schemes are Berlin,

[45] Aldy et al., 2006
[46] Skumatz, 2008
[47] Reichenbach, 2004

Brussels, Munich, Vienna and Dublin. In most cases, PAYT has been implemented in the context of selective door-to-door collection.

In the USA, pay-per-bin with individual tally systems predominate in the largest municipalities and urban and suburban areas, whilst there are more pay-per-bag or pay-per-bin with tag systems in smaller, more rural towns[48]. In Europe, the most common model is pay-per-bin, although there has been a sharp increase in the use of the chamber system, especially in densely populated areas[49]. This scheme is common in German cities, such as Dresden, Heidelberg, Hamburg, Berlin, Freiburg and Düsseldorf.

Pay-by-volume schemes have generally been used to measure the amount of waste produced, although recently pay-by-weight systems have begun to be deployed.

The application of pay-as-you-throw is based on three main factors:

- The identification of the waste generator.
- The measurement of the amount of waste generated and/or the services that are used.
- Individual taxation.

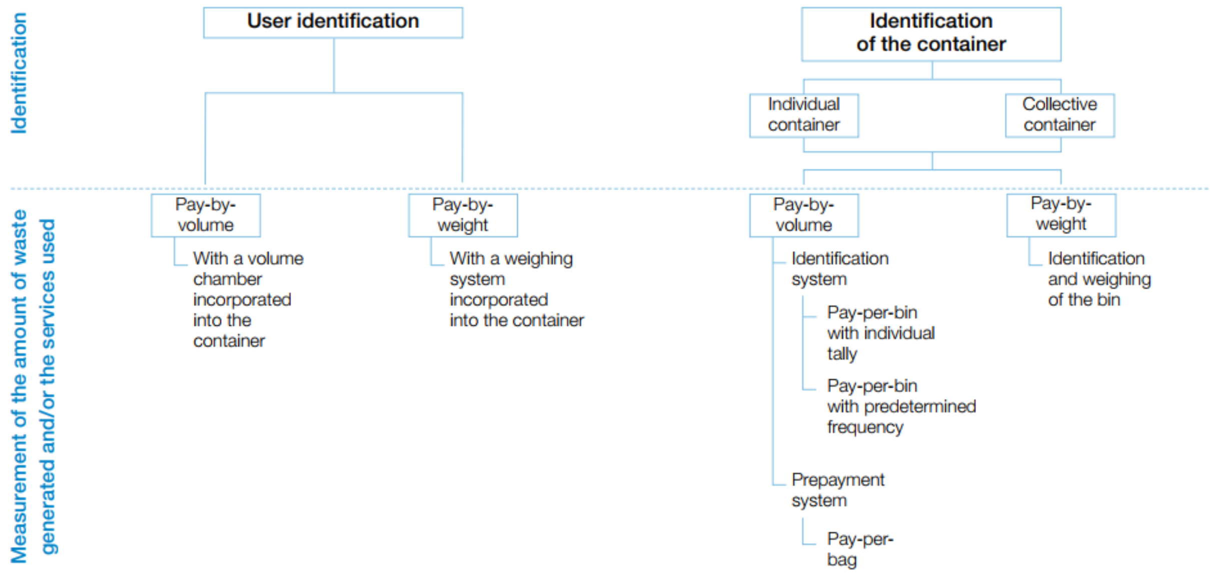

Figure 20. Main alternatives for implementing a pay-as-you-throw system[50]

According to a study developed by the Agència de Residus de Catalunya and the Generalitat de Catalunya in 2010, **Table 13** compares the different PAYT

[48] Skumatz, 2008
[49] Reichenbach, 2008
[50] Agència de Residus de Catalunya and Generalitat de Catalunya, 2010. (Adapted from Reichenbach, 2004)

models aatending to different factors such as the efficiency, eassiness or convenience.

Table 13. Comparison of pay-as-you-throw models

	CONTAINER IDENTIFICATION SYSTEMS				USER IDENTIFICATION SYSTEMS	
	Pay-per-bin with individual tally	Pay-per-bin with predeterm. frequency	Pay-per-bag	Identification and weighing of the bin	Pay-by-volume with a volume chamber incorporated	Pay-by-weight with a weighing system incorporated into the bin
Prevention and recycling incentive	Average	Low	High	Very high	High	Very high
Technological complexity	High	Low	Low	Very high	Very high	Very high
Implementation cost	High	Average	Low	Very high	Very high	Very high
Maintenance cost	Average	Low	High	Very high	High	High
Reliability and transparency of tax calculation	High	High	High	High	High	High
Certainty of revenue	High	Very high	Average	High	Average	Average
Fraud risk	Low	Very low	Average	Low	Average	Average
Collection efficiency	High	Low	High	Low	High	High
Correspondence between volume or weight and charge	High	Average	Very high	Very high	High	Very high
Convenience for users	High	High	Average	High	Average	Average

PlastiCircle solution will implement a user identification module which will allow a user identification PAYT system. This system can be incorporated in self-compactors, pneumatic collection drop-off points or municipal waste collection containers.

The following decisions should be taken:

- Select the chargeable fractions.
- Choose what to measure: volume, weight, was characteristics, quality...
- Identify the most suitable place for the units.

- Choose the data transfer method. Two possible options are:
  - Management software and a PDA to download data.
  - Using a GSM modem that automatically downloads data. This includes a modem for the chamber containers, a modem in the office and the communications management software.

User identification systems only need to be installed in the bins for chargeable fractions. The collection of the other fractions can continue in the same way, but may be a potential point for chargeable waste to escape.

To introduce pay-as-you-throw systems, tax ordinances or principles regulating waste charges needs to be modified to include the characteristics of the new charge. In addition, a legal framework is required to regulate the principles of the new system. This can be achieved by adapting (or creating) the ordinance regulating municipal waste.

Although it is the most known, PAYT is not the only rewarding scheme for separate packaging waste collection. Some municipalities are implementing waste incentive neighbourhood schemes. This is the case, for example, of Cornwall County (UK). A 'waste incentive neighbourhood scheme' has been launched in Cornwall, asking town and parish councils to submit ideas on how to reduce, and encourage residents to reduce black bag waste within their local areas.

The scheme has been awarded government funding to reduce the amount of residual waste collected in the county. One council will be chosen and given start-up funding to launch the campaign and a potential reward following completion, dependent on the amount of waste reduction.

The trials will be evaluated upon completion based on their success in reducing waste.

But also non-monetary incentives could be an option for rewarding well-performing attitudes. The use of award ceremonies, good public relations and promotional items are some inexpensive ways to provide a recycling incentive in a community. Below are some examples of non-monetary incentives used as a mechanism for increasing participation.

In the summer of 2008, DPPEA provided a number of local governments with large quantities of minor league baseball tickets to use as an incentive for recycling. Across the state there was an enthusiastic response to this effort and the message of recycling was actively promoted during this initiative. The state allotted a given amount of tickets to each community which were distributed at the discretion of the various municipalities. The communities then tracked both recycling bin requests as well as recycling questions via email and telephone. Communities had an increase in recycling interest and many of the communities also had visible increases in tonnage. Almost 4,000 tickets were distributed to the participating communities across the state.

Other incentive program is, for example, the 'RecyclingBank'. This organization has been set up to bolster recycling efforts and encourage sustainable practices. RecycleBank partners with either an independent waste hauler or a municipality to bring its program to a community. Homes earn RecycleBank Dollars that they can spend on rewards and discounts at businesses, both national and local. RecycleBank provides homes with a 35-, 64- or 96-gallon RecycleBank container that has an imbedded barcode. A user can place all items that can be recycled (paper, plastic, glass, cardboard, steel, aluminium) into this container. During each weekly pickup, the container is weighed and the barcode is read, recording the amount a user has recycled. This data is then transferred to a user's individual RecycleBank account.

PlastiCircle project pretends to stablish a rewarding procedure based not only in the quantity (volume/weight), but in the quality of the sorted products. For this purpose, citizens participating in the pilot experience should be registered in the PlastiCircle product and need to identify themselves when using a smart container. Bags put in the container will be directly associated to the citizen and this information will be saved in the system. With a stablished periodicity (e.g. once per week) some bags collected will be randomly selected to be manually analysed.

Citizens will receive incentives according to two main factors: quantity and quality of the sorted product.

- Quantity will be measured taking into account the number of bags in correlation with volume disposed and the frequency in the use of the system. A formula will be applied, taking into consideration the deviation with respect to the average value of users' disposal (e.g. extremely high or low values are considered as inefficient). Factors affecting quantity of waste generated will be analysed in T3.3. *'Definition of the characterization protocol and compensation procedure'*.
- Quality of bags will be checked during the sampling procedure. Some factors that will be analysed are:
    - Impurities (non-packaging items)
    - Type of packaging
    - Size of products
    - Organic presence

  These factors will be pondered taking into account both, the affections to the recycling process and the capacity of influence of the citizen on them.

Incentives will be studied taking into consideration both, economic and non-economic rewarding and individual vs. group benefits, taking into consideration the background and necessities of the city implementing them.

5. Users/stakeholders requirements

To achieve sustainability in waste management it is important to look at the roles, interests and power structures of stakeholders that are prevalent in waste management. Experiences in several countries have shown that co-operation and co-ordination between different stakeholder groups such as government institutions, service users, NGOs, CBOs, the private sector and donor agencies, will ultimately lead to increased sustainability" of a waste management system, such as changes in behaviour and sharing of financial responsibilities[51]. The role of stakeholder groups has transformed over time from being merely recipients of impacts to playing an important function in the design, implementation and promotion of MSW management systems. Nowadays environmental problems in cities can be addressed in large part by the interaction of several stakeholder groups.

Stakeholders involved in waste transport activities and compensation procedures attend to different groups integrating different levels: public sector, private companies and citizens.

For the scope of this deliverable, role and requirements of the next following users have been analysed:

- Central and regional government
- City councils (e.g. Alba Iulia, Utrecht, Valencia and Velenje)
- Non-profit organizations for the selective collection of light packaging (e.g. Ecoembes)
- Waste managers (e.g. SAV and Polaris)
- Citizens

In the next sheets are presented the main characteristics and roles of the different stakeholders involved in this part of the project and also are identified its main requirements concerning waste transport and compensation procedures.

[51] Bernstein, 2004

National and regional government

Role:

National government is ultimately responsible for ensuring that the waste collection process is being performed efficiently and complying with the EU Directives

They are responsible of:

- Establishing the National Waste Management Strategy.
- Setting national norms and standards.
- Establishing and maintaining any national waste information system or national waste statistics.

In addition, national government or regional bodies are also in charge of stablishing the waste management taxes to the citizens.

Requirements:

National and regional governments need focus on the compliance of the specific laws and normative concerning waste collection services.

They will need to dispose of the necessary information for the evaluation and assessment of waste collection systems in the different cities.

Moreover, they need to check that the service is provided according to the defined standards (if any) in order to guaranty citizens' satisfaction and wellness.

City council

Role:

Local government must provide waste management services, which include waste removal, storage and disposal services. Municipalities must provide additional bins for separation at-source. Municipalities must choose and designate a waste management company for the collection of different domestic waste streams.

Municipalities may also set local waste service standards for waste separation, compacting, management and disposal of solid waste, amongst others. Local standards must be aligned with any provincial and national standards where these exist.

Requirements:

Local authorities need to count on an efficient collection and transport system for the different waste streams.

In addition, local authorities need to guaranty a minimum service for citizens (e.g. minimum collection frequencies). They are responsible of selecting the area of implementation of the smart collection system and they will require a well-performing complete system for this area, which allow every citizen to use containers (both, participants and non-participants in the project pilot).

One of its main aims is to increase the current quality of collected waste and the recycling ratios.

Finally, they require a flexible system which will require few additional resources and which could be manage without any additional difficulty.

Waste manager

Role:

Waste managers are the responsible companies for collecting the recyclable materials deposited in the containers destined for this purpose and transporting them to a manager who reintroduces them into the production cycle.

Waste managers are usually private companies contracted by a local authority through a tendering process.

Requirements:

Waste managers' main requirements of the transport system is the obtainment of optimal routes which will allow them to reduce transport costs and to increase efficiency of collection activities. In addition, they will require to obtain information about routes performed and the main incidents registered in order to optimize their operative processes.

On the other hand, waste managers would benefit from an increased quality of the collected waste, which will increase benefits on the material selling.

Finally, they would prefer a system that could be easily adaptable to their current operative and which would not require high investments or big changes y current processes.

Non-profit organizations for the selective collection

Role:

Organizations that coordinate the selective collection and recovery of light packaging for subsequent recycling.

They collaborate with the regions and municipalities in the selective collection of packaging. They usually contribute to paying the difference in cost between the collection of urban solids and the cost of selective collection. This difference is financed by the adhered packing companies and their economic contribution depends on the quantity and type of the packages offered for sale.

They also are in charge of managing some different packaging sorting plants, where light packaging is separated into diverse fractions.

Requirements:

Non-profit organizations for the selective collection would need a well-performing system where collection rates and quality of collected waste were increased.

In addition, the system should comply with the specific legislation for the managements of EPR schemes.

Citizens

Role:

Citizens are the main agents for the success of separate collection systems. They are the main responsible of littering problems and it depends on their commitment to reach a good separation rates and an increased quality of disposed material.

The best measures to increase citizens' commitment are public awareness campaigns and education. Also economic incentives can be motivators for best-performing separation.

Citizens rely on collectors to take and handle trash and other waste products.

Requirements:

Local administrations need to satisfy citizens waste collection demand.

The system to be used need to be as simply as possible and adapted to the different groups of citizens (e.g. young vs. elder people, disabled, low income groups, etc.).

Containers should be accessible for every user and transport frequency and schedule convenient for citizens.

In addition, if collaboration is expected, the system should not require an extra effort nor cost for citizens. However, benefits and incentives will be well appreciated by local communities.

Finally, it is needed to take into account that an information campaign and additional visual instructions will be necessary in order to better known how the new system is functioning.

6. General architecture of the collection and transport system

Figure 21 shows a preliminary architecture of the PLASTICIRCLE collection and transport system. It includes the different elements and parts (modules), and how information is transferred between them.

The scheme includes different working modules to take into consideration:

- Collection
- Transport
- Sorting (including sampling and manual sorting)
- PlastiCircle IoT/cloud platform

As better explained in D2.1., the **collection system** is composed mainly by the smart container. It is also integrated by several modules:

- Identification module
- Label dispenser
- Filling level sensor.
- Vandalism protection features
- Communication module

The identification module will be able to read the information about the user participating in the project pilot through a NFC reader, to which the user will approximate a NFC card or mobile phone. Each user participating in the pilot activity would need to previously register in the PlastiCircle database through different options such an app (which is planned to be developed during the project), a form in the project web-site or through physical registration points.

Once the user is registered and identified in the container, the system will provide the user a label, which should be fixed on the bag. The system will automatically associate the label code to the user, to be able to track each bag for the sampling and sorting process.

The container will also register the information about the filling status, which is the main input for the routing platform. For that purpose, a commercial filling ultrasound sensor will be used.

Other anti-vandalism and protection measures will be also integrated such as overturning and temperature detectors, to measure risk of fire. Physical elements will be also designed as integrated as possible with the container body.

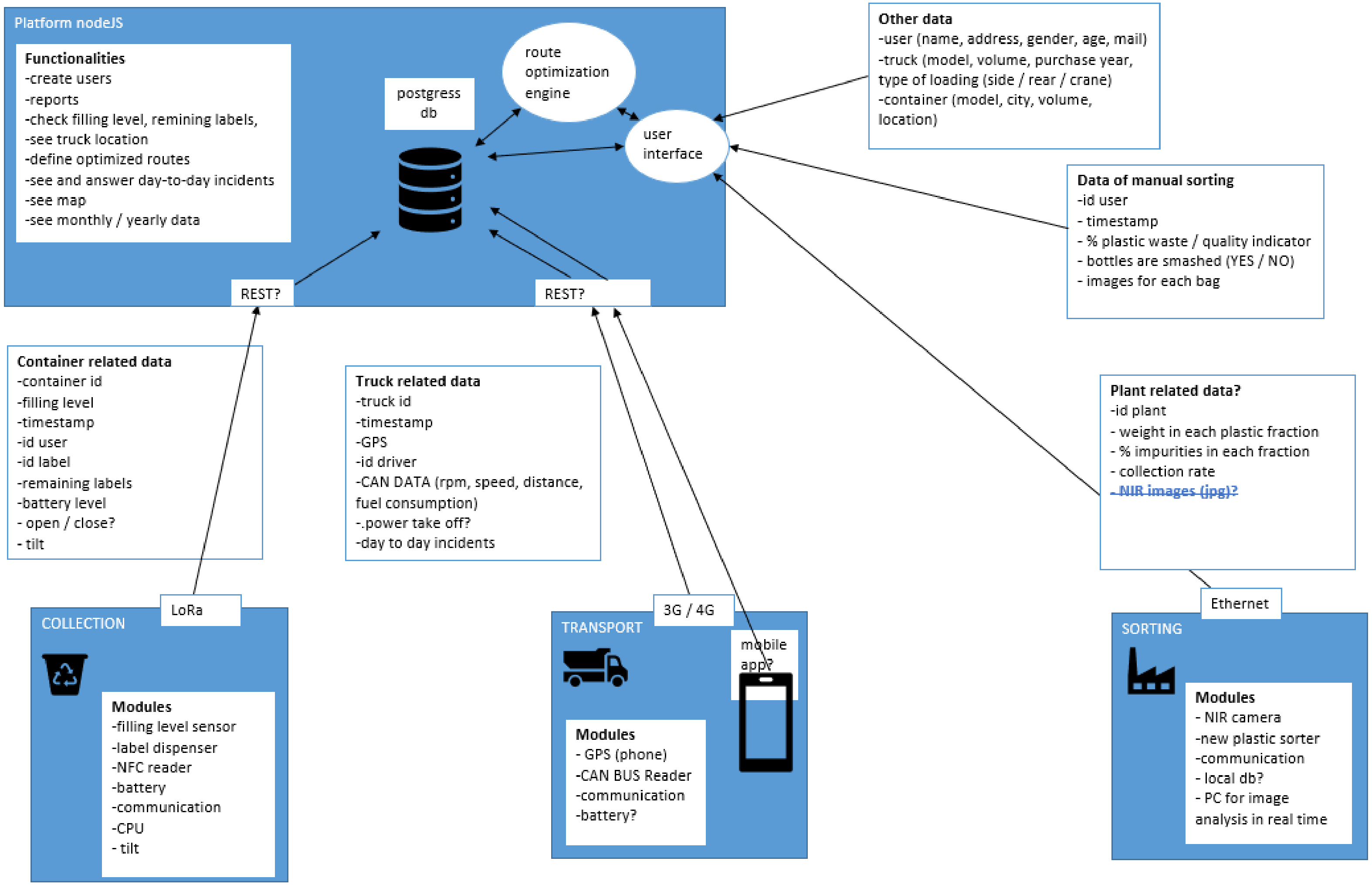

Figure 21. Modules and communications scheme

Container will periodically communicate with the PlastiCircle platform using LoRa system. Periodicity of data transmission needs to be stablished in order to fulfil requirements of the different components of the smart container.

On the other hand, the **transport module** will be mainly represented by the truck equipment. The different elements of the transport module are:

- Tracking system (GPS)
- Data gathering technology (CAN BUS reader)
- Communication technology

For the tracking of the vehicle, it will use GPS technology. For this purpose, it would be enough with the availability of a smart phone which will be used by the truck driver. The smart phone will serve as GPS device, but it will also be useful for the interaction between the driver, the smart-container and the PlastiCircle platform. For example, the driver will receive the route to be done via the smartphone and will also report the status of the containers and the collection process (e.g. a container has been already collected or not). Any incident would be also registered via the smartphone app.

Additionally, the vehicle will contain a CAN BUS reader (through an OBD connector) to collect information about the operative performance. Data about speed, revolutions per minute, idling, acceleration and breaking, fuel consumption, etc. will be measured on board. This information will be recorded and periodically transmitted to the PlastiCircle platform for a further analysis on eco-efficient driving. The truck driver will receive some alerts in the smartphone in case of detecting abnormal values and also recommendation taking into account the driver behaviour guidelines developed in Task 3.4.

Communication between truck and PlastiCircle platform will be performed through a 3G/4G connection. The platform will register information about the truck and driver id, GPS position, timestamp, truck parameters, collection status, incidences, filling level of the truck, etc.

Collection and transport modules will periodically interact with the **sampling and sorting** processes. With a stablish periodicity, a random sampling process will be done to the bags collected from smart containers. Bags will be selected during the truck collection process, just before emptying containers. This process will avoid damage to the labels by the compacting procedure inside the truck. The bags will be transported to SAV facilities in order to perform a manual sorting and product characterization.

During the manual sorting, the label included in the bag will be read, registering the code associated (in the platform) to the user. The user data will stay completely anonymous during the characterization process, due to the inability to track label codes with users' information (this association will be only done in the PlastiCircle platform and only will be use for the rewarding process). During manual sorting, a template with the information about the sample will be completed. The information to be collected will include data about:

- Size of the bag (volume and weight)
- Number of plastic packaging elements
- Number of metal packaging elements (cans)
- Number of beverage cartons
- % of impurities
- Presence of organic waste
- Smashed elements (yes/no)
- Etc.

Templates will be digitally completed and sent be the end of the day to the global PlastiCircle platform. For the identification of each template it will be used the number of the bag included in the label.

Finally, the general **PlastiCircle platform** will store all the information collected from the smart container and during the transport and sampling and manual sorting process.

The main functionalities of the platform will include the creation of new users (register), visualization of containers position and status (e.g. collection status, level of battery, number of labels available, filling level, etc.), truck location and routing maps, incidents information, users' data and profiles, generation of reports about waste collection and transport parameters, etc.

The platform will be connected to the routing software, which will be in charge of calculating optimal routes for collection trucks, taking into account containers position, filling level and truck fleet available and their characteristics. By the end of each day, just before starting the collection of containers waste, the routing process will be activated and each route will be send to the corresponding truck driver. Each truck driver should follow routing instructions as far as possible. They will also have an option for recalculating the route in case of incidents and automatically when emptying a container.

The platform will also dispose of a user-friendly interface in order to facilitate the work of the platform and routing manager. During pilots, the platform functionalities will be tested and review in order to integrate new options if necessary.

For the development of the web application, the next technologies have been initially chosen:

- Frontend: HTML5 technology for the web structure, CSS for the different styles and AngularJS (JavaScript) for improving the performance and events.
- Backend: NodeJS, for the routing algorithm and for the communication with the database, which will be developed using PostgreSQL.

7. Conclusions

PlastiCircle transport platform will be composed by different components which are analysed in this deliverable.

First of all, a literature review has been done in **section 4** order to identify he most common technologies in use for tracking and data gathering, including its main characteristics. Based on that, the vehicle tracking system selected for PlastiCircle project will use GPS technology for the location of the vehicle, that will use cell-phone technology. Additionally, some other aspects such as speed, acceleration, break use, start & stop process, engine spinning, etc. will be considered to evaluate driver performance and develop individualized retraining to improve driver skills. For that measurements a personalized device collecting data from CAN Bus (Controller Area Network) will be used.

In a second stage, with the information gathered by the GPS system and, taking into consideration the operation needs set by the waste manager and the city responsible, an optimization routing system will be designed. The problem to be solved is to obtain an optimal route, which minimizes the travel distance of household plastic packaging collection form bring banks, these routes have to comply with the next restrictions: capacity of collection vehicle, number of vehicles available, maximum schedule for the route and cover demand of 'full containers'. The problem to be solved in PlastiCircle project is defined as a MFVRP (Mixed Fleet Vehicle Routing Problem), where the capacity and characteristics of each vehicle is variable, but all the vehicles start from the same depot and finish in the same point. For the resolution of this problem it is not feasible to use an exact resolution algorithm, so the most convenient option would be to use a route construction heuristic algorithm, which we would later improve with two improvement heuristics.

After the gathering system will be installed and routes optimized, one of the most important aspects that influence the fuel consumption and affects the life of the vehicle, is the driver behaviour. Some examples of eco-driving guidelines have been reviewed in D3.1. All documents highlighted that the main advantages of improving driving attitudes are: energy and economic savings, reduction of maintenance costs, increment of road safety, comfort improvement, no time loss, less noise and an environmentally and climate friendly system. Also some consensus on technical factors affecting driving style have been adopted. Speed, aerodynamic resistance of the vehicle, engine spinning regime, slow motion time, power take off time, acceleration and braking, tyres status and air conditioning use are the most common ones.

In parallel, to achieve better prevention and selective waste collection results, the use of tax instruments and incentives in the area of waste management is an increasingly popular option. Some options such as PAYT (Pay As You Throw) taxing systems; waste incentive neighbourhood schemes; social bonus or award ceremonies, good public relations and promotional items have been analysed in order to explore different examples that should be in consideration for a proper definition of PlastiCircle incentives scheme. Among the aspects to take into consideration for the evaluation of 'users' performance', PlastiCircle will consider both, quantity (volume/weight) and quality (impurities, type of packaging, size of products, organic presence, etc.) of the collected product.

Finally, for a good optimization of the whole transport system, it is necessary to consider different collection and current operation systems in each city. **Sections 2 and 3** of the current deliverable analyse the situation for each city participating in PlastiCircle project and those aspects that could affect the design of the improved transport system. Also roles, interests and power structures of stakeholders are prevalent in waste management. **Section 5** identifies main agents participating in the waste transport system and their specific role and necessities. Experiences in several countries have shown that co-operation and co-ordination between different stakeholder groups such as government institutions, service users, NGOs, CBOs, the private sector and donor agencies, will ultimately lead to increased sustainability.

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Annexes

Annex A: City description questionnaires

1. **Geographic and socioeconomic characterization of the city/region.**

   Please, include a description of the main characteristics of the city where the pilot will take place, taking into account:
   - Where is the city located?
   - Which is the area covered?
   - Number of inhabitants (and population density)
   - Evolution of population in the past years
   - Distribution of population by age
   - Kind of housing (flats, town houses, single-family homes, etc.)
   - Environmental awareness of citizens
   - Etc.

2. **Description of the general waste collection system.**

   Please, describe the current collection system in the city (considering every waste stream, and after describing particularly the plastic waste flows –yellow bin–). Take into consideration:
   - Which kind of waste streams are being collected?
   - How is being developed the collection system? (door-to-door, bring banks, ecoparks, etc)
   - Which amount of waste is being collected? (per year, average per household…)
   - Is there any tax for the citizen? How is it calculated?
   - Which is the frequency of collection for each waste stream?
   - Is the same company collecting every waste stream?
   - Is there any regulation to take into consideration?
   - How do you manage waste after collection? (is it transported to a sorting plant? Is it directly sold?
   - Who is paying the collection system? (do you receive funds? Is there a EPR system? Is it paid through the citizens' taxes?)
   - Etc.

Focusing specifically on the **plastic packaging waste stream** (yellow bin):

3. **Performance**
    - Which companies are performing the waste collection? How are they selected and contracted? (direct contract, tendering, …)
    - How many vehicles are used for the collection?
    - Which is the collection frequency?
    - Total amount of plastic waste generated (per inhabitant or household and year)
    - Quality of the collected product (Is this info being collected? Where and who is doing it? which parameters are used? Which values did you obtained?)

4. **Trucks characteristics**
    - Brand and model
    - Engine
    - Fuel used (petrol, gasoil, gas, electric vehicles, etc.)
    - Average consumption of vehicles
    - Distance travelled yearly per truck
    - Capacity
    - Age of fleet

5. **Information about routes followed by trucks for waste collection.**
    - Origin and final destination of these routes.
    - Average distance travelled (per truck and route)
    - How are the routes planned? (e.g. using a routing software)

6. **Audiovisual material from: trucks, containers, collected material**
    - Photos
    - Videos
    - Drawings
    - Schemes

7. **Regarding the pilot experience, could you please describe the area where it is planned to be developed?**
    - Extension
    - Number of households affected
    - Kind of households in that area

- Number of containers nowadays available and necessary
- Average distance to containers
- Number of citizens expected to participate

8. Other aspects

- Technologies nowadays used (fleet and route management software, tucks tracking devices, driving parameters monitoring, users' identification for rewards, waste quality measurement tools, etc.)
- Is there any reward for citizens taking into account well-performing in separating waste streams? Which aspects are considered to calculate it? How is it rewarded?
- There is any legal aspect that we should take into consideration for the collection, transport and management of plastic packaging waste in your city? And for a 'hypothetic' rewarding process?
- Is there anything else that you consider relevant to include?